Australian Government

Australian Institute of Marine Science

Methods for Ecological Monitoring of Coral Reefs

Jos Hill and Clive Wilkinson

Version 1

A Resource for Managers

ReefBase

GCRMN
Global Coral Reef Monitoring Network

Reef Check

This compendium of methods contains those known to be in common use for coral reef monitoring or were provided by coral reef resource managers and researchers from around the world. Much of the information is based on questionnaires distributed widely and from the coral reef literature. This should not be considered as a definitive list. Interested persons are invited to contact the authors for information or to indicate errors and omissions.

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ISBN 0 642 322 376

Acknowledgements
Special thanks go to those people who provided method descriptions and assessments from a management perspective through discussions and responses to questionnaires. We are particularly grateful to those who provided financial support for the GCRMN and this publication: the US Department of State, the National Oceanographic and Atmospheric Administration, the Department of Environment, Food and Rural Affairs of the UK, through the International Coral Reef Initiative, IUCN The World Conservation Union, CRC Reef Research Centre, the Total Foundation and the International Coral Reef Action Network. Scientific and technical advice was received from AIMS, AGRRA (Atlantic Gulf Rapid Reef Assessment), CARICOMP, NOAA, ReefBase, Reef Check, CORAL The Coral Reef Alliance, The Nature Conservancy and the GCRMN Management Group (UNEP, IOC-UNESCO, IUCN, the World Bank, The Secretariat of the Convention on Biological Diversity). Personnel from IMPAC (International Marine Project Activities Centre), CRC Reef Research Centre and Alison Green provided advice and support. Tim Prior, Michael Phelan and Madeleine Nowak are thanked for their suggestions and proof reading. Finally special thanks go to the production staff at AIMS, Wendy Ellery and Tim Simmonds; again a very professional job under a tight schedule.

Cover photographs were provided by Jos Hill, Dean Miller and Katerina Kupcikova.
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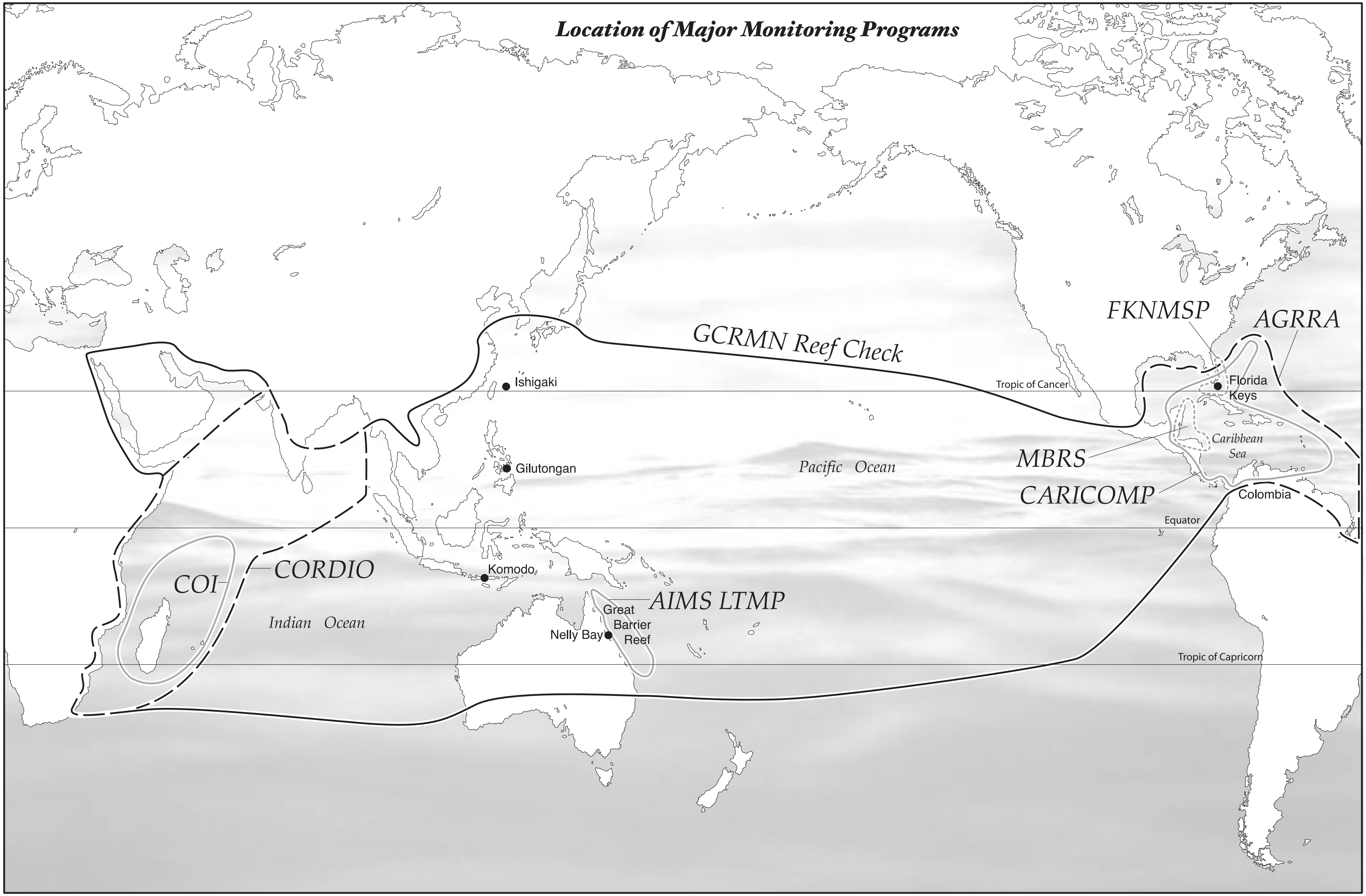

Location of Major Monitoring Programs
GCRMN Reef Check
FKNMSP
AGRRA
Florida
Keys
Tropic of Cancer
Ishigaki
Gilutongan
Caribbean
Sea
MBRS
CARICOMP
Pacific Ocean
Colombia
Equator
COI
CORDIO
Komodo
AIMS LTMP
Great
Barrier
Reef
Nelly Bay
Indian Ocean
Tropic of Capricorn

Preface

Potential methods to use for monitoring disturbance impacts. It is recommended that monitoring is done of the damage sites and control sites, preferably before the damage, during and after damaging impacts have ceased. Monitoring sites for success of recovery is a measure of the success of management intervention.

Threat	Impacts	What to monitor (few resources)	Pages
Over-exploitation of marine resources	Over-fishing Hunting e.g. turtles & dugong	❍ Fisheries - catch per unit effort – **fishery dependent monitoring**; ❍ Impacts on populations of target species: abundance & size - **fishery independent monitoring** ❍ For suspected ecosystem over-fishing, monitor impacts on non-target species - **cover of algae, coral, prey species etc.**	51, 64, 78, 79, 86, 88
	Destructive fishing practices	❍ Physical damage to habitat - **broken coral; live and dead coral cover;** ❍ Impacts of over-fishing - **see above.**	22, 31, 33
	Coral mining	See habitat destruction below	—
Land based impacts	Habitat destruction: coastal development; dredging & filling; coral mining	❍ **Area of habitat lost**; ❍ Impacts on adjacent coral communities - **cover, diversity, and health.**	22, 27, 31, 33
	Point source pollution: e.g. sewage, industry outfalls etc.	❍ Water quality - measure relevant pollutant e.g. **sediments, nutrients, fertilisers, pesticides at source and receiving waters;** ❍ Impacts on coral communities - **cover, diversity, and health**.	22, 31, 33, 95
	Non-point source pollution: land clearing, agriculture, septic systems etc.	❍ Water quality - **measure relevant pollutant e.g. sediments, nutrients, fertilisers, pesticides in delivery mechanism (rivers/ streams during floods) and receiving waters;** ❍ Impacts on coral communities - **cover, diversity, and health.**	22, 31, 33, 95
Shipping based impacts	Pollution e.g. fuel spills	❍ **Type, quantity and distribution of pollutant**; ❍ Impacts on benthic communities, **particularly cover of coral and algae, diversity and health of coral communities and other indicator species e.g. clams, urchins**.	33, 36, 51, 64
	Groundings/wrecks	❍ Physical damage to habitat - **area of broken/smashed coral; changes to hydrology of area e.g. new channels;** ❍ Type, quantity and distribution of pollutants e.g. **oil, diesel, antifouling paint & and impacts on benthic communities (see above).**	22, 31, 51
	Introduced species in ballast water etc.	❍ **Diversity, size and abundance of introduced species**; ❍ Impacts on native species e.g. due to **competition or predation**;	31, 64, 68
	Navigation aids: lighthouses etc.	❍ Physical damage to habitat **- area of broken/smashed coral; area of habitat lost; changes to local hydrology;** and ❍ **Impact on adjacent coral communities**.	22, 31, 33
Tourism & Recreation	Coastal development: resorts, marinas, jetties etc.	See habitat destruction above	—
	Offshore structures e.g. pontoons	❍ Physical damage to coral communities - **broken coral; area of habitat lost;** ❍ Impacts on adjacent coral reef communities from shading - **coral cover, diversity, and health;** ❍ Impacts from fish feeding – **fish abundance, size and diversity**.	22, 31, 33, 79
	Diving and snorkelling	❍ Broken coral and coral cover at key sites.	33
Large scale disturbances	Coral bleaching	❍ Sea surface temperatures; ❍ Extent, severity and recovery of coral communities - **cover, diversity, size structure, changes in relative abundance of growth forms;** ❍ Identify bleaching resilient species and sites.	22, 33, 51, 95
	Major storms, cyclones, hurricanes and typhoons	❍ Physical damage - **broken coral;** and changes to coral communities - **cover, diversity and relative abundance of growth forms.**	22, 33
	Population outbreaks of corallivores: COTs, *Drupella* etc.	❍ **Abundance and size of corallivores**; ❍ Impacts of coral community - **coral cover, diversity, and relative abundance of growth forms.**	22, 33, 51,64, 68
	Geologic activity: earthquakes, volcanoes, tsunamis	❍ **Area of habitat lost or destroyed** e.g. buried by lava and ash; ❍ Physical damage - **broken coral in coral communities**; ❍ Type, quantity and distribution of pollutants e.g. lava, ash, pumice and impacts on coral reef communities **- coral cover, diversity and relative abundance of growth forms**.	22, 27, 33, 51

Preface

The aim of this book is to help managers of coral reefs select appropriate ecological monitoring **programs**, **protocols** and **methods** for your coral reef management needs. This book was written in response to requests from coral reef managers for advice on monitoring, especially:

- How monitoring can help management;
- How to choose the best methods to suit your needs; and
- The good and bad points and associated costs of a wide range of monitoring methods.

Monitoring can be specific or general. There are different management information needs for each coral reef area, so monitoring programs must be designed to include a selection of protocols and methods to meet those needs. The protocols and methods outlined in this book represent the ones most commonly used on coral reefs around the world. Our advice is to use the standard and frequently used methods to monitor your reefs because these have been extensively tested. Using standard methods also means that you will be able to compare the status of your coral reefs with other reefs at regional and global scales.

Some important definitions

There are lots of terms used when talking about monitoring. We use the same definitions throughout the book to make it simple to follow.

- **A survey** is collecting data and information about a coral reef site;
- **Monitoring** is when surveys (or parts of them) are repeated;
- A **monitoring program** consists of series of monitoring protocols that together provide a manager with the information needed to manage their reefs;
- **Protocols** are the selections of methods and how they are used to gain information at a site. This will include numbers of replicates, lengths of transect lines, specific information gathered, e.g. animals or plants to be counted or measured;
- A **method** is the description of how the information is collected, e.g. line or point intercept transect or how to lay the transect;
- **Ecological monitoring** is monitoring the natural environment, e.g. the fish or coral. This includes both biological and physical monitoring;
- **Socio-economic monitoring** is monitoring the way humans use the natural resources, e.g. the methods used to catch fish;
- A monitoring **site** is the area of coral reef selected for monitoring;
- A **sample** is the area where you count the animals and plants e.g. along a transect or inside a quadrat. The sample areas selected for monitoring will depend upon the type of information needed and the type of things you want to count. You will need to use a number of separate samples to survey one site. These are called **replicates.**

Coral reef managers around the world have similar problems and questions that monitoring can answer. For example, managers need to know if:

- Coral reefs are healthy and improving;
- Threats are damaging the corals or other organisms;
- Fish populations are increasing in a protected area;
- Management actions have been successful;
- Economies of local communities are maintained or improved;
- Communities understand the need for management and want to assist;
- Tourism is a positive or negative benefit for the coral reef area.

These questions and many others can be answered with an effective monitoring program, which will consist of a number of monitoring methods, often at a mix of scales from the whole reef to a small area. This reference book should be kept current. We invite you to recommend additional methods to be included as well as other suggested updates. Please write to us at c.wilkinson@aims.gov.au.

1: Introduction to Monitoring

What is monitoring?

Monitoring is the gathering of data and information on coral reef ecosystems or on those people who use coral reef resources. Monitoring should be repeated on a regular basis, preferably over an extended period of time.

Ideally a coral reef manager will perform a detailed baseline survey that includes many measures or parameters that may or may not change over time. These include:

- Mapping the extent and location of major habitats, particularly coral reefs;
- Understanding the status of coral communities, fish populations and fishing practises;
- Measuring the size and structure of the human population using these resources;
- Understanding government rules and regulations on coral reefs and conservation; and
- Determining the decision making process in local communities.

The coral reef manager has to select which variables (things to measure) to be included into a **monitoring program**. In this book, the term monitoring includes both the initial baseline survey and continued monitoring.

How can monitoring help you?

A major goal of a coral reef monitoring program is to provide the data to support effective management. As more Marine Protected Areas (MPAs) are established, it is becoming increasingly important to monitor whether they are achieving their management goals. Monitoring can assist with the effective management of coral reefs through the following tasks:

1. **Resource assessment and mapping** – what and where are the resources in your coral reef area that should be managed;
2. **Resource status and long-term trends** – what is the status of these resources and how are they changing over time (Monitoring large areas: Great Barrier Reef Marine Park, p 9;
3. **Status and long-term trends of user groups** – who are the major users and stakeholders of your coral reefs, what are their patterns of use and attitudes towards management, and how they are changing;
4. **Impacts of large-scale disturbances** - how do impacts like coral bleaching, crown-of-thorns starfish (*Acanthaster planci* or commonly known as COTS) outbreaks and tropical storms affect your coral reefs, p 63;
5. **Impacts of human activities** – how do the activities of people affect the coral reef and its resources. This includes fishing, land use practices, coastal developments, and tourism (see 'reactive monitoring at Nelly Bay Harbour, Magnetic Island, North Queensland, Australia', p 7);
6. **Performance evaluation & adaptive management** - how can monitoring be used to measure success of management goals and assist in adaptive management (Monitoring broad scale impacts on coral reefs: 'how monitoring demonstrated effective control of blast fishing in Komodo National Park', p 7);
7. **Education and awareness raising** – how to provide support for coral reef management through raising awareness and education of user communities, government, other stakeholders and management staff ('Using Reef Check to stimulate community management of Gilutongan, Central Philippines', p 6 and 'How monitoring demonstrated effective control of blast fishing in Komodo National Park', p 7);
8. **Building resilience into MPAs** - how to design MPAs so they are more resilient to large scale disturbances such as coral bleaching or outbreaks of COTS;
9. **Contributing to regional and global networks** – how to link up with and learn from other coral reef managers around the world and assist others manage their coral reefs (see 'Global and regional programs', p 98.

For more detail on how monitoring can help conserve reefs see Wilkinson *et al.* (2003).

Ecological and socio-economic monitoring

There are two main types of monitoring:

- **Ecological monitoring;** and
- **Socio-economic monitoring.**

Ecological and socio-economic parameters are often closely linked; therefore ecological monitoring and socio-economic monitoring should be done in the same place at the same time. For example, monitoring of fish populations should be directly linked to surveys of fish markets, fishermen and their catches. Similarly ecological parameters describe the natural state of the coral reef, which will have impacts on socio-economic factors such as income and employment.

Ecological monitoring includes the natural environment (biological and physical) e.g. the fish, coral or sedimentation.

Biological parameters measure the status and trends in the organisms on coral reefs. Biological parameters focus on the major resources, and these parameters can be used to assess the extent of damage to coral reefs from natural and human disturbances. The most frequently measured ecological parameters include:

- Percentage cover of corals (both live and dead) and sponges, algae and non-living material;
- Species or genus composition and size structure of coral communities;
- Presence of newly settled corals and juveniles;
- Numbers, species composition, size (biomass) and structure of fish populations;
- Juvenile fishes, especially target species; populations of organisms of special interest such as giant clams, COTS, sea urchins etc.;
- Extent and nature of coral bleaching; and
- Extent and type of coral disease.

Physical parameters measure the physical environment on and around the reefs. This provides a physical description of the environment surrounding reefs which assists in making maps, as well as measuring the change in the environment. Parameters include:

- Depth, bathymetry and reef profiles;
- Currents;
- Temperature;
- Water quality;
- Visibility; and
- Salinity.

Socio-economic monitoring: This aims to understand how people use, understand and interact with coral reefs. It is not possible to separate human activities and ecosystem health, especially when coral reefs are important to the livelihoods of local community members. Socio-economic monitoring can measure the motivations of resource users as well as the social, cultural, and economic conditions in communities near coral reefs. Socio-economic data can help mangers determine which stakeholder and community attributes provide the basis for successful management.

The most frequently used socio-economic parameters include:

- Community populations, employment levels and incomes;
- Proportion of fishers, and where and how they fish;
- Catch and price statistics for reef fisheries;
- Decision making structures in communities;
- Community perceptions of reef management;
- Tourist perceptions of the value of MPAs and willingness to pay for management etc.

This book is only about ecological monitoring methods. See Bunce *et al.* (2000); Wilkinson *et al.* (2003) for information on socio-economic methods

The **ecological monitoring** methods listed in this book fall under the following categories:

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2: What Type of Monitoring to use?

Your choice of monitoring program will depend on a number of factors. Our aim is to guide you through the following issues:

1. What information do you need to know? Is your question general or specific? (p 4);
2. What do you need to monitor? (p 4);
3. What resources do you have available? (p 5);
4. What scale of monitoring program do you want? (p 6);
5. What types of reef do you have in the area? (p 8);
6. What methods should you use? (p 8);
7. How often should you monitor? (p 12);
8. Quality control and training? (p 13);
9. Data handling and communicating results (p 14);
10. The need to involve the public (p 14).

What information do you need to know? What is your question?

The information you need to manage your reef will determine which monitoring protocols you use (see 'how can monitoring help you', p 2). If you want to determine the effect of particular impacts on your coral reef see table on page vi. Threats to coral reefs can be categorised as human, natural or climate-related, although some natural impacts may be exacerbated by human impacts. For example, global climate change may increase the severity and frequency of coral bleaching, while COTS outbreaks may be influenced by increased fertiliser pollution.

What do you need to monitor?

You will need to consider the following:

1. What biological and physical variables (things on the reef) do you need to monitor?
2. In what detail (taxonomic resolution for biological parameters) do you need to monitor these variables?
3. At what scale do you want to collect information?
   - Broad-scale (wide area);
   - Medium-scale (medium area);
   - Fine-scale (small area).

What are the main ecological monitoring categories?

1. Physical parameters;
2. Biological parameters;
   - Benthic communities (living and non-living components);
   - Invertebrates;
   - Fishes.

What variables should you measure?

A **variable** is a component of the ecosystem, physical or biological, that has an effect on other components of the ecosystem. For monitoring, the variables are the components or species that we collect data on, e.g. percentage cover of hard coral. We cannot measure every variable on a coral reef, therefore we use 'indicators' to detect change or impacts, or show reef 'health'. Indicators used for coral reef monitoring are either **ecologically** or **economically** important. Examples of ecological indicators include **percent hard coral cover,** which is an indicator of coral reef health because many other organisms rely on hard coral for their survival; and **abundance of COTS**, other predators or disease, because disease and predators may reduce coral cover and tourism potential.

Most managers use percent coral cover, and particularly changes over time in cover, as their main indicator of coral reef health. Scientists usually want to know the coral species and how these change with time to understand changes in coral cover, but this is not essential information for decision making by coral reef managers.

Economic indicators are species harvested by humans and important to the local economy e.g. conch, giant clams, trochus shells. Monitoring the abundance of these organisms and those that are closely linked to them is important for managing their sustainable use. Examples of economic indicators include **percent hard coral cover** (because tourists like to see beautiful coral), and **size and abundance of fishery species** e.g. grouper and snapper and because tourists also like to see lots of colourful or large fish.

What detail to measure (e.g. taxonomic resolution)?

Three levels of monitoring programs can be defined. These are:

- **Level 1 - Community monitoring** is at a lower detail level, i.e. you cover a larger area in less time, for less cost;
- **Level 2 - Management monitoring** adds more detail, is more expensive, takes more time and covers less area, but aims to provide the best information for MPA management; and
- **Level 3 - Research monitoring** provides very detailed data, but it is expensive, takes more time, requires more expertise to assess a smaller area, and is usually designed to answer a specific question.

Detail can be added by recording family, genus and species or sizes of animal groups. The highest level of detail (genus and species) usually requires **Level 3 - research monitoring.** Also more detail can be added to provide more accurate measures and reduce the uncertainty (i.e. reducing the variance in the estimate in 'sample design'). **It is important that the monitoring team only collect information at the level of detail that matches their training.**

You may wish to combine level 2 or 3 monitoring at a small number of sites with level 1 monitoring over a larger area (see Monitoring large areas: Great Barrier Reef Marine Park, p 9).

What resources do you have available?

Monitoring costs can vary on the basis of:

- Expertise of the people to do the monitoring;
- Cost of equipment and time.

Coral reef managers at a meeting in Manila in 2003 (ITMEMS2), recognised that monitoring programs should be designed in the context of limited resources and competition with other elements of management. Managers suggested that between 5 and 10% of the budget for the total coral reef or MPA management should be put into monitoring.

Costs will also be affected by the size of the reef area to be monitored, and therefore how many surveys are needed. You need to consider the resources available before you decide which monitoring program level you want to implement.

Expertise

Who will do the monitoring? The task will include data collection as well as data analysis and interpretation. Monitoring staff could include:

- Community members or volunteers (Level 1 program – Community monitoring);
- Staff with some scientific training (tertiary or learned through work experience) (Level 1 or 2 programs - **Community** or **Management monitoring**);
- Staff with some tertiary scientific training (Level 2 program – **Management monitoring**);
- Scientific researchers (Level 3 program – **Research monitoring**);

Level 1 – Community monitoring relies on using lesser-trained people (volunteers and community members) with some scientific supervision to gather broad-scale data at lower resolution. These data provide a cost-effective 'early warning system' of environmental changes over larger areas than is possible with more expensive level 2 or 3 programs. A Level 1 program will usually consist of:

- Some broad scale surveys, e.g. random swims;
- Point intercept transects assessing corals and other benthos using low detail categories;
- Fish transects to count major target fishes on the same transect line as the corals.

The most commonly used community monitoring program is Reef Check, which involves rapid and cost-effective collection of data by people without extensive training or experience. Reef Check provides a low level of detail, but useful information on reef status and the causes of reef degradation. It is particularly useful as an 'early warning system' for managers of changes in coral reef resources. Reef Check is recommended for people with the lowest level of expertise and funding, and is particularly useful for monitoring programs aimed at community education and awareness-raising by rewarding government agencies, companies and NGOs for their support, p 100.

Community monitoring builds public support for management initiatives and ensures that the community understands the status of the resources and what is happening to them. Community monitoring methods, such as the Reef Check methods or REEF fish census methods, are not sufficient to provide a complete picture of coral reef health, but they can illustrate long-term trends and indicate where more detailed monitoring is needed.

Advantages of community monitoring	*Limitations of community monitoring*
❍ Cost effective to cover large areas; ❍ Very useful as an 'early warning system' of changes in the coral reef; ❍ Enhances education, awareness and local stewardship of resources through the participation of community members.	❍ Data precision tends to be low; ❍ A large amount of time must be spent on training (ongoing) to ensure reliable data; ❍ Reduced detail but managers often only use low detail information e.g. percent coral cover.

Using Reef Check to stimulate community management of Gilutongan, Central Philippines

Fishing pressure on the reefs was high around Cebu when an MPA was established in 1991 at Gilutongan, a small island near Cebu. However the fishery regulations were not enforced, and the reefs continued to decline from overuse.

What was done?
In 1998, a team of 20 local divers was trained to do Reef Check. The results were presented to the community and the poor condition of the reef was widely discussed. The active participation of community members in the surveys was considered to be an important factor in the community decision to start active management in the marine sanctuary. Previous monitoring had been carried out by trained scientists, however little of the data or information was being presented to the local communities. Since the community became involved, the corals and fish stocks have improved and tourism is a major income source for the community.

Gilutongan marine sanctuary has been an outstanding success (Wilkinson *et al.* 2003). Contact Mike Ross, mikeross@mozcom.com or Gregor Hodgson, gregorh@ucla.edu

Ideally, a long-term monitoring program should include both community monitoring, such as Reef Check, and some more detailed surveys, such as identifying the major species (p 4 'what do you need to monitor?'). Unfortunately, detailed surveys require teams of highly trained scientists and are more time consuming and costly than community programs. In many countries, the initial goal of setting up a network of community monitoring sites at a few areas is a major challenge. Therefore, we recommend starting with a network of Reef Check-type sites as the first step towards a local or national monitoring program, and then if this is successful, level 2 and 3 programs can be added later.

Level 2 – Management monitoring relies on staff with scientific training (tertiary or through work experience), e.g. environment or fisheries government staff, to gather medium-scale data at medium to high resolution.
A level 2 program will usually consist of:
- Broad scale surveys to select monitoring sites and assess large areas using manta tow or timed swims;
- Point intercept or line intercept transects. These methods assess corals and other benthos at a chosen level of detail, e.g. shape categories or corals at genus level;
- Fish transects to count fishes on the same transect line as the corals with emphasis on size measurements of target species.

The Global Coral Reef Monitoring Network (GCRMN) was specifically developed to assist managers gather useful data and requires a low to moderate level of funding and expertise. Further information is on www.gcrmn.org/ (p 99.) Other level 2 programs are CARICOMP (p 102), AGRRA (p 101) and MBRS SMP (p 105).

Level 3 – Research monitoring relies on experienced scientists (university researchers, experienced environment or fisheries government staff) to gather specific, small-scale, high detail data. This level is often used to assess impacts of developments, e.g. building of a tourist resort.

Monitoring broad scale impacts on coral reefs: how monitoring demonstrated effective control of blast fishing in Komodo National Park (KNP)

The coral reef communities of KNP were seriously threatened by blast fishing, reef gleaning and over-fishing putting the Park's function as a replenishment source for surrounding fishing grounds at risk. The Nature Conservancy set up a conservation program to reduce blast fishing within the park. The indicators of blast fishing are rubble and hard coral cover, which is low detail information. KNP is 219,322 ha and resources limited, therefore low detail, broad-scale methods were appropriate.

What was done?
Park staff were trained to conduct simple timed swim surveys (p 31) to estimate the percentage of live coral and blast scars. This method enabled useful information to be obtained over a large area at low cost. Surveys were repeated every 2nd year and provided broad scale information on coral cover and damage from blast fishing. The results suggested that the conservation program successfully reduced blast fishing and that coral recovery was most rapid near protection and enforcement areas. The sharing of monitoring results with the community helped to build support for the park management.

Contact: Peter Mous, pmous@tnc.org

A Level 3 program will usually consist of:

- Broad scale surveys to select monitoring sites and assess impacts using manta tow or timed swims;
- Line intercept transects or video transects to assess coral and other benthos at genus or species level;
- Fish transects to count all fishes on the same transect line as the corals with emphasis on size measurements of target species.

These programs tend to be the **most expensive** and require **high levels of scientific expertise.** The Australian Institute of Marine Science Long Term Monitoring Program provides a good example of a research monitoring program on the Great Barrier Reef (www.aims.gov.au). A similar program is operated for the Florida Keys National Marine Sanctuary (www.floridakeys.noaa.gov/research_monitoring). Research monitoring programs are only recommended where managers have a high level of technical expertise and adequate financial resources.

Reactive monitoring at Nelly Bay Harbour, Magnetic Island, Australia to manage marine construction activities

The fringing reef at Nelly Bay is highly valued by residents and tourists for diving, fishing and snorkelling. Construction plans for Nelly Bay raised concern that the coral reefs would be damaged. The development within Nelly Bay lasted 2 years and involved the construction of a commercial ferry terminal, barge ramp, a canal/harbour estate with residential and tourism developments, a public boat ramp and public areas.

What was done?
Risks were identified as sedimentation plumes from harbour dewatering and dredging. The monitoring program was designed to alert managers when sediment levels reached 'unsafe' levels. This allowed managers to take action before excessive sediment levels could cause widespread damage to the Nelly Bay coral reef. Trigger levels were developed to help managers identify what 'unsafe' levels of sediment were, or when coral health had been affected. When monitoring showed that a trigger level had been reached, managers either called for more monitoring or shut down the activity causing the problem until the sediment levels returned to 'safe' levels.

For more information contact Andrew Chin, a.chin@gbrmpa.gov.au or Paul Marshall, p.marshall@gbrmpa.gov.au

Advantages of research monitoring	*Limitations of research monitoring*
❍ Accurate and precise data collection; ❍ Data are most reliable; ❍ Collect high detail data, which are used by scientists to understand trends or processes at a specific site; ❍ Used for environmental impact assessment	❍ Expensive. Many governments cannot afford to employ scientists to survey large areas of reef; ❍ Trained staff are often not available or are employed elsewhere; ❍ Can survey only small areas at one time.

Cost of equipment and time

The equipment required to conduct various monitoring methods can range from snorkel gear and an underwater slate to expensive video equipment and boats. It is essential to include the cost of transport to and around the reef. To find out what equipment you will need to monitor your reefs, see Appendix 2, p 107. The time taken to monitor is also an expense. You will need to consider who you can afford to pay to monitor reefs and for how long.

What scale of monitoring program do you want?

The program scale is the level of detail at which you want to collect information. This can be:

- Broad scale;
- Medium scale; or
- Fine scale.

These scales are illustrated in Figure 3, p 15.

This is an important question. Monitoring a large area will require more resources than a small area, and so the level of monitoring will have to be considered carefully if resources are limited. Data collected from one site on a reef will not provide enough information about the entire reef; similarly data from one reef will not provide information about the reefs in the region. The sampling effort needs to be spread throughout the area of interest to be able to make general statements and conclusions about the area (Oxley 1997). You may choose to monitor a few select sites in detail and use broad-scale monitoring of the wider area (see manta tow, p 22). Coral reef managers should ask two questions as part of this balancing act to decide which level to use:

- Do you want more detail over smaller areas or less detail over a larger area (or can you find more money for monitoring)?
- Will more detail provide more useful information to assist in management?

Also see 'How many samples should you take' (p 11). 'Reactive monitoring at Nelly Bay Harbour, Magnetic Island, Australia to manage marine construction activities' and 'Using Reef Check to stimulate community management at Gilutongan, Central Philippines).

What types of reef do you have in the area?

The type of reef will affect the type of monitoring method you select due to the **accessibility** and **habitat** types.

Accessibility: You may wish to monitor accessible reefs more frequently than less accessible ones. Methods that require frequent site visits, e.g. sedimentation traps (p 96) or coral recruitment plates (p 56) are cheaper to do at accessible sites.

Habitat type: Do you have patch reefs or continuous reefs? Long transects may not be suitable for patch reefs, but quadrats or a stationary fish census can be used (p 86). A continuous reef is better suited to most sampling methods, such as transects, which require tens of metres of area.

What methods should you use?

Many methods have been developed to monitor the different reef components. Several major coral reef monitoring programs have refined and integrated protocols and we recommend using the standard methods to develop your program. This will enable comparisons with data collected by other monitoring teams in your region. See page 98 for information on major coral reef monitoring programs.

The first consideration: what type of reef **habitat** do you want to monitor? If you want to compare monitoring sites, they must be of the **same habitat type**. Coral reef habitats change with depth and position on the reef e.g. front reef, back reef and lagoonal reefs are distinct habitats (see figure 2). Many scientists select a particular depth at the front reef for their monitoring sites. The front reef is often easier to monitor because it is often more continuous than back reefs, which tend to be patchy. Most coral growth occurs on the front reef. However, front reefs may be difficult to get to due to rough weather, therefore you may select the side or back reef. It is usually necessary

Monitoring large areas: Great Barrier Reef Marine Park

The Great Barrier Reef (GBR) is the world's largest series of coral reefs stretching over 2000 km with more than 3000 reefs. The challenge was to design a program to monitor the GBR to assist the management agency, the Great Barrier Reef Marine Park Authority (GBRMPA) assess localised changes and develop effective management strategies.

What was done?
The Australian Institute of Marine Science Long-term Monitoring Program was designed to provide both broad and medium scale information on the status of the GBR. Detailed medium scale transect-based surveys are done at permanent monitoring sites on 48 reefs to assess the status and long-term trends on the coral reefs. Information gathered includes benthic communities: coral cover, species richness, incidence and type of disease (p 38); and fishes, species richness and abundance (p 79). Broad scale manta tow (p 22) and timed swims (p 31) are done annually at another 50 reefs to provide general trend information on coral cover, COTS and bleaching.

There are 2 community programs monitoring other sites on the GBR. The 'Eye on the Reef' program (p 30) and Reef Check (p 36) provide general, 'early warning' information to managers. Reef Check teams are supported by the dive industry, which assists with annual surveys to provide low detail, medium to broad scale information on coral reef health. Eye on the Reef is a GBRMPA/CRC Reef program with the Australian Marine Park Tourism Operators (AMPTO), the Queensland Parks and Wildlife Service (QPWS) and 10 dive operators provide weekly reports on the status and broad scale general descriptions of tourism dive sites. Both programs increase public awareness of coral reef issues and involve the public in management of the GBR.

AIMS LTMP contacts: Hugh Sweatman, h.sweatman@aims.gov.au or David Wachenfeld, d.wachenfeld@gbrmpa.gov.au; Eye on the Reef contacts: Andrew Chin, a.chin@gbrmpa.gov.au or Robin Aiello, robin.aiello@iig.com.au; Reef Check contacts: rcheck@ucla.edu

Another example of a multi-tier monitoring program is the Florida Keys Marine National Marine Sanctuary Coral Reef Monitoring Program that uses detailed research-level monitoring in combination with community programs by trained recreational divers. For further information see: www.fknms.nos.noaa.gov/research_monitoring/zpr98.html

to conduct a broad survey, e.g. manta tow and some ground truth surveys (exploratory dives) to ensure that the selected sites are in a comparable habitat, p 21.

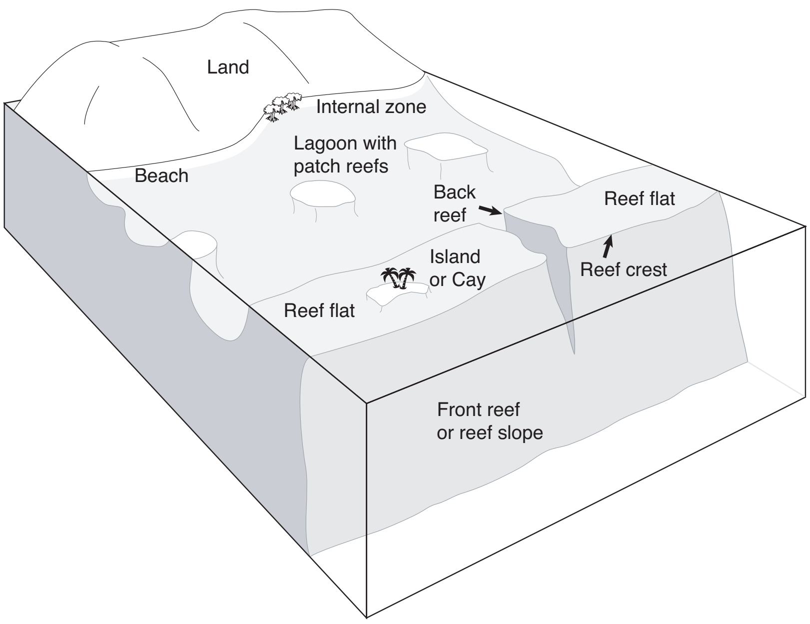

Figure 2. *Cross section through a coral reef showing the major zones.*

How do you select your sites?

The sites you choose should be:

- **Representative** of the area of interest;
- Contain the **same habitat** so that the different sites can be compared through time.

Site selection is a critical step in designing a monitoring program and will depend upon the objectives of your program e.g. if the objective is to determine if fish abundance is higher inside an MPA than outside, you should monitor both inside and outside your MPA (for an example, see 'Using Reef Check to stimulate community management at Gilutongan, Central Philippines', p 6). This is called an impact study (see 'Impact studies', p 13). The actual sites you choose for the surveys should be **representative** of the area of interest. Therefore, fish surveys should be conducted in an area of the MPA that is representative of the whole MPA and similar to the outside area.

Because we cannot measure everything on a coral reef, we must measure a small part. The part of the coral reef that is measured is called a **sample**. To measure a part of the environment is called **sampling**. To repeat sampling through time is called **monitoring**. A sample is intended to be **representative** of the whole coral reef.

The **method** is the description of how the information is collected, e.g. line or point intercept transect or how to lay the transect. The **protocol** is the size and shape of the sampling method e.g. transect length and number, duration of a timed swim or quadrat size.

To select a site, you may need to consider the following:

- The degree of environmental degradation and/or recovery;
- The level of management protection, e.g. no-take MPA;
- The extent of wave exposure, i.e. can the monitoring team dive at that site under most conditions?
- Which sites are representative of the coral reef area you want to monitor?

How do you select which type of monitoring method to use?

1. First decide what **method family** to use, i.e. transects, quadrats or timed swims etc. This decision will depend upon the scale of your monitoring area, the level of detail at which you want to monitor and the type of reef habitat you want to monitor, e.g. continuous front reef, or patch back reef;
2. Second, decide what method **protocol** to use, i.e. line intercept or point intercept transects; or visual or photo quadrats. This will depend upon the expertise of your monitoring team, the time you have available for monitoring and the detail and precision of the data you wish to obtain;
3. Third, decide what method **size** should you use, i.e. transect length or quadrat size. This will depend upon the type of reef habitat you want to monitor, the size of the area of interest that you monitoring area must represent, the size and spatial abundance of the animals and plants you wish to monitor and the level of precision you want from the data collected (precision is also affected by the number of replicates you use see page 11).

Broad-scale methods will use large units that are defined by the time taken to swim them, e.g. 'manta tow' (p 22) or 'timed swim' (p 31).

Medium-scale methods may have units that are defined by a measured length of reef, e.g. line transects (p 33) or belt transects (p 64).

Fine-scale methods tend to measure smaller areas in more detail e.g. quadrats (p 41).

To detect coral reef changes through time or to compare reefs, it is important to use standard methods with standard sample method sizes. Methods of a specific and consistent size, i.e. defined by space or time, provide **quantitative** information. On the other hand, q**ualitative** information is collected where there is no control over the sample size.

Quantitative information (from 'quantity') is when the subject of interest (e.g. coral cover) is expressed as a number (e.g. 32% coral cover). Quantitative information is standardised and therefore comparable.

Qualitative information (from 'quality') is a subjective description of the object of interest (e.g. medium coral cover) and is difficult to use for comparative studies because one observer's idea of 'medium' coral cover may be very different to that of another observer. Qualitative information can be useful to support quantitative information e.g. photographs of reef change can support trends illustrated on a graph. The general public will relate better to photographs than graphs.

The sample method size you select will depend upon what you want to measure. An abundant organism can be sampled with a smaller sampling area, whereas rare organisms will need larger sample areas. It is important to realise that a very small sample area may not adequately represent your area of interest. However, a large sample area may be difficult to search carefully enough to provide accurate or precise results. The actual size of the habitat being surveyed may also determine the size of the sample method, e.g. patch reefs are not suitable for long transects. For more detailed information on ecological sampling see Kingsford (1988).

How many replicates should you survey?

1. **How many** samples (called **replicates**) should you make?
2. **Where** should you put your replicates?

Coral reefs are variable in both space and time. To understand the extent of this variability, and therefore collect information that is representative of the coral reef area of interest, you need to take more than one sample at a survey site. Additional samples are called **replicates.** Use of replicates is called **replication.**

The number of replicates needed to provide a **representation of the area of interest** is dependent upon its **scale** as well as the magnitude of change you want to be able to detect over time. The magnitude of change you can detect is related to how well your sample represents the coral reef area of interest, or its **precision**.

Large-scale studies involve sampling across large areas, which are widely spaced. Within each area, replicate samples should be taken and the level of variation should be established for each area before trying to compare with other areas. This is called a **nested** (or hierarchical) sampling design where successively smaller spatial (or temporal) scales e.g. one reef, are nested within the scale above e.g. group of coral reefs (Oxley 1997).

Precision is important if you want to be able to detect environmental change in space and time. Collecting data from enough samples is important to ensure the **precision** (smallest standard error — SE) of the surveys because this will tell you if your sample is representative of the local area.

Where should you put your replicates?

You should select sites that are **representative** of the coral reef area. Statisticians prefer that all sites are selected **randomly**, but this is often logistically difficult to achieve. In the real world the best method of choosing where to put your sample methods is **stratified haphazard** selection. This means you first select the reef habitat (reef zone and depth) that you want to monitor, then haphazardly select suitable sample sites within this area. For repeat surveys, you can go back to the same site and haphazardly re-lay the transect in approximately the same area as on the previous visit.

It is also important that replicates do not overlap with each other because the statistics used to analyse your monitoring information rely upon each replicate sample being **independent** of, or not associated with, the other replicates. Replicates that are not independent are called **pseudoreplicates**.

Permanent versus haphazard sampling units

To measure change over time, you can either measure the same part of reef each time, called fixed or permanent survey sites, or you can use the stratified haphazard selection method each time you survey. When you re-survey **permanent** sites, differences in the results e.g. percent coral cover, between the two survey periods can be attributed to environmental change. When you re-survey **random or haphazard** sites, only the change beyond the variance in your sample set can be interpreted as environmental change. There are advantages and disadvantages with using either of these methods of survey site selection so you have to consider which method to use. Note that there will always be some human error when monitoring coral reefs. This means that some of the change in your results from one year to the next will be caused by human error rather than environmental change. See 'Quality control and training' below to find out how to minimise this.

Permanent or fixed survey sites

Permanent sites are generally recommended for **long-term monitoring** because they offer the greatest amount of information, consistency, repeatability and reliability. Managers usually prefer permanent sites because they are more comfortable with comparisons of a fixed sample of the environment rather than relying upon the statistics of random sampling, which are more difficult to understand. Permanent sites should always be selected using a random or stratified haphazard selection process to ensure they are representative.

How do you mark permanent sites?

Permanent sites must be marked so that the transect tapes, quadrats or photographic equipment can be placed as close as possible to the same position on each visit. Stainless steel stakes or reinforcing rods or star pickets should be hammered into the reef at 5 to 10 m intervals along a transect line (p 33) or to mark out the corners of a permanent quadrat (p 43). Observers can wrap the tape measure around these stakes to ensure that the transect is in the same position.

Should I do a pilot study?

Pilot studies can help you decide what **size** of sample method to use (e.g. length of transect or quadrat size) and **how many** replicates are needed. The monitoring methods described in 'section three' of this book recommend the size and number of replicates. For **research** monitoring where you want to detect fine-scale environmental changes, you will need to conduct a pilot study. However, if you wish to reduce the number of replicates suggested by a standard monitoring method (maybe to save costs) we recommend you conduct a pilot study to determine the resolution of environmental changes you will be able to detect. For more information on pilot studies see Appendix p 112.

How do you find permanent sites?

Maps, global positioning systems (GPS) and surface or subsurface-buoys can help you to find these sites again.

1. **Maps** are rarely useful on their own and must include triangulated references (line of sight objects) both above and below the water;
2. A hand-held **GPS** is very useful to re-locate permanent sites and is accurate within a few tens of metres, however, they are expensive. It is essential that you record which GPS datum system you have used, e.g. WGS 84, because you will need to use the same datum system to find your monitoring location again;
3. **Surface or subsurface buoys** should be used to mark the start of a series of transects or quadrats. Sub-surface buoys are more appropriate than surface buoys because they are less likely to be stolen or wrenched off the reef by rough weather. You must ensure they are well below the surface so that they don't get caught in boat propellers. If you don't have access to a hand-held GPS, surface buoys may be necessary.

We recommend you use all 3 methods to find your sites. For more information see www.aims.gov.au

How often should you monitor?

There is a trade-off between the frequency of monitoring and the number of locations to monitor, e.g. a large monitoring effort at a small number of sites in a large reef area may give a biased picture of the overall reef health. To represent a large area, several monitoring locations will be necessary. To be useful, monitoring surveys should be carried out every year or at least every second year. However, more frequent monitoring may be required to answer some management questions, such as 'what is the abundance of highly mobile fish?' and so quarterly surveys at one location may be better (Hodgson 2003).

Permanent sites

Advantages:

- Once set up, repeat monitoring is easy;
- Interpreting results from fixed transects is much easier for the general public and resource managers to comprehend;
- More precise information is produced than for random sites because you don't have to account for spatial variability.

Limitations:

- Time consuming and can be expensive to set up;
- Can be difficult to find, which can waste survey time;

If not marked properly they are no better than random transects.

Non-permanent (stratified haphazard) sites

Advantages:

- Quick and easy to choose the sample site if you are familiar with the habitat in the area, e.g. from maps made after previous surveys.

Limitations:

- Cannot compare results from one study to those at another location if different habitats (e.g. depth) are surveyed.

Impact studies

Human impacts on coral reefs must be distinguished from background effects that are often extremely variable in space and time. This means we need to monitor the resources many times and at many sites (with replicate samples taken at each site) both before and after an impact to control spatial variability. The Beyond Before, After, Control Impact (Beyond BACI) design should be used for impact studies. This design monitors both an impact and at least 2 control sites at many times before and after an impact. An impact is indicated by a greater environmental change at the impact site compared to the controls.

For further information on Beyond BACI designs see Underwood (1994); Underwood (1995); Russ (1996); Russ and Alcala (1996); Kaly and Jones (1997); Russ (2002).

Quality control and training

Human error in monitoring will reduce the precision of the information collected. Although human error can never be eliminated entirely, it can be reduced through **regular training and testing,** and **knowledge reviews** of team members. It is essential that initial training, ongoing training, and a review of skills, are built into the cost of the program. Training must include both how to collect precise data on surveys as well as use of equipment, e.g. how to use a GPS.

Survey training and review sessions should include comparisons with known standards e.g. photographic or video reference material or collected specimens. Training will generally involve field trips dedicated to training and laboratory studies. For example, fish size estimation training can be done by asking observers to estimate the size of fish models underwater (English *et al.* 1997). This training should be repeated at 6 monthly intervals. Fish abundance and identification training must be done by observers together in the field.

The training the team requires depends upon their previous experience and the monitoring level selected. Examples on how to train observers are provided in many of the major program manuals (See 'Section four: monitoring programs', p 98). GCRMN/Reef Check provide regional training workshops in recommended methods. For more information see www.gcrmn.org/ or www.reefcheck.org.

Data handling and communicating results

After monitoring, somebody must **record** the data as soon as possible (e.g. entered into a spreadsheet), **analyse** them, **interpret** the analysis and **report** the findings.

Data entry

Data should be recorded in a format for easy analysis as well as stored for comparisons with data collected in later years. It is essential that data be organised in a way, which makes them easily accessible for future reference. These data should be recorded in columns as in the example below.

Date	Observer name	Site name	Depth	Latitude	Longitude	Replicate No.	No. of grouper	No. of snapper	etc
12.08.04	Sally Smith	Pink Reef	5 m	19.48.67 S	149.03.83 E	1	5	2	

Data storage

A database is used to store data. A computer spreadsheet is the ideal way to store your data if you have access to a computer and the relevant software. It is essential to use systematic methods to store and retrieve data using computer-based management systems. All data should be stored in two safe places immediately after collection to avoid loss. Microsoft Excel is commonly used to store information and can also be used to make graphs and to do basic statistical analysis. For more advanced databases, Microsoft Access is recommended.

Data analysis

Analysis of data allows **interpretation** of the changes that are occurring on the coral reef and may help answer questions e.g. are increasing nutrient levels correlated with decreases in coral cover.

There are many ways to analyse data. It is important that you decide what level of analysis you can achieve before starting to monitor. Analysis of data essentially means calculating the numbers of each of your variables counted during surveys. For example, the average percentage cover of hard coral or the average number of target fish from replicate samples at a particular site. The average grouper count on 4 replicate transects is the total count divided by 4.

Graphs or bar charts are often needed to report the analysis; these can be hand drawn or made on Excel. For more advanced statistical analysis, we recommend SPS or SPSS software and a talk with a scientist with statistical experience in analysis. Some programs, such as Reef Check, provide Excel data sheets to enter data. Once data are entered, basic statistics (e.g. averages and standard deviations) are automatically calculated. So all you have to do is make a graph! In addition, ReefBase and the GCRMN are designing a data entry and analysis package based on Access software to help managers analyse the data they collect (see www.reefbase.org). For more information on statistical analyses see English *et al.*, (1997). For advanced information on experimental design and statistical power see Cohen (1988); Kingsford (1988); Underwood (1994); Zar (1999).

Data reporting

After monitoring has been completed, it is important to present the results in a format that is most useful to key stakeholders. The actual monitoring data and analyses on paper are more appropriate for scientific audiences, but open meetings may be more appropriate for community groups who may communicate more by talking than reading. It is essential to involve the community leaders, as they are the ones that most people listen to (e.g. traditional owners, chiefs, religious leaders), and who can interpret the results of monitoring and explain the value of management actions to the broader community. The steps in this process should include identifying:

- The target audience;
- The key messages you want to get across and when; and
- The communication products that will best suit your needs (many products may be required for different audiences).

For example, scientists read scientific papers and reports; resource managers mostly read status report; and the general public attend meetings, use radio and television, read newspapers, read websites, look at posters etc.

The need to involve the public

Monitoring is a powerful tool to raise awareness of the problems facing coral reefs and the need for management among local communities, tourists and management staff. To ensure that management staff understand the resources they are managing, it is important that all managers and staff participate in some monitoring, whenever possible. Therefore, we recommend that all coral reef management staff undertake basic one day training in monitoring, e.g. Reef Check (p 100). This ensures that managers understand monitoring methods and the data they produce, and keeps them in touch with user communities.

Involving community volunteers and tourists in monitoring not only provides basic scientific data over a wider area, but also ensures that the wider community understands the need for coral reef management. It also creates a sense of awareness and stewardship for the resource amongst user groups. This is particularly true for repeat visitors who are usually interested in learning about the reef as well as in participating in its management. Volunteer monitoring programs are usually low cost, more frequent and cover a larger scale, and the data may complement research programs. They can also provide comparison data from other areas the volunteers and tourists have visited ('community monitoring', p 5).

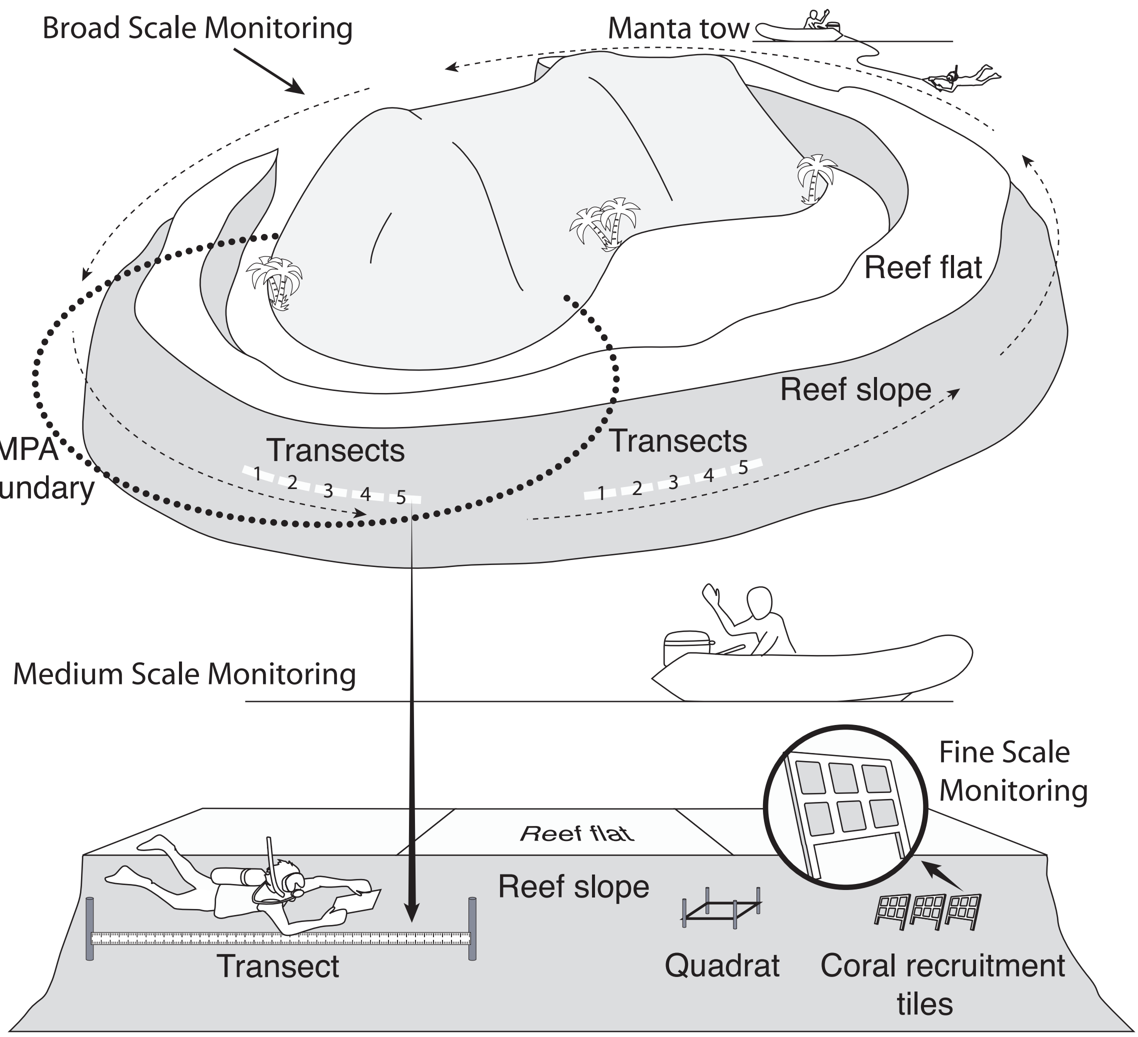

Figure 3. *An illustration of the three scales of monitoring: broad-scale covering large areas at lower resolution, e.g. with manta tow; medium-scale for higher resolution at medium scales e.g. line transects; and fine-scale for gathering high resolution data at small scales.*

3: General monitoring methods

The purpose of this section is to introduce you to the different method families as a guide you on when to use them. The different method families can be classified as follows:

- Manta tow;
- Timed swim;
- Transects;
- Quadrats.

Manta tow and timed swims

These are the best methods for obtaining a broad scale, general description of a reef site and involve either towing a diver behind a boat around a reef or a diver swimming for a set time or distance (p 22 for the protocols).

Transects

Transects provide medium scale information. They are lines put on the reef floor where corals and other objects are counted underneath. Lines can be tape measures, ropes or chains of different lengths with measurements made under fixed points or where something happens e.g. counting chain links or where benthic species change.

Transects can vary in length. Common lengths used are 10 m, 20 m, 30 m and 50 m. The length you should use depends upon the abundance and spatial distribution of the variable to be monitored as well as the **spatial heterogeneity** of the site. Spatial heterogeneity is where the types of animals and plants found on your reef vary in space. If spatial heterogeneity is high (e.g. patch reefs or spur and groove habitat), a long transect (e.g. 50 m) will encompass too much of this spatial variation (e.g. coral, sand and rock) and the power of your surveys to detect change will be reduced (Brown *et al.* 2000).

Transects are generally positioned parallel to the reef crest along a constant depth contour. A transect laid perpendicular to shore may be appropriate if you want to include different reef zones (or depths) in the same transects. Surveying a range of zones may be useful to ground truth remote data on habitat types (see 'Mapping and site selection' p 21).

Advantages of transects:

- Easy to use;
- Tape measures are easy to carry in the water.

Limitations of transects:

- Transects are not suitable where hard corals or target invertebrates are widely spaced and small. Manta tow is better for widely spaced organisms (p 22);

Transects are not suitable for patchy reefs because they require sufficient continuous reef over which to lay the transect replicates. Quadrats or stationary fish counts (p 86) are better suited for patchy reef habitats.

There are 4 ways to survey transects:

1. Line transects (includes line intercept transects and chain transects under a line);
2. Point intercept transects which measure things at specific intervals either below the line or below and to the side of the transect tape;
3. Belt transects measure things in a belt beside the transect; and
4. Chain intercept transects.

1. Line intercept transect

Measurements on line transects are taken along the entire length of the line. Commonly used line transects are called 'line intercept transects' (LIT), which focus on the horizontal plane of the reef (LIT; p 33), and 'chain intercept transects' (CIT), which measure the benthic cover in 3-dimensional terms as the chain follows the contour of the reef (CIT; p 54). CIT enable the collection of information on reef **rugosity** (structural complexity) and are often used with LIT. The rugosity can provide information on the 'spatial index' of the reef, which is the ratio of reef surface contour distance to linear distance. As part of a long-term monitoring program, the spatial index provides a way to quantify changes in the topographical complexity of the reef.

2. Point intercept transect
Point intercept transects (PIT) measure objects at specific intervals either below the transect tape, or below and to the side of the transect tape. With sufficient points they can provide comparable information to LIT.

For discussions on point and line intercept techniques see: Carleton and Done (1995); Vogt et al. (1997); Aronson (2001); Segal and Castro (2001).

3. Belt transects
Belt transects are the same as line transects but wider and are often used for surveying specific impacts to the benthos, such as bleaching or disease, or counting invertebrates (p 64) and fishes (p 67). The appropriate width depends upon what you are measuring. For small species or fish recruits, narrow belt transects (e.g. 2 m wide) are often used (see English *et al.* fish recruits belt transects p 84), for impacts such as coral disease and Drupella snails, 4 m width is used (see invertebrate belt transects used by AIMS p 65). For other key macro-invertebrates wider transects may be used, e.g. 5 m (see the invertebrate belt transect used by Reef Check p 64).

4. Chain transects
Before fibreglass tapes were available, chains were commonly used to mark transects. Chains can be difficult as only short lengths can be carried underwater by divers. This means that longer transects must be made up of several lengths of chain placed in succession.

Another variation is timed swims where the 'transect' length is measured by the swim time.

Do transects cause damage to the reef?
Damage to the reef can be avoided if transects are laid carefully. However, it is difficult to avoid damaging the reefs when using chain transects.

Achievable precision for transects:
High (but not as high as permanent quadrats).

Generic equipment for transects:
How do you mark out transects?
- Tape measures (waterproof fibreglass in a spool with a winding handle);
- Rope (with coloured markers or knots to indicate distance);
- Chain – plastic (chain links of known length used to calculate distance; 1 cm links are easiest).

We recommend using a tape measure as these are the most widely used to mark transects and can be used to measure distance and size. We recommend placing a hook or elastic loop at the end of the tape measure to attach it to the substrate. To learn how to mark permanent transects, see the section on 'permanent transects' (p 33).

How do you measure the belt transect width?
Transect width can be measured or estimated, and there are several methods to measure the width:
- PVC pole or T-bar;
- Body length estimation;
- Tape measure (or equivalent).

1. The **PVC pole or T-bar** should be half the width of the path. Wide poles can be difficult to use underwater. T-bars for narrow transects (e.g. 2 m) are commonly used;
2. The stretched distance from your fin-tip to your hand is a useful **body length** measure to check your estimations of transect width throughout the survey;
4. **Tape measures** can be laid out at the start of each replicate to provide a reference for belt estimations. Another way to test your ability to estimate belt width is by fixing on a point you think is the required width and measuring that distance.

Quadrats

A quadrat is a square or rectangular sampling unit in which organisms are counted or measured. The appropriate quadrat size is dependent upon the size and spatial abundance of the organism being counted. Generic quadrat sizes that are used include:
- 0.5-1m^2 or larger quadrats to assess species diversity. This is the most common size for general benthic community surveys (see 'visual quadrat' by COI p 41);
- 25 cm by 25 cm to measure coral recruits and other small organisms like algae species, *Diadema* or *Drupella* (see the AGRRA coral condition, algal and *Diadema* methods p 58).

There are 3 ways to survey quadrats:

1. Visual estimation;
2. Visual point sampling (grid quadrats);
3. Photo quadrats where images are digitised or point sampled to determine percent cover.

Quadrats provide precise information for fine scale, species-specific questions. Permanent quadrats are useful for observing specific coral colonies over time.

Do quadrats cause damage to the reef?

- Permanent quadrats – Damage to the reef can be avoided if quadrats are set carefully;
- Random quadrats - Some potential carrying these underwater; placing them on fragile corals.

Advantages of quadrats:

- Quadrats can be made with inexpensive equipment;
- Useful for fine-scale monitoring.

Percent cover estimations

Rare or uncommon species are less frequently overlooked in comparison to the point intersect method.

Point intercept in quadrats

Reasonably accurate measures of percent cover, species diversity, relative abundance, density and size can be obtained.

Photo-quadrats

Photo-quadrats provide a permanent record of the benthic communities, can be analysed using random or set points (p 43) or the images can be digitised to provide very accurate percentage cover estimates. Digitised images can be used to compare fine-scale changes in benthic communities through time.

Limitations of quadrats:

- Quadrats provide data from the projected surface area only and cannot be used to measure rugosity. This is a problem on complex reef surfaces. Plate-shaped corals tend to be over-represented relative to columnar shaped corals (linear transects are more appropriate in these situations);
- Difficult to use in areas dominated by fragile branching corals.

Percent cover estimations:

- Estimations are the least precise method to measure percent cover or abundance because of observer bias;
- Time-intensive, which limits the number of replicate quadrats that can be searched on a dive.

Point intercept in quadrats:

- Rare and uncommon species are frequently overlooked.

Photo-quadrats:

- Digitising of photographs from photo-quadrats is time consuming and requires access to computers and specific software. Comparisons of digitised images are also time-consuming;
- The use of random dots is also time consuming but less so than digitising.

Types of data obtained from quadrats:

- Estimations of percent cover (visual quadrats);
- Precise measure of percentage cover (point intercept methods either done manually in the field or from photographs);
- Frequency of occurrence (calculated from the number of quadrats in which a species occurs);
- Species diversity, relative abundance, density, size and interactions between corals.

Achievable precision for quadrats:

- Visual estimations provide reasonable precision if done by the same person each time or if observers are trained together;
- Point intercept is more precise than visual estimations.

Generic equipment for quadrats

Quadrats can be made from a variety of materials, such as iron re-bar, stainless steel or PVC pipes. PVC is good for larger quadrats as they are easier to handle but it is important to drill holes in the pipe to avoid buoyancy problems. When used on relatively flat substrates, it is possible to create a grid on the quadrat using nylon string to use for point intercept methods. It is useful to put similar grids on the top and bottom of the quadrat frame to avoid parallax error and remove bias. Observers should line up the grids to ensure they are looking directly down at the substrate (Hallacher and Tissot 1999). For irregular surfaces, grid positions can be estimated from painted reference marks at known distances (e.g. 10 cm) along the quadrat frame. Collapsible quadrats are useful to make entry into the water easier. References for quadrats: Rogers *et al.* 1994; English *et al.* 1997; Hallacher and Tissot 1999.

Photography and video monitoring

The use of digital equipment in coral reef monitoring has become more popular recently. These methods can greatly reduce field expense and time because they require less time under water compared to visual methods, and they can be used by experienced divers who may not be scientists.

For information on how to attach still cameras to avoid movement, or to ensure the cameras are in the same position on repeated surveys, see Rogers *et al.* (1994); English *et al.* (1997).

How do you analyse photographs or video frames?

- Dot Grid – this involves placing random or sequenced dots over the photograph or frame. The benthos beneath is identified (see 'point intercept transects' p 36);
- Digitising – this involves manually drawing the different benthic items on a digital image with digitising software. The software can be used to calculate very precise percentage cover. Although this is the most accurate method, the equipment required is expensive, expertise is necessary and it is the most time-consuming method.

The camera, underwater housing and computer software analysis equipment are expensive to buy and maintain. We recommend that photography and video methods only be used for research level monitoring. See p 20 for advantages and limitations of these methods.

When is videography better than photography?

Video footage of the general reef area can provide useful qualitative information. For quantitative studies, videos are more appropriate for ecological monitoring of a large area, e.g. using belt transects. The distance the video is held from the coral reef benthos determines the width of the belt. Reproducing the exact path, speed and distance from the substrate for repeated sampling of a video transect is difficult. Lasers positioned on the video underwater housing to cross at a fixed distance from the substrate can help observers to maintain a constant distance but this is expensive, and therefore impractical in most situations
(see NOWRAMP http://hawaiianatolls.org/research/NOWRAMP2002/features/rea.php).

Advantages and limitations of visual counts and photography/video

Underwater visual counts

Advantages:

- Data are ready to be analysed immediately following the survey.

Limitations:

- More time spent underwater.

Digital/video surveys

Advantages:

- Observers need not be trained scientists, only experienced divers;
- Less time is spent in the field, which reduces the cost of field work;
- Provides a permanent record;
- Footage can be analysed to provide quantitative information as well as provide a visual image of data. Visual images can be more powerful than statistics and certainly a useful combination to demonstrate reef change to non scientists;
- Relatively easy to use;
- It takes up to 4 hours underwater to collect data from a 20 m chain transect, or 2-5 minutes to collect the video images.

Limitations:

- Photographs or video frames must be analysed using digital equipment, which is expensive to buy and maintain. This often makes use of photography or video unsuitable for programs with limited budgets;
- Requires a trained team of people in the laboratory to analyse images (otherwise the images remain in filing cabinets and are never analysed);
- Organisms under coral plates or rock ledges are not visible;
- Field observations are necessary to distinguish some species. Small organisms such as coral recruits and macro algae cannot be distinguished;
- It is difficult to obtain quantitative information from photographs where soft corals are abundant because they overshadow other organisms;
- Photographs or videos provide a 2-Dimensional view of the reef, therefore, these methods are not suitable to estimate spatial relief. Although stereo-photography will provide 3-D photographs it is technically more complex and requires sophisticated analytical systems;
- To accurately detect small changes within a small area, you must photograph the area from *exactly* the same spot each time. Shifts in coral heads or rubble due to storms or bio-erosion can make this almost impossible. This problem can be minimised by use of monopod frames (Rogers *et al.* 1994);
- Corals may be damaged if you place frames over them, especially in topographically complex areas;
- Photo coverage of large areas is problematic. If a photo is taken from a long distance, the resolution and water clarity may not be sufficient to identify organisms. An alternative is to take a series of overlapping photos and create a photo-mosaic. Under optimal conditions, it is possible to make a repeatable and accurate mosaic.

4: Mapping and Site Selection

Mapping coral reef areas is the essential first step to management and can be done with a range of techniques. Habitat maps can be made using maps of the area, local knowledge, and manta tows for broad scale surveys, or snorkel or scuba transects for medium scale surveys to confirm the location of major habitat types.

If considerable scientific and financial resources are available, you can map the reefs using satellite imagery and/or aerial photographs and GIS technology (to prepare spatially referenced images showing the location and size of major habitat types). This process involves obtaining the images of the area, interpreting them to identify where major habitats appear to occur (between coral reef and other tropical coastal habitats such as seagrass beds), and checking these predictions (ground-truthing) using local knowledge and transects or manta tow. The major habitat types can be located on the images using GIS technology, however, remote techniques should always be used in combination with field survey techniques to 'ground truth' the data.

The most cost-effective satellite sensors for habitat mapping are Landsat TM for areas greater than 60 km in any direction and SPOT XS for areas less than 60 km in any direction. Colour aerial photography can resolve slightly more detailed ecological information on reef habitats but, for general purpose mapping, satellite imagery is more effective because it has slightly more accuracy, is cheaper and uses less staff time. Low altitude, infra-red aerial photography can be used to estimate live-coral cover over shallow (<1 m deep) reef flats, however, this is only appropriate for small areas as the low altitude restricts the area covered in each photograph.

The most accurate, but expensive, means of making detailed reef habitat maps is use of airborne multi-spectral instruments such as CASI (Compact Airborne Spectrographic Imager). In the Caribbean, CASI was used to map assemblages of benthic species and substrata with an accuracy of >80% (Green *et al.* 2000).

For more information on how remote sensing can help coral reef monitoring and management, see Green *et al.* (2000) at: http://www.unesco.org/csi/pub/source/rs.htm. To obtain detailed maps of your coral reef area go to www.ReefBase.org.

The next major step after mapping is **site selection** for monitoring. We describe two broad-scale ways of selecting sites: towing a snorkel or scuba diver behind a boat e.g. manta tow; and random or timed swims, either by a snorkel or scuba diver.

Which mapping and site selection method should you choose?

Broad scale	**Choose this method for mapping, site selection and to cover a large area quickly.**	**Page**
Random swim	Useful to determine site suitability but limited to the areas surveyed; large areas of reef are not covered; greater depths can be examined if scuba used.	26
Manta tow or video towed diver	Useful to determine site suitability; can cover large areas quickly; limited to shallow depths if done on snorkel; scuba can be used for deep reefs.	22 24

Manta tow

Programs that use this method:

- Australian Institute of Marine Science Long-term Monitoring Program (AIMS LTMP);
- English *et al.* is the GCRMN recommended method.

Method description:
This involves towing a snorkeller behind a boat at a constant speed with regular stops to record data (e.g. every 2 minutes). This is the best method to obtain a general description of large reef areas or measures of broad changes in abundance and distribution of organisms and large-scale disturbance (cyclones, COTS, bleaching). This method is good for variables seen over long distances and for site selection.
Information obtained:
For site selection, the diver can only determine where there is continuous reef, and can provide an estimate of hard coral cover (collected as a % hard coral cover); see figure below.

Manta tow can be used to monitor changes in coral cover, determine abundance of impacts, such as bleaching and disease, count giant clams or COTS. Observers must be trained to estimate these abundance categories to ensure that estimations are consistent among observers.

Manta tow can also provide broad scale information on benthic communities especially specific impacts, such as bleaching or destructive fishing practices; and key macro-invertebrates, such as COTS, *Diadema* or giant clams. Usually 50-60 tows provide sufficient power to detect a 20% change in COTS abundance. Manta tow tends to underestimate abundance, but data can easily be calibrated using scuba surveys to produce more accurate results (see 'belt transects' used by the AIMS LTMP). Scuba benthic monitoring and manta tow techniques should ideally be combined. To obtain broad data on benthic communities you can assess the following parameters:

- Percent hard and soft coral;
- Percent dead coral, rubble and sand;

Equipment required:

- 17 m long, 10 mm diameter towing rope;
- Rope harness to attach to the rear of the boat;
- Mantaboard with fitted harness and attached pencil;
- Aerial map of the reef to be surveyed;
- Marker buoy (to mark where you stopped if the reef survey is not done at one time);
- Waterproof watch for timing each survey. It is useful if this has a countdown function.

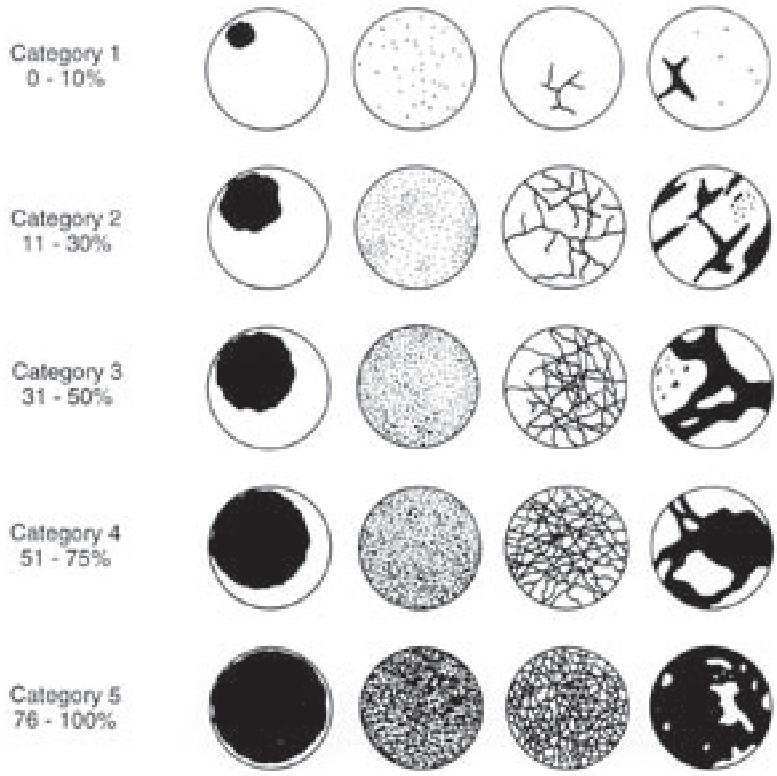

Figure 4. *Visual estimation categories for percent coral cover from Dahl (1981) in English* et al. *(1997).*

Field personnel:

- 1 boat driver/surface watch who is trained to maintain the boat at a constant speed;
- 2 trained observers (boat drivers and observers can be interchangeable).

Lab personnel:

- Data entry, analysis, interpretation and reporting.

General procedures:

- Divide the whole reef survey into 2 minute surveys. At the end of each tow, stop the boat to allow the observer to record the data on the data sheet on the manta board. The boat driver marks the tow number and position of the boat on the aerial photograph. The process is repeated when the observer signals 'go' until the whole reef perimeter or a long length is surveyed;
- Tow path is parallel to the reef crest over a 5-10 m depth so the maximum amount of slope is visible;
- Tow speed is a constant 3-5 km per hour (1.5 knots). Factors such as currents and sea conditions may require a change in tow speed;
- The observer scans a width of 10-12 m depending upon visibility, reef gradient, distance from the bottom and the distribution and density of the organisms being counted;
- Survey direction is determined by factors such as wind, currents and the angle of the sun. The survey direction should be standardised to avoid the need to correct data for re-surveys.

Parameters that can be surveyed using this method:

- ✓ Benthic communities
- ✓ Key macro-invertebrates

Monitoring level:

- ✓ Research
- ✓ Management
- ✓ Community

Scale:

- ✓ Broad

Level of detail:

- ✓ Semi-quantitative

Causes damage to the reef?

- ✓ No

Achievable precision:

- ✓ Low

Advantages:

- A large area is covered in a short time, which reduces the chance of overlooking population changes or occasional disturbances (e.g. dynamite fishing, COTS, bleaching, disease and storm damage);
- Easy to use following minimal field training;
- Cheap equipment with mantaboards easily manufactured locally;
- Suitable for remote locations with minimum support (can be done on snorkel);
- Large distances covered with minimal observer fatigue;
- Relatively accurate (when calibrated with a scuba search) and a cost effective way to determine the abundance of non-cryptic COTS and corals over large areas in clear water;
- Excellent for an overview of the site and assessing the type of reef and the resources.

Limitations:

- Boat driver controls the tow route, so inappropriate sections e.g. sand or deep reef slopes, may be covered;
- Cryptic animals are easily overlooked e.g. juvenile COTS, or COTS underneath plate corals, small giant clams (*Tridacna);* therefore real abundances are underestimated. Results should be calibrated with medium scale surveys e.g. AIMS scuba search, p 50;
- Includes few variables because the observer must remember all observations during each 2 minute tow;
- Can survey shallow reef only, especially in poor visibility;
- Precision is limited by the difficulty of visually assessing the dominant reef organisms;
- Can only measure coral cover in large categories e.g. 0-10%, 11-30%, 31-50%, 51-75% and 76-100%
- Care is needed in turbid environments where there may be sharks or other potentially vicious fish!

Training required:

- Boat driving at a constant speed;
- Minimal identification, skills required;
- Abundance estimates; these should be calibrated among observers

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Reference: English *et al.* (1997); Bass and Miller (1998); www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop1/mon-sop1-10.html and www.oneocean.org/download/_index.html; Uychiaoco *et al.* (2001).

Video towed diver (video manta tow)

Programs that use this method:
- NOAA Fisheries Pacific Islands Fisheries Science Center Coral Reef Ecosystem Division (CRED)

Method description:
This method involves towing two SCUBA divers behind a boat at a constant speed (~1.5 knots). One diver manoeuvres the 'benthic towboard' (another name for manta board) equipped with either a downward-facing video camera or a still camera to photograph the benthos at selected intervals. The other diver manoeuvres the 'fish towboard' (p 76) equipped with a forward-facing video camera to record fish and general reef topography. Towed-diver surveys are good to obtain a general description of a large reef area, assess large-scale disturbance e.g. bleaching, and assess general distribution and abundance patterns of selected macro-invertebrates e.g. COTS or giant clams. They are best for covering large distances at low levels of taxonomic resolution.

Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ invertebrates

Monitoring level:
- ✓ Research

Scale:
- ✓ Broad

Level of detail:
- ✓ Quantitative

Causes damage to the reef:
- ✓ No

Achievable precision:
- ✓ Low

Information obtained:
Percent cover estimations of benthic communities recorded by the diver can be used for rapid, preliminary analyses. The habitat types recorded can be used to geo-reference coral reef habitats. More precise quantitative data must be extracted from recorded imagery by trained analysts using digital image analysis software. In obtaining broad data on benthic communities, the percentage cover of the following parameters can be assessed:
- Coral (sub-categories by taxon or colony morphology depend on the biogeographic area surveyed);
- Macroalgae and turf algae;
- Coralline algae;
- Other macro-invertebrates;
- Non-encrusted (recently dead) coral;
- Sand, rubble, and pavement (rock).

Field equipment required:
- 60 m long, 9.5 mm diameter, low-stretch towing rope;
- Towing bridle affixed to towboard;
- Towboard with fitted cut-outs or mounts to attach cameras and other instruments (data sheets and pencils);
- Housed digital video camera, or housed still camera;
- 2 strobes and slave sensors (when using housed still camera);
- 2 lasers calibrated to project dots 20 cm apart on recorded imagery;
- Depth/temperature recorder e.g. SBE 39;
- Waterproof watch with countdown function to signal intervals for visual assessment;
- Separate waterproof watch as backup and to monitor dive time;
- Depth gauge bottom timer (UWATEC);
- GPS unit(s) in towing boat to geo-rectify survey track e.g. Garmin 76;
- Depth sounder in towing boat to maintain constant towing depth.

Lab equipment reguired:
- Video player and s-video cable (for imagery recorded on digital video);
- Software to play video through computer and grabbing still frames from digital video e.g. DVRaptor; image thumbnails colour correction e.g. ACDSee; quantitative whole-image analysis e.g. SigmaScan; data compilation e.g. Excel;
- Digitizing tablet e.g. WACOM;
- High-resolution monitor e.g. PELCO desirable;
- ArcView GIS.

Field personnel:
- Efficiency is enhanced when there are 4 field people in two teams of 2 scuba divers, so that the surface team (driver and data recorder) can switch at the end of each tow survey.

Lab personnel:
- Analysts experienced in the identification of coral reef benthos and trained in specific analysis protocols;
- Experienced ArcView GIS user.

General field procedures:

- Maintain constant tow speed of ~1.5 knots. Currents and sea conditions may require a change in tow speed;
- Benthic diver begins video (or still camera) after reaching bottom and coordinating start time with fish towboard diver (see section on assessing fish populations for discussion of coordination of GPS tracking signals between divers and surface personnel p 76);
- Benthic diver attempts to manoeuvre towboard 1 m above bottom;
- Each minute the benthic diver marks the habitat type on the data sheet;
- At 5 minute intervals (alerted by countdown watch timer), benthic diver estimates percent cover of major components on data sheet;
- Macro-invertebrates are recorded when observed in each 5 minute segment on the data sheet;
- A standard survey lasts 50 minutes.

Advantages:

- A large area is covered in a short time;
- Different habitats e.g. patch reef, sand flats, rubble zones can be observed during a single tow, as well as the transitions between them;
- Suitable for remote locations that can only be visited infrequently;
- Towed divers can survey areas that are unsuitable for roving divers due to strong current, surge, or poor anchorage;
- Divers can work to limits of conventional scuba (30 m);
- Use of alternating surface and dive teams increases the number of surveys per day;
- An archived visual record can be re-sampled or re-analysed;
- A GPS receiver on the tow boat allows geo-referencing the survey path, linking imagery to location;
- Provides a spatial link between remote sensing data and local, site-specific surveys.

Limitations:

- Requires experienced divers trained in specific hazards of manoeuvring towboards;
- Field equipment is expensive and requires regular maintenance, therefore this method is only suited to research projects with large budgets;
- Lab equipment needed to analyse imagery is expensive;
- Image analysis is time-consuming;
- Preliminary results from diver estimations of percent cover involve subjective evaluations that are difficult to standardize or replicate;
- Time required to record diver estimations while being towed overlaps with ongoing observations;
- Taxonomic resolution of analysed imagery is low compared to roving diver benthic survey methods;
- Cryptic animals are easily overlooked e.g. COTS hiding under plate corals, juvenile COTS, and small giant clams; therefore real abundances are underestimated, so results should be calibrated with finer-scale surveys, or used only for comparison with other areas and times surveyed with the same method (belt transects p 64).

Field training required:

- Certified scuba divers trained in safely manoeuvring towboards;
- Operation of small boats and driving at a constant speed, GPS units, digital video and still camera;
- Recognition and percent cover estimation of major benthic categories.

Lab training required:

- Coordinated use of hardware e.g. digitising tablet and software e.g. DVRaptor, SigmaScan, ACDSee, Excel in analysing digital imagery;
- Arcview GIS.

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Reference:
Maragos and Gulko (2002)
crei.nmfs.hawaii.edu/eco/tow_board.html
www.hawaiianatolls.org/research/NOWRAMP2002

For information on the fish monitoring method that can be done by the buddy of the observer who does either this benthic towed diver method, or the 'Manta tow', (p 22). The validity of towed-diver surveys as a monitoring technique is still under development.

Random swim

Programs that use this method:
- Community monitoring programs may use the random swim for monitoring;
- Management or research monitoring programs may use the random swim for site selection.

Method description:
For site selection, this involves a snorkel or scuba diver buddy pair selecting suitable sites for monitoring e.g. checking if there is sufficient continuous reef for transects.

Random swims can also be used for monitoring various coral reef parameters ('Eye on the Reef' p 30).

Information obtained:
General description of the site with semi-quantitative counts of various coral reef variables.

Equipment required:
No special equipment.

Field personnel:
- 1 boat driver/surface watch;
- 2 trained observers.

Lab personnel:
- Data analysis, interpretation and reporting.

General procedures:
- Swim around the general reef area to determine suitability for monitoring methods selected, or make a species list to decide which parameters to count during monitoring.

Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ Macro-invertebrates
- ✓ Fishes

Scale:
- ✓ Broad

Monitoring level:
- ✓ Community
- ✓ Management
- ✓ Research

Level of detail:
- ✓ Qualitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Low

Advantages:
- Useful to determine site suitability;
- Useful to decide on the type of monitoring methods to use e.g. transects work well for continuous reef areas (p 33), whereas quadrats are more suitable for patch reefs (p 43); and the level of detail required e.g. species or genus level.

Limitations:
- The area covered is limited to where the divers look and this may not be the best location. We recommend using manta tow to select sites, and then random swims for more detail and to make species lists.

Training required:
Site selection
- Knowledge of the type of site to select and the possible target monitoring methods.

To determine level of detail for monitoring program
Basic coral reef identification expertise in order to decide what things to count.

5: Benthic Communities

Coral reef managers need information on the status and trends in benthic communities to effectively manage the resources. Most focus is on hard corals, but managers also need data on soft corals, algae, sponges and other invertebrates (see 'Section 6: Invertebrates', p 63). Therefore the emphasis in these methods is to assess corals by monitoring diversity, coral cover, coral health and disease, growth and recruitment.

Coral species diversity

Assessing coral diversity is easier where there are fewer species, e.g. the Caribbean, or where a few species are very dominant. In the Indo-Pacific, it often necessary to assess coral growth form as a substitute for diversity. Other 'species diversity' measures are for fish, p 73.

Percent cover

Percent cover of hard coral is the information most frequently used by managers to assess reef health. Percent cover of various benthic animals and plants, as well as rock and rubble, is easy to measure and understand.

Coral health

Monitoring various indicators of coral health is important to determine and understand the causes of coral death. Coral bleaching has become a major concern in coral reef management over the last few years (Wilkinson 2002) and coral diseases are apparently increasing in frequency and distribution (Bruckner and Bruckner 1997; Bruckner 2002).

Broad scale surveys can provide information on the general health of corals and causes of death at a large number of sites; medium scale surveys can provide more detailed information on the abundance and type of coral disease, bleaching or mortality; and permanent fine scale surveys can provide more information on how different species and specific coral colonies are affected. Questions might include:

- Are there coral diseases at our sites, if so what is the type and abundance?
- How has coral bleaching affected corals?

Coral bleaching specific methods

To further understanding of the ecological implications of mass coral bleaching, detailed information on the amount and patterns of coral mortality from bleaching is required. Broad scale surveys will provide information on the extent of bleaching, whereas medium and fine scale monitoring provide more precise information about the percentage and types of corals that bleach, and then subsequently die or survive.

All of the methods described previously for percentage cover or coral health can be used to monitor bleaching. However, the methods described below have been designed specifically for bleaching.

Disease-specific methods

The occurrence of disease in corals is apparently increasing. Disease-specific surveys are useful in regions where this is a particular problem.

Structural complexity (rugosity)

Monitoring the rugosity of the reef is useful to determine how the coral reef structure changes over time. Chain intercept transect methods (CIT) provide a good measure of rugosity, but are more time consuming and cumbersome. An alternative to the chain methods are line intercept transect (LIT) methods where the collection of growth form (coral shape) information can be used to determine how reef topography changes through time. Note growth form data provide less detailed information on topography than CIT.

Coral growth

See 'Permanent photo quadrats' for use to collect growth information, p 43. Other coral growth measuring methods are presented in Rogers *et al.* (1994).

Coral recruitment

Information on coral cover or coral mortality over the long-term is not sufficient to determine whether a reef is healthy. A healthy reef must have young recruits, and monitoring coral recruitment is important to identify coral reef areas that function as a source or sink of larvae. Such information can determine recovery potential of a reef after disturbance. Coral recruitment can be measured using either settlement plates, which provide information on new recruits that are too small to observe in the field; or visual or photographic searches, usually in quadrats. Field searches look for successful recruits i.e. those that have survived for their first year. At this point they are visible to observers in the field. Methods detailed here include:

- English *et al.* coral recruitment settlement plates;
- MBRS SMP Coral recruitment settlement plates;
- AGRRA coral recruitment quadrats.

Other benthic communities

Percent cover of algae

Increases in algae often occur when coral reefs are impacted by increased nutrients or removal of herbivores. It is important to monitor the abundance and type of algae if you suspect that the reef could be severely affected by algal increases. Otherwise methods to measure percent cover are sufficient. The methods of AGRRA, CARICOMP and Rogers *et al.* (1994) provide specific methods for monitoring algae. These include quadrats and the collection of algae to determine biomass.

Key macro-invertebrates can be monitored using methods described on p 63.

Table 1. Which benthic communities monitoring method should you choose?

Monitoring Category & Scale	When should you choose this method?	Page
Broad scale	**Site selection and to cover a large area in short time**	
Manta tow or video towed diver	**Percent cover:** Estimates percent coral cover over large areas in short time, at low detail; limited to shallow, snorkel depths; **Coral health**: Estimates only bleaching % cover of live or dead coral.	22
General observations	**Percent cover:** Estimates of reef change. Good for dive tourism staff to keep an eye on the reef during frequent visits. General information only, low precision. **Coral health:** Recreational divers and researchers can make observations on coral health; some training required; many sites covered at low cost. **Coral bleaching**: Less instruction required.	30
Timed swim	**Percent cover:** Estimates coral cover or large invertebrate abundance of a large area, and at various depths if scuba used; not as quick and cost effective as manta tow, but more detailed. **Disease specific:** Easy to do; information on extent of bleaching and types of corals affected; lower precision than belt transects.	31
Medium scale	**Smaller area, more detailed and more precise than broad scale methods. More time consuming and expensive than broad-scale methods.**	
Timed swim	**Species diversity:** The highest level of expertise is required.	31
Line Transects LIT & PIT	**Percent cover: LIT -** experienced staff, low to high detail, precise information; time consuming. **PIT** - less experienced staff needed, quick and easy; can have similar precision as LIT. **Coral health:** High detail and precise, but expertise required and time consuming. **Disease specific:** Detailed information, time consuming. **Structural complexity:** Size information collected along lines provides estimates of rugosity (MBRS SMP and Line transect by AGRRA).	33 36 51
Belt Transect	**Coral health:** Medium detail and fairly quick; low to high expertise required depending on level of detail wanted (Reef Check or AIMS LTMP); **Coral bleaching:** Easy to do, but expertise is required; detailed information on the extent of bleaching and types of corals affected. **Disease specific:** As above.	64 47 49
Chain transect	**Percent cover:** experienced staff, low to high detail, precise information; more time consuming than LIT. **Disease specific:** Difficult to do; experience required; detailed information on extent of bleaching and types of corals affected. **Structural Complexity:** Difficult to do; experience required.	54
Video transect	**Percent cover:** High precision, medium detail; permanent record; experienced divers to collect data and experienced scientists for analysis; expensive equipment to buy and maintain; **do not use** unless suitable resources available.	38
Fine scale	**Useful for asking detailed, small-scale questions. More time consuming and expensive than medium-scale surveys.**	
Visual quadrat	**Percent cover** High precision and detail, but lower precision than permanent photo quadrats. Smaller animals, e.g. coral recruits can be recorded more reliably with visual methods than photo quadrats. **Disease specific:** Very high detail and time consuming. Information on the extent of bleaching and the types of corals affected. **Coral recruitment:** Provides information on coral recruits that have survived their first year on the reef.	41
Permanent photo quadrat	**Percent cover** High precision and detail; permanent record; experienced divers to collect data; experienced scientists to analyse; expensive equipment to buy and maintain; **do not use** unless suitable resources are available.	43
Tagging coral colonies	**Disease specific:** Highest detail and most time consuming; provides precise information on specific coral colonies and how these are affected by disease.	53
Recruitment tiles or plates	**Coral recruitment:** Collects information on coral recruits that are newly arrived on a reef.	56

General observations

(e.g. Eye on the Reef.)

Programs that use this method:
- GBRMPA/CRC Reef (in collaboration with Australian Marine Park Tourism Operators (AMPTO), the Queensland Parks and Wildlife Service (QPWS) and 10 Dive Operators).

Method description:
Broad scale rapid early warning system that involves the dive tourism industry on a voluntary basis.

Information obtained:
Presence/absence of target organisms or impacts through time.
The data are highly subjective.

Equipment required:
No special equipment.

Field personnel:
- Can be conducted by dive professionals on tourist operations.

Lab personnel:
- Data entry, analysis, interpretation and reporting (all performed by program coordinator in Queensland).

General procedures:
- Diver observes the reef whilst on a tourist dive (no control on time, depth or direction) and records on a daily or weekly basis the presence and abundance of target organisms on data sheets.

Advantages:
- Encourages dive operator staff to participate in monitoring coral reef health;
- Fosters stewardship amongst marine tourism operators and their staff;
- Early warning indicator of potential environmental changes;
- Development of nature diaries, which are useful for tourism interpretation;
- Documentation of sporadic events.

Limitations:
- Qualitative data only;
- Very low precision because there is no control of data quality;
- Requires coordinator to continue to motivate participants.

Training required:
- Minimal. Very easy for non-trained personnel; designed for professional divers who have experience on reefs and can identify the major reef organisms

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Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ Key macro-invertebrates
- ✓ Fish

Monitoring level:
- ✓ Community

Level of detail:
- ✓ Qualitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Low

Timed swims

Programs that use this method:
- The Nature Conservancy (species diversity);
- World Wide Fund for Nature (species diversity);
- World Wide Fund for Nature; Great Barrier Reef Marine Park Authority; ReefBase Global Bleaching Survey Program;
- Komodo National Park Coral Reef Status Monitoring — Marine Conservation Program of The Nature Conservancy, Indonesia;
- Indian Ocean Commission (COI);
- AIMS Long-term Monitoring Program.

Method description:
This involves observers swimming at a constant depth and speed for a set amount of time. This is a broad scale, rapid early warning system of impacts such as change in coral cover, dynamite fishing, bleaching, COTS.

Information obtained:
Estimated percent cover of basic benthic community categories: hard coral, soft coral, macroalgae. Estimations of overall site characteristics can be used to help site selection. For bleaching surveys use taxonomic groups such as:
- *Acropora;*
- *Pocillopora;*
- *Favia.*

Equipment required:
No special equipment.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

Monitoring level:
- ✓ Management

Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ Key macro-invertebrates
- ✓ Fish

Monitoring level:
- ✓ Management

Scale:
- ✓ Broad
- ✓ Medium

Monitoring level:
- ✓ Community
- ✓ Management
- ✓ Research (when used for species diversity)

Level of detail:
- ✓ Semi-quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Low

General procedures:
Species diversity
- Swim along a depth contour for a specific length of time (e.g. 30 minutes to 1 hour) and make lists of all species encountered. Abundance estimates can be made for each species.

Bleaching program
- 2 depth profiles, 1-4 m and 5–10 m;
- 2 divers swim randomly around an area of 25 m diameter for a period of 2 minutes;
- One diver is the primary observer.

Komodo National Park
- Observers make repeated swims of 4 minutes duration at 4 m, 8 m and 12 m depths;
- After each swim the observer stops and records cover estimates of benthic organisms and substrates.

COI

- Observers (on scuba or snorkel) swim randomly for 5 minutes for 9 replicates per site;
- Record assessment of coral cover using 5 abundance categories (Manta Tow p 22).

Advantages:

- Provide greater accuracy than manta tow since the observer can spend more time in a particular area and get closer to the substrate to ensure optimal visual resolution;
- Minimal training required;
- Large areas can be covered in little time;
- Useful to acquire lists of species present.

Limitations:

- Low precision when used for monitoring percent cover; limited ability to detect small amounts of environmental change.

Training required:

- Low if basic categories measured, medium if coral families are included;
- Tertiary scientific training and research experience if species diversity counts are required.

Contact:

- Species diversity: Donnelly *et al.* (2003);
- www.komodonationalpark.org/ or contact one of the major NGOs: The Nature Conservancy at www.nature.org; the World Wide Fund for Nature, www.wwf.org; and Conservation International, www.conservation.org.
- Bleaching: Naneng Setjasih at WWF Indonesia: nsetiasih@wallacea.wwf.org.id, Paul Marshall at GBRMPA: p.marshall@gbrmpa.gov.au or Jamie Oliver at ReefBase, j.oliver@cgiar.org
- Dynamite damage: Komodo National Park www.komodonationalpark.org: Andreas H Muljadi, amuljadi@cbn.net.id, ah_Muljadi@yahoo.com or Peter Mous, pmous@tnc.org
- Site selection: COI (p 104) COI Secrétariat Général, Recif_members@coi.intnet.mu

Also see 'coral bleaching' p 47 for use of timed swim surveys to monitor the extent and effects of coral bleaching.

Line intercept transect

Programs that use this method:

- GCRMN recommended methods (English *et al.*)

Method description:
Line intercept transect (LIT) is used to determine the percentage cover of benthic communities. It can be used on its own or in combination with other methods, such as quadrats (p 41). The LIT is the standard method recommended by the GCRMN to determine percentage cover and colony size for management level monitoring.

Information obtained:
Percentage cover of benthic communities e.g. hard coral, soft coral, sponges, algae, rock, dead coral. Medium to detailed information can be collected from growth forms (shape) to family, genus or species level depending on objectives or expertise available. Growth form data can describe reef topographic changes, but with less detail than the Chain Intercept Transects (p 54).

Parameters that can be surveyed using this method:
✓ Benthic communities

Scale:
✓ Medium

Monitoring level:
✓ Management

Level of detail:
✓ Quantitative

Causes damage to the reef:
✓ No

Achievable precision:
✓ High

Equipment required:

- 5 x 50 m fibreglass measuring tapes;

Field personnel:

- 2 observers (scuba divers) with expertise in identification of coral reef benthic communities;
- 1 boat driver/surface watch.

Lab personnel:

- Data entry, analysis, interpretation and reporting.

General procedures:

- Mark 5 x 20 m long replicate transects at each of 2 depths (3 m and 9-10 m depths). If permanent transects are used, place stakes every 5 to 10 m ('how do you mark permanent sites?', p 12);
- Stretch the transect line tightly and close to the bottom (0-15 cm);
- Move slowly along the transect recording the growth forms (species if possible) directly under the tape;
- Record the transition point on the tape (in cms) where the organism, substrate, growth form changes.

Advantages:

- Growth form categories allow the collection of useful information for those with limited experience in the identification of benthic communities, especially on high species diversity Indo-Pacific reefs;
- Minimal equipment required;
- LIT, point intercept transects and video transects 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; 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.* 1996).

Limitations:

- It is difficult to standardise some of the growth form categories among observers;
- 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 (see English *et al.* 'permanent photo-quadrats' p 43);
- Not good for quantitative assessments of percent 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 (see English *et al.* 'permanent photo quadrats' p 43; English *et al.* 'tagging coral colonies' p 53);
- Does not measure rugosity or uneven surface of coral reefs (Chain methods p 54; MBRS SMP PIT p 36);
- Time consuming.

LIT is the most rigorous method to determine percent cover of benthic communities, but is more time consuming than PIT. Recommend LIT if underwater time is not a problem; however, if time is a problem, PIT may be more appropriate (p 36).

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.

Contact:
Sue English, s.english@aims.gov.au

Reference:
English *et al.* (1997); www.aims.gov.au

Variations on this method:
LIT can be varied by using a chain to calculate rugosity (CIT p 54) or can be combined with other methods (p 79).

Table 2. Comparison between Reef Check, MBRS SMP and ReefKeeper PIT methods.

Method	**Reef Check**	**MBRS SMP**	**ReefKeeper**	**Pacific point intercept**
Categories	1. Hard coral 2. Soft coral 3. Sponge 4. Nutrient indicator algae 5. Recently killed coral 6. Rock 7. Silt 8. Sand 9. Rubble 10. Other	1. Coralline algae 2. Turf algae 3. Macro algae 4. Sponges 5. Gorgonians 6. Specific genera of hard corals 7. Bare rock 8. Sand 9. Dead coral	1. Hard coral 2. Soft coral 3. Palythoa 4. Bare rock 5. Sand 6. Sponge 7. Algae (covered rock) 8. Other	1. Coral (lifeform) 2. Miscellaneous (hydrozoan, sponge, clam, zooanthid, soft coral, ascidian, echinoderm) 3. Macroalgae (encrusting coralline algae, branching coralline algae, fleshy macroalgae, halimeda, blue green algae, encrusting algae) 4. Nonliving (matrix, rock, sand, rubble, crevice/hole)
Transect length	4 x 20 m separated by 5 m	5 x 30 m	2 x 50 m	5 x 50 m
Survey depth	❍ Shallow (2-6 m) ❍ Deep (6-12 m)	❍ Back reef (1-5 m) ❍ Fore reef (1-5 & 8-15 m)	❍ Inshore (3 m) ❍ Terrace (7 m) ❍ Shelf-edge (10 m)	Site specific
Point interval	50 cm	25 cm	50 cm	3 points every 2 m (1 on either side of the line &1 directly below)
Number of points per transect	40	120	100	75
Total points used	160	600	200	375
Additional information collected	If possible, Reef Check advises taking site photographs or video transect (p 38) for permanent record.	Coral condition of 50 corals per site is also collected (coral health p 45); coral size provides rugosity information	1. Still photo taken every 4 m & continuous video transect; see 'photography and video in monitoring' p 20. 2. Percent of stressed corals per transect is calculated to give the coral stress index	
Other comments	Regional and global descriptions on coral reef health. Up to 3 full Reef Check (4 x 20 m) transects required to detect environmental change at a local scale on 1 km long reef			Precise to detect 10% change when tested at various locations in the Pacific.

Point intercept transect (PIT)

Some programs that use this method:
- Reef Check;
- MBRS SMP;
- ReefKeeper;
- Pacific point intercept.

Method description:
A scuba diver or snorkeller swims along a transect line and records the benthic category that is directly below the transect line at specific points (distances) along the transect.

Information obtained:
Percent cover of benthic communities. Reef Check data can be entered quickly into Reef Check Excel spreadsheets and percent cover and basic statistics are calculated. For MBRS SMP, percent cover can be calculated using the formula (# records/120)*100.

Equipment required:
- Tape measures;
- Plumb line (small metal object tied to 1 m of string);
- Tape measure, string or PVC pole to measure the width of the belt transect.

Additional equipment required for MBRS SMP:
- Underwater cards to aid species identification.
- A 1 m long measuring device (PVC piping).
- Small plastic ruler on underwater slate or writing cylinder.

Additional equipment required for ReefKeeper:
- Still camera and underwater housing.

Additional equipment for Pacific point intercept:
- 1 x 2 m line that is marked at 1 m.

Parameters that can be surveyed using this method:
- ✓ Benthic communities

Scale:
- ✓ Medium

Monitoring level:
- ✓ Management
- ✓ Community

Level of detail:
- ✓ Quantitative

Causes damage to the reef:
- ✓ No

Achievable precision:
- ✓ High

Field personnel:
- 1 dive buddy team lays the transect tape and conducts the substrate survey.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- Lay the transects at each depth contour;
- Observers swim along the transect and record the substrate or benthos that is directly below the line. The plumb line removes bias and parallax error. The plumb line is used to determine the benthos directly below the line at the point interval required by the methods, e.g. Reef Check data are recorded every 50 cm.

Advantages:
- LIT, PIT and video transects give the best estimates of percent coral cover and diversity as long as PIT has sufficient points (e.g. fewer points required for broad categories, e.g. hard coral cover (Reef Check) rather than genus/species cover; and for coral reefs that are less variable spatially);
- Quick to learn;
- Easy for recreational divers to learn and implement well;
- Provides education and public awareness benefits p 14);
- Photographs provide a permanent record (Reef Keeper);
- MBRS SMP survey provides some information on structural complexity ('structural complexity' p 27)

Limitations:
- The number of points required for high precision will depend upon the spatial variability of the reef;
- Not good for rare species on a reef;
- Information on the size of coral colonies, a useful indicator of coral community stability, is not obtained.

Training required:

- Identification and calibration between observers.
- 1 day of training required for the full Reef Check survey. These observers can collect data with sufficient precision for the regional/global comparisons and for use as an early warning system;
- To detect environmental change at a local level with higher precision, additional training and testing for multiple observers, is recommended. To increase the power to detect local change, up to 3 surveys per 1 km of coral reef are needed.

For a variation on this method for research monitoring see video transects p 38.

Contact:
Reef Check: rcheck@ucla.edu
ReefKeeper: Alexander Stone, reefkeeper@earthlink.net
MBRS SMP: Alejandro Arrivillaga, aarrivillaga@mbrs.org.bz or mbrs@blt.net
Pacific point intercept: Alison Green, agreen@tnc.org

Reference:
www.reefcheck.org; www.reefkeeper.org; www.mbrs.org.bz; Choat and Bellwood (1985); Green (1996b); Green (1996a); Green (2002).

Video transect

Major programs using this method:
- GCRMN (English *et al.*);
- Australian Institute of Marine Science Long-term Monitoring Program (AIMS LTMP);
- Hawai'i Coral Reef Assessment and Monitoring Program (CRAMP);
- Florida Keys National Marine Sanctuary Coral Reef Monitoring Program (FKNMS CRMP).

Method description:
A video camera is used for a permanent record of transects. Video transects are analysed in the laboratory using point sampling techniques.

Information obtained:
A permanent record of percent cover and a visual record of the site. The video is analysed on a TV screen, and data are reported as percent cover. The footage can also be used as qualitative information in monitoring reports to reinforce trends illustrated by graphs.

Field equipment required:
- Tape measures (for 5 x 50 m transects – LIT English *et al.* and AIMS LTMP);
- Digital video camera and underwater housing (including lenses) with instruction manuals;
- Appropriate colour filter;
- Mini DV tapes;
- Cleaning equipment for camera and housing, including O-ring kit and O-ring grease;
- Video head cleaning cassette;

Lab equipment:
- Television monitor with 5 points arranged in a face-centred cube on the screen;
- Video recorder/player with counter/time code display and the ability to display a 'jitter free' clear still picture when paused;
- Personal computer;
- Database software for data entry.

Field personnel:
- 2 experienced scuba divers to collect the field data and lay the transect tape;
- 1 boat driver/surface watch.

Parameters that can be surveyed using this method:
- ✓ Benthic communities

Monitoring level:
- ✓ Research

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ High

Lab personnel:
- 2 observers experienced in the identification of coral reef benthos off video should work together to eliminate observer biases in data analyses.

General procedures:
- Prior to field work prepare camera and check it is functioning corectly.
- Record videos between 08.30 and 15.30 hours for best lighting conditions;
- Set the zoom to wide angle and camera on automatic focus;
- Record replicate transect number on the data sheet and video the completed data sheet for 3-5 seconds to help identify the transects when analysing the videos in the laboratory. Information recorded should include the date, location, site and transect numbers and any irregularities during recording;
- First record a panorama of the site and counter code on the data sheet;
- Position the camera above and parallel to the substrate and to one side of the transect tape to avoid glare on the video image from the tape;
- Swim along the transect at a constant speed;
- At the end of the tape, record the tape marker for a few seconds then stop the video;
- Record the counter time and swim to the next transect;
- Repeat the process for the remaining transects.

Table 3. Comparison between AIMS LTMP, English *et al.*, Virgin Islands, CRAMP and FKNMS video transect methods.

Method	AIMS LTMP	English *et al.*	CRAMP	FKNMS
Camera distance from substrate	15-20 cm	25 cm	50 cm (2 lasers cross at 50 cm maintain constant distance)	40 cm (lasers used as with CRAMP)
Swim speed	10 m / minute	10 m / minute	10 m / 4 minutes	4 m / minute
Transect number & length	5 x 50 m	5 x 50 m	10 x 10 m	10 x 10 m
Survey depth	9-12 m	9-12 m	3 m and 10 m	14-17 m and 6-9 m
Number of points analysed	200	200	50 – 60 frames per transect; 50 points analysed per frame	

The larger distance the video is from the bottom, the more benthos is included. Short video distances, e.g. 15-20 cm are recommended for the identification of coral and other benthos species; larger distances, e.g. 40-50 cm include more benthos, which is useful when observing less detail, e.g. the effects of bleaching, p 47).

Lab
- Label the tape and its case with a description of the information on the tape;
- Analyse the tape by stopping at fixed time intervals; considerable software has been developed for video analysis. AIMS use AVTAS; the US Virgin Ids Program uses WinBatch for Windows (download from www.winbatch.com); CRAMP uses PhotoShop Photo DV to grab frames and analysed using PointCount99;
- A pilot study is recommended to determine the number of points required to sample the video; 40-80 pauses (200-400) points on each 50 m transect are recommended for the Great Barrier Reef;
- Enter the data and information into a database and the identification codes for the substrate under each of the 5 points on each frame;
- Convert the video data to percentage cover data for each transect;
- Data entry, analysis, interpretation and reporting.

Storage of tapes
- Do not leave tapes in the VCR for an extended period of time;
- Store the tapes in their cases and store these vertically;
- Avoid storing the tapes in places where there is dust, excessive heat, moisture or magnetic fields. A fireproof cabinet is recommended;
- If possible store the tapes in a data cabinet designed for magnetic media;
- Fast forward the tapes every two years to prevent them sticking;
- To protect from erasure, ensure that the copy protect switch on each tape is placed ON after recording;
- Duplicate copies of tapes should be made and stored separately. Tapes will last about 10 years if they are maintained. DVDs are good for storing data but care should be used in selecting appropriate computer software to transfer these data, as image quality can be lost with low quality software.

Advantages:
- Can be implemented by experienced divers without expertise in the identification of marine organisms;
- Faster than still photography; quick to implement in the field therefore useful if sampling a large area is a priority;
- Provides a permanent record;
- High precision, e.g. 2.5 – 5% change in coral cover can be detected using the FKNMS CRMP methods;
- Useful in most diving conditions including limited visibility;
- Allows comparison between observers (correction for observer bias) at a later date;
- Use of lasers help to standardise video belt size, but add to the expense;
- Statistical power of the transects can be increased in the lab by increasing the number of points or frames analysed. Studies suggest that increasing the number of frames per transect increases statistical power more than increasing the number of points per frame.

Limitations:
- Still photos offer higher resolution than earlier videos, but newer high resolution video is adequate for benthic monitoring;
- Software is expensive, but easily accessible; costly and time consuming to analyse;
- Expensive equipment and requires regular maintenance;
- Results are not immediate as tapes must first be analysed;

- Requires safe storage space for video equipment and tapes;
- Only organisms 5 cm diameter or larger can be identified consistently;
- Species identification is only possible if the characteristics required to distinguish them are large, or if the organism has distinguishing features. Therefore, the video method cannot measure coral species diversity accurately;
- There is a risk of low quality or missing data as poor video technique will result in inadequate images which may not be discovered until after the field trip;
- Substrates with higher rugosity (roughness, corrugation) have lower resolution in a video image;
- Very complex substrates (many small or overlapping biota) have lower resolution in a video image;
- Separating growth form categories consistently with a two dimensional image is not always possible; therefore the power to detect temporal change of percentage cover of individual growth forms may be low in some environments;
- Information on the size of coral colonies, a useful indicator of coral community stability, is not routinely obtained.

Training required:
- Regular training and recalibration between observers is required for consistent analysis of the video footage;
- Camera use and care.

Contact:
English *et al.* and AIMS LTMP: Hugh Sweatman, h.sweatman@aims.gov.au
CRAMP: Dr Paul Jokiel, jokiel@hawaii.edu

FKNMS: John Ogden, jogden@seas.marine.usf.edu

Reference:
- English *et al.*: English *et al.* (1997);
- www.gcrmn.org, www.aims.gov.au
- AIMS LTMP: Page *et al.* (2001); www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop7/sop7-2001a.html.
- CRAMP: cramp.wcc.hawaii.edu/Overview/3._Methods/3._Site_Survey_Protocol/Benthic_Monitoring/3._video_transects/default.asp;
- FKNMS: John Ogden, jogden@seas.marine.usf.edu, www.fknms.nos.noaa.gov/research_monitoring/zpr98.html;
- Also see: Virgin Islands U.S. Geological Survey, Biological Resources Division: www.cpacc.org/c5wn.html. This manual gives good step-wise details on camera care, software and data analysis;
- Other references on video monitoring: Carleton and Done (1995); Tomkins *et al.* (1999).

Visual quadrat

Major programs using this method:

- Commission de l'Ocean Indien (COI);
- Atlantic and Gulf Rapid Reef Assessment (AGRRA).

Method description:
Involves random set quadrats. and the observer estimates percentage cover of categories of benthic communities and coral recruits.

Information obtained:
Percent cover estimation.

Field personnel:

- 1 boat driver/surface watch;
- 2 observers (scuba divers).

Lab personnel:

- Data analysis, interpretation and reporting.

Parameters that can be surveyed using this method:

- ✓ Benthic communities
- ✓ Invertebrates

Monitoring level:

- ✓ Management
- ✓ Research

Scale:

- ✓ Fine

Level of detail:

- ✓ Quantitative

Causes damage to the reef?

- ✓ Potential for some damage

Achievable precision:

- ✓ Medium to high

Example 1: COI method
Equipment required:

- 1 m^2 PVC quadrat divided into 25 cm squares;
- Transect tape.

General procedures:

- Place a quadrat on the benthos at random intervals along the LIT transect tape ('English *et al.* p 33);
- Count the life forms (percentage cover of various benthic communities, coral recruits and key macro-invertebrates) within the quadrat, making separate estimates for each 25 cm square (to make location and counting organisms easier), then total the results for each 1 m^2 quadrat;
- Repeat for 8 replicates;
- Note the location of the quadrat along each transect for repeated monitoring of coral colonies.

Example 2: AGRRA method (algal survey)
Equipment required:

- 10 m transect line marked at 1, 3, 5, 7 and 9 m intervals;
- Plastic ruler;
- A 25 cm^2 quadrat.

General procedures:

- Use the same transect as the AGRRA coral assessment. Following the coral survey, re-swim the transect with the 25 x 25 cm quadrat to estimate relative algal abundance (at 1,3, 5, 7 and 9 m). Place the quadrat every 2 meters directly below the transect line starting at 1 m. If a suitable area is not available at this mark, the quadrat should be placed within a 1 m radius. If this is not possible, go to the next 2 m mark. A suitable place should have greater than 80% of the area covered by algae and no more than 20% of other benthic cover. A minimum of 5 quadrats should be measured along each 10 m transect;
- For each quadrat, record the following:
  - Substrate type;
  - An estimation of percent abundance of crustose coralline algae;
  - An estimation of percent abundance of living fleshy macroalgae;
  - Measure approximate the average canopy height of fleshy and calcareous macroalgae in the quadrat (cm);
  - An estimation of percent abundance of living calcareous macroalgae;
  - Count and record the number of all small stony corals. Identify to genus level if possible;
  - Within a 1 m radius at 1, 5 and 9 m intervals along the transect, measure maximum reef relief as the difference between the highest and lowest point;
  - Repeat for at least 30 quadrats per site.

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;
- Estimations can vary between observers. We recommend standard training for all observers but precision is still not as high as point quadrats which have less human error. Also see ‘English *et al.* photo quadrat’ p 43.

Training required:

- Calibration of identification and estimation skills.

Contact:
COI: Secrétariat Général, Recif_members@coi.intnet.mu
AGRRA: Robert Ginsburg, agrra@rsmas.miami.edu

Reference:
COI: coi.intnet.mu/; Conand *et al.* (1999); Conand *et al.* (2000);
AGRRA: http://www.coral.aoml.noaa.gov/agra/

PERMANENT PHOTO QUADRAT

Major programs using this method:
- GCRMN; English *et al.*;
- FKNMS; 'coral recruitment'.

Method description:
This involves taking still photographs of a fixed quadrat that are analysed in the lab. This method is useful to determine temporal change in shallow macrobenthos communities. Permanent photo-quadrats complement LIT and are suitable for small-scale questions and to follow the fate of individual colonies. For use of permanent photo quadrats to monitor coral recruitment.

Information obtained:
Detailed temporal change can be determined for individual corals for:
- Biological condition;
- Growth;
- Mortality;
- Recruitment;
- Data can be used to estimate percent cover, species diversity, relative abundance, density and size.

Monitoring level:
✓ Research

Scale:
✓ Fine

Level of detail:
✓ Quantitative

Causes damage to the reef?
✓ Potential for some damage

Achievable precision:
✓ High

Percentage cover of target organisms can be determined in the lab by either point sample methods by placing a grid over the quadrat or by digitising the image (digitising is more expensive, time-consuming, requires special software and expertise). Precision depends on apparatus used and ability to take photo from exactly the same spot as well as observer differences for analysis. If observers train together, precision can be reasonable.

Equipment required:
- Permanent quadrat markers (e.g. stainless steel stakes; see 'how do you mark permanent sites' p 33);
- Portable quadrat 1 m^2 divided by string to 16 equal squares;
- Flexible architect's ruler and callipers;
- Digital camera with a 15 mm lens, flash or strobe, and underwater housing;
- Stable tetrapod frame to hold the camera a fixed distance (0.8 m) from the bottom;
- Tags to label the coral;
- Cable ties to attach the tags.

Field personnel:
- 2 observers (scuba divers)
- 1 boat driver/surface watch

Lab personnel:
- Experience in coral taxonomy;
- Data entry, analysis, interpretation and reporting.

General procedures:
- Mark the position of a 2 m^2 quadrat with steel rods hammered deep into the substratum;
- Divide marked site in 4 x 1 m^2 sections.

Repeat the following every 6 months:
- Securely tag a selection of coral colonies within each 1 m^2 section of the quadrat to allow individual identification for temporal monitoring;
- Draw a detailed map of the type, position and size of the colonies in each section and record the position of the tagged colonies;
- Measure the length and width of the tagged colonies;
- Measure the maximum length and width of the live non-branching corals;
- Tag the individual branches that are measured on branching corals;
- Secure the camera on the tetrapod at right angles to the substratum;
- The tetrapod frame should cover a 1 m^2 area. Four photographs are taken per quadrat. Reduce the photograph frame size in poor visibility.

Advantages:

- Detailed and careful observation, photography and mapping provide a good record of temporal change;
- Fixed photo quadrats provide the highest statistical power (as compared to visual quadrats or video transects) for the least effort;
- Permanent record. Photos can also be used as qualitative information to support the information presented in graphs;
- Good for small-scale questions;
- Field work can be done by non-specialists.

Limitations:

- Time-intensive;
- Requires specific computer software;
- Equipment intensive and expensive to buy and maintain;
- Cumbersome equipment, especially in currents;
- The reef may get damaged in areas with delicate coral forms;
- Relatively flat areas are required for photography;
- Only small areas are examined which makes inference on general reef condition difficult;
- Curved images between the photo quadrat edges makes it difficult to join them together;
- Does not take into account the rugosity or uneven surface of many coral reefs (Chain intercept transect', p 54; PIT MBRS SMP p 36);
- Cannot be used to measure spatial relief;
- Data are only obtained for the projected surface area;
- Unsuited to areas with large or abundant soft corals that conceal other species;
- Measurements cannot be determined until the photographs have been digitised or analysed using point sampling.

Training required:

- Methods training;
- Experienced personnel with tertiary qualifications necessary for data analysis.

Contact:
Sue English, s.english@aims.gov.au

Reference:
English *et al.* (1997);
FKNMS CRMP: www.fknms.nos.noaa.gov/research_monitoring/zpr98.html

Coral health general observations

Programs that use this method:
- Reef Condition Monitoring Program (RECON) – The Ocean Conservancy

Method description:
Volunteer coral reef assessment program for recreational divers. The data provide information on hard coral health as an early warning system

Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ Invertebrates

Scale
- ✓ Broad

Monitoring level:
- ✓ Community

Level of detail:
- ✓ Qualitative

Information obtained:
- ✓ Description of hard coral health

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Low

Equipment required:
- Underwater slate with ruler attached and data sheet;
- 10 m survey line for algae survey.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting done by RECON coordinator

General procedures:
Coral health
- Swim to pre-established RECON survey site;
- Swim 4 kick cycles in a direction that will maintain the desired depth for the survey site (selected between 3 and 18 m);
- Stop at the closest colony of pre-selected coral and ensure it is at least 25 cm long when viewed from above with some live polyps and distinct borders;
- Measure the maximum projected length and width of the colony in cm;
- Estimate the percent of dead coal and the percent of bleached coral;
- Note physical damage or disease;
- Count any coral recruits, *Diadema,* conch or lobsters;
- Repeat until you have surveyed 10 colonies or when a maximum of 1/2 the bottom dive time or 1/2 your air supply used.

Reef algae
- Make 8 kick cycles;
- Unreel the 10 m survey line;
- Estimate horizontal visibility;
- Use the ruler to estimate the amount of line that lies over mud or sand patches, live stony corals and macro algae;
- Return along the 10 m line and survey a 2 m belt and estimate abundance of turf algae, cyanobacteria, macroalgae and coralline algae;
- Note the presence of disease and bleaching;
- Note presence of *Diadema,* lobster, conch, megafauna;
- Note human physical damage, e.g. anchor damage, fish traps or nets etc.

Advantages:
- Recreational divers with minimal training;
- Can be performed as a part of a recreational dive;
- Very basic.

Limitations:
- Low precision.

Training required:
- Completion of RECON course.

Contact: recon@oceanconservancyva.org www.oceanconservancy.org/dynamic/getInvolved/events/coral/coral.htm

Bleaching general observations

Programs that use this method:
- Great Barrier Reef Marine Park Authority BleachWatch Program;
- Coral Watch.

Great Barrier Reef Marine Park Authority BleachWatch Program

Method description:
This involves divers estimating the extent of coral bleaching during a random swim of a site. Useful to determine the extent and severity of bleaching over a wide area.

Information obtained:
Estimations of bleaching and the growth form (shape) and family (if known) of corals affected.

Equipment required:
No special equipment

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- Record estimates of the amount of hard coral at a site using the same categories as the manta tow (p 22);
- Estimate the amount of hard coral that is bleached using the same categories;
- Record water temperature;
- Record the 3 most prevalent coral growth forms at the site and which were bleached;
- Record the bleached coral families (if known);
- Record the minimum and maximum depth limits of the corals and any other comments.

Parameters that can be surveyed using this method:
- ✓ Benthic communities

Scale:
- ✓ Broad

Monitoring level:
- ✓ Community
- ✓ Management

Level of detail:
- ✓ Qualitative
- ✓ Semi-quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Low

Advantages:
- Recreational divers as well as professionals can do this while on a recreational or other survey dive;
- Quick and easy to do;
- Large areas can be covered by using a wide range of data collectors.

Limitations:
- Low precision.

Training required:
- None.

Contact:
Jessica Hoey, jessicah@gbrmpa.gov.au

Reference:
www.gbrmpa.gov.au/corp_site/info_services/science/bleaching/bleach_watch.html
'Bleaching belt transect' is an example of how BleachWatch fits in a coral bleaching monitoring program (p 47).

Coral Watch

Coral Watch has developed the Coral Health Chart™, to monitor the health of corals around the world using scientists and the public. Observers match the colour on the charts with the coral to determine an index of health. For more information see www.vthrc.uq.edu.au/ecovis/CurrentRes.html#Prawns or contact Justin Marshall, Justin.Marshall@uq.edu.au

Bleaching belt transect

Programs that use this method:

- Great Barrier Reef Marine Park Authority Coral Bleaching Response Program (GBRMPA CBRP);
- This program has been modified for international use by WWF/ReefBase/GBRMPA.

GBRMPA CBRP method

Method description:

This is a 2-tier monitoring program to assess the spatial extent and severity of coral bleaching and determine the direct ecological impacts (coral mortality) from bleaching. The first tier is a broad-scale aerial survey to obtain a overview of where bleaching is occurring over spatial scales relevant to management (on the GBR this is hundreds to thousands of kilometres). For smaller reefs, random swims (p 26) or manta tow (p 22) can be used for the broad scale survey.

Confirmation of extensive bleaching from aerial surveys triggers the second tier of the monitoring program: fine-scale ecological impact assessment (below). This involves rapid visual assessment (RVA), which records observations on the condition of corals and other benthos; and more detailed video transect methods. If video is not available, line intercept transects (LIT; p 33) or point intercept transects (PIT; p 36) can be used.

Information obtained:

Percentage and types of corals that bleach, and then subsequently die or survive. Percent cover estimations follow manta tow method (p 22). Bleaching is categorised in the table below.

RVA site assessment:

Reef zone and exposure. Percent benthic community cover: live hard coral; live soft coral; algae; dead coral (pre-bleaching); bleached corals; degree of bleaching; evidence of coral disease; COTS scars etc.; evidence of bleaching in other organisms, e.g. clams.

Percent cover, proportion bleached (percentage of population) and degree of bleaching (bleaching categories below) of:

- *Pocillopora;*
- *Acropora* (branching);
- *Acropora* (plate);
- *Monitpora;*
- *Porites* (massive);
- *Favia;*
- Soft corals.

Parameters that can be surveyed using this method:

- ✓ Physical parameters
- ✓ Benthic communities

Scale:

- ✓ Medium

Monitoring level:

- ✓ Management
- ✓ Research

Level of detail:

- ✓ Quantitative

Causes damage to the reef?

- ✓ No

Achievable precision

- ✓ High

Site bleaching categories (for the RVA).

Index	Percent	Description	Visual assessment
0	<1	No bleaching	No bleaching observed, or only very occasional, scattered bleached colonies (1 or 2 per dive)
1	1-10	Low or mild bleaching	Bleached colonies seen occasionally and conspicuous; vast majority of colonies not bleached
2	10-50	Moderate bleaching	Bleached colonies frequent but less than half of all colonies
3	50-90	High bleaching	Bleaching very frequent and conspicuous, most corals bleached
4	>90	Extreme bleaching	Bleaching dominates the landscape, unbleached colonies not common. The whole reef looks white

Colony bleaching (for use in LIT, PIT or video transect).

Category	Description
0	No bleaching evident
1	Partially bleached (surface/tips) or pale but not white
2	White
3	Bleached and partly dead
4	Recently dead

Over the long-term, this program will enable the direction and rate of benthic community recovery to be evaluated.

Equipment required:
- 50 m tape measure;
- Video equipment.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- Lay 4 x 50 m transects (haphazard) at 3 separate reefs at 2 depth zones: reef crest and upper slope (1 – 4 m) and lower reef slope (5-10 m). Survey shallow depths where water is turbid, or reef development is poor; survey deeper sites if water is clear;
- Two divers swim along the transect, 1 doing a RVA and the other doing a video transect;
- The RVA involves recording 3 sets of information along a 5 m belt transect: station information; percent cover of coral and bleaching category; and detailed information for selected coral groups;
- The video transect is held 40 cm above the substrate at a speed of 10 m per minute (video transect, p 38).

Advantages:
- The 2-tier design enables broad and medium-scale information to be collected by one diver pair;
- RVA is easy and cost effective to do;
- Video provides a permanent record.

Limitations:
- See 'video transects' (p 38);

Training required:
- Percentage estimations and coral identification.

Contact:
Paul Marshall, p.marshall@gbrmpa.gov.au

References:
GBRMPA Coral Bleaching Response Program (CBRP): www.gbrmpa.gov.au/corp_site/info_services/science/bleaching/response_program.html
The Great Barrier Reef Marine Park Authority/ReefBase/World Wide Fund for Nature have developed a Global Bleaching Survey Program, which is a modification of the GBRMPA CBRP for international use. See 'timed swim' p 31 and www.reefbase.org for details.

For further information on how to respond to and monitor coral bleaching see Marshall and Schuttenberg (2004).

DISEASE BELT TRANSECT

Programs that use this method:
- Caribbean Coastal Marine Productivity Program (CARICOMP) – Coral communities – Coral-Octocoral Disease Survey – Protocol Level 1 and 2;
- Australian Institute of Marine Science Long-term Monitoring Program.

CARICOMP method

Method description:

This method will work with many different sampling methods to include:
- Quadrats (fine scale; p 41);
- Chain transects (medium scale; p 54);
- Belt transects (medium scale; p 64);

We describe its use with a belt transect.

Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ Invertebrates

Scale:
- ✓ Medium

Monitoring level:
- ✓ Management

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ Potential for some damage

Achievable precision:
- ✓ Medium

Information obtained:
- Percentage of healthy and non-healthy hard and soft (octocoral) corals;
- Description of health and coral identification.

Equipment required:

Level 1:
- Standard disease ID cards (developed by Bruckner *et al.*);
- Transect belt measuring device, e.g. PVC pole or string.

Level 2:
- Stakes for permanent markers;
- 1 m long PVC pipe that is marked in cm.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:

Level 1
- Standard disease ID cards in Spanish and English are available to identify disease and mortality in the Caribbean;
- Lay 10 x 10 m long transects using a chain at each locality and survey along a 2 m wide belt transect;
- Count and categorise all hard and soft colonies within the belt as healthy, or un-healthy. A non-healthy colony is put into one of three categories: bleached; injured; or diseased. The diseases must be further categorised;
- Corals should be identified to species if possible, genus at minimum as well as recording the growth form and soft corals should be categorised into growth forms.

Level 2
- Select a minimum of 2 sites that are at least 5 km apart. Preferably one near and the other far from anthropogenic impact areas;
- Conduct a preliminary qualitative survey to determine levels of disease and distribution within the 2 site areas;
- At each of 3 depth intervals (0 – 5 m, 6 – 15 m and 16 – 30 m if sufficient reef slope) set up a minimum of 3 x 20 m permanent belt transects 2 m wide. These transects should be separated by a minimum of 10 m;
- Use the PVC pipe to judge the distance either side of the line. Conduct the survey as in protocol level 1. Measure the surface area of diseased colonies of hard coral and *Goniopora* spp.;
- Identification of colonies should be to growth form (shape), genus and species level if possible.

Advantages:
- Using a belt transect enables more area to be searched per shorter transect distance. This is advantageous if the reef is patchy or small;
- Permanent belt transects enable more precise estimates of temporal change (‘permanent or fixed sites’, p 13).

Limitations:
- It can be difficult to carry PVC poles and write at the same time – especially in currents;
- Permanent transects can be difficult to re-locate (‘permanent or fixed sites’ p 13).

Training required:
- Survey methods and coral identification.

Contact:
Dulcie Linton, dmlinton@uwimona.edu.jm; John Ogden, jogden@marine.usf.edu

Reference:
For a copy of the manual see: www.ccdc.org.jm/caricomp_main.html

Timed swim

Programs that use this method:
- Australian Institute of Marine Science Long-term monitoring program (AIMS LTMP);
- A full description and variation of timed swim for bleaching surveys and blast fishing surveys is on p 31

Method description:
This involves 3 divers randomly swimming along a specific depth contour and recording incidences of coral disease, bleaching and predation. This is a medium scale survey conducted at non-permanent monitoring sites in conjunction with the broad scale manta tow technique to assess coral reef health.

General procedures:
- Each reef is manta towed to select sites for the presence of disease, feeding scars and COTS. Sites noted during the manta tow are marked with a buoy and the position recorded using a GPS. Divers should search 3 to 6 sites if possible on a reef;
- Ideally 3 divers each swim parallel to the reef slope along 3 separate depth contours (4 m, 8 m and 12 m). This will depend on the topography of the reef slope; if the slope is less than 12 m, divers should swim parallel to each other, 4 m apart covering the maximum practicable depth range between the crest and the base of the reef slope;
- Each diver swims for 20 minutes and scans approximately 1 m either side of the swim path looking for evidence of coral mortality. Areas of recently dead coral should be examined to determine the cause of mortality, and observations are recorded on the data sheet.

Contact:
Hugh Sweatman, h.sweatman@aims.gov.au

Reference:
Bass and Miller (1998); www.aims.gov.au

The Commission de l’Ocean Indien (p 104) use a variation of this technique with 5 minute swims for coral cover and general reef health.

Line transect (Bleaching, Disease)

Programs that use this method:
- Atlantic and Gulf Rapid Reef Assessment (AGRRA) – Coral condition, algae and *Diadema*;
- Mesoamerican Barrier Reef System – Synoptic Monitoring Program (MBRS SMP) – used with the MBRS SMP point intercept transect.

The combination of quadrats and LIT provide percentage cover and coral health information of benthic communities. AGRRA combine this method with algae quadrats and *Diadema* abundance (p 51 and p 68). This method can also be used to detect bleaching during mass bleaching events.

Information obtained:
High taxonomic detail (can be simplified). Coral health is described for corals identified by species and size. Coral condition is defined as the ratio of living, recently killed and long dead coral. Severity of bleaching in mass bleaching events is graded using the following categories:
- P - Pale (discoloration of coral tissue);
- PB - Partly bleached (patches of fully bleached or white tissue);
- BL - Bleached (tissue is totally white, no zooxanthellae visible).

Type of disease
- BB - Black band;
- WB - White band;
- WS - White spots, patches or pox;
- WP - White plague;
- YB - Yellow blotch (sometimes called yellow band);
- RB - Red band;
- UK – Unknown.

Quantification of the extent of damage to corals related to the size of the colony provides information on likely recovery. Small colonies either have no mortality or total mortality, whereas larger coral are likely to survive partial mortality.

Equipment:
Coral condition
- 10 m transect line marked at 1, 3, 5, 7 and 9 m intervals;
- 1 m long PVC stick or measuring tape marked in 10 cm intervals.

Parameters that can be surveyed using this method:
- ✓ Benthic communities
- ✓ Invertebrates

Level of detail:
- ✓ Quantitative

Causes damage to the reef:
- ✓ Potential for some damage.

Achievable precision:
- ✓ High

Monitoring level:
- ✓ Research
- ✓ Management

Field personnel:
- 1 boat driver/surface watch;
- 2 observers (scuba divers). One must have experience in using the method and the required level of coral identification.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

Example 1: AGRRA method
General procedures for coral condition
- Haphazardly lay the 10 m line at each of 2 depths in the fore reef (1-5 m and 8-15 m) parallel to the reef;
- To estimate live coral cover, swim along the transect line with the 1 m measuring stick and estimate how many metres (to the nearest 10 cm) of line lies over living coral. Record the area of sand or rock patches;
- Return to the start of the transect, swim along and stop at the first coral head, cluster or thicket directly under the line, which is at least 10 cm wide and in original growth position. For colonies that have been displaced, only assess ones that have reattached to the substratum or are too large to move. For each record the following:
  - Genus (or species if possible);
  - Water depth at the top of the coral at the beginning and end of each transect. Where bottom topography is very irregular, or the size of the individual coral is very variable, record the water depth at the top of each coral beneath the transect line at any major change in depth (> 1m);

- Measure the maximum projected colony diameter (live + dead areas) in plan view and maximum height to the nearest cm;
- Estimate the % of the colony that is recently dead (very recent, recent and older recent are combined together) and long dead;
- Scan the surviving parts of the entire colony and note any disease or bleaching. Characterise the diseases and severity of bleaching;
- Record any other sources of recent mortality that can be unambiguously identified;
- While examining the coral head, count and record the number of territorial gardening damselfish or the total number of damselfish algal gardens on each coral head;

- Go to the next coral (over 10 cm wide) and repeat this process;
- After you complete a transect, collect the line and haphazardly reset the next transect line, **at least** 1 m laterally away from its previous position. Remember to avoid other lines, and whenever possible, abrupt changes in slope, large areas of sand and rubble, and any other unusual reef features. Try to ensure that the transects are distributed around the site, not concentrated together.
- Repeat the above steps for each transect.

You can continue to reset transects in new positions until you survey a minimum of 6 transects per site. However, a bare minimum of 50 coral heads (and 30 algae quadrats, see AGGRA manual for details) should be assessed at each site. Appropriate sample sizes will depend on the variance in the local habitats, so we cannot prescribe 'a one size fits all protocol'.

Example 2: MBRS SMP method
General procedures:

- Following the point intercept survey, swim back along the transect and stop at the first coral head, cluster or thicket directly beneath the transect line, least 10cm in diameter in original growth position. If it has been displaced, only assess reattached corals. For each coral surveyed, record the following:
  - Genus (or species if possible);
  - Depth at the top of the colony at the beginning and end of each transect or for each coral colony recorded where topography is irregular and creates a depth change of > 1 m;
  - Measure to the nearest cm the maximum colony projected diameter (live + dead areas), in plan view and maximum height;
  - Estimate the % of the colony that is recently (very recent, recent and older recent) and long dead;
  - Scan the surviving portions of the entire colony and note any diseases or bleaching. Characterise the diseases;
  - Record any other sources of recent mortality that can be unambiguously identified;
- Go to the next colony and repeat the process. The SMP requires a minimum sample of 50 colonies per site.

Advantages:

- Quantitative assessment of coral colonies showing recent mortality, which also provides colony size. This is useful because larger colonies are usually more able to survive partial mortality than smaller ones, therefore, this method can calculate size–frequency distributions as well as size related-size mortality patterns.

Limitations:

- Individual coral descriptions are time consuming and require expertise.

Training required:

- Taxonomic identification and calibration between observers.

Contact:
AGRRA: Robert Ginsburg, agrra@rsmas.miami.edu
MBRS SMP: Alejandro Arrivillaga, aarrivillaga@mbrs.org.bz or mbrs@btl.net

Reference:
AGRRA: www.coral.aoml.noaa.gov/agra/
MBRS SMP: Almada-Villela *et al.* (2003a); http://www.mbrs.org.bz

Tagging coral colonies

Programs that use this method:
- GCRMN (English *et al.*)

Method description:
Monitoring of tagged colonies is an excellent way to precisely measure mortality or recovery after bleaching and for examining issues such as susceptibility of bleached colonies to disease or subsequent bleaching.

Information obtained:
Specific to individual colonies.

Equipment required:
- Plastic tags, such as cow tags that are numbered for identification;
- Cable ties or plastic coated wire for attaching tags to branching colonies;
- Galvanised roofing nails for attaching tags to massive colonies.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- Tag 2—50 colonies for each species of interest. Select colonies from a range of sizes;
- For bleaching studies, select species from the most abundant families (Pocilloporidae, Acroporidae, Faviidae, Poritidae for the Indo-Pacific);
- Once per year measure the length, height and width as well as its condition, such as bleaching, disease and other damage;
- Map the area in which the tagged colonies are found to assist finding them again for future surveys.

Parameters that can be surveyed using this method
- ✓ Benthic communities

Monitoring level:
- ✓ Research
- ✓ Management

Scale:
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ Potential for some damage.

Achievable precision:
- ✓ High

Advantages:
- Provides size frequency data on a number of colonies;
- Monitoring a colony from the onset of bleaching to mortality or full recovery provides the best measure of mortality that can be unambiguously related to bleaching;
- Investigation of coral adaptation to bleaching. This is the relationship between the severity of coral bleaching and subsequent mortality/recovery, or the susceptibility of coral which have previously bleached and recovered in subsequent years;
- Time-series studies of physiological aspects of bleaching or disease.

Limitations:
- Time consuming;
- Can be difficult to relocate colonies if not clearly marked.

Training required:
- Coral identification.

Reference:
English *et al.* (1997)
www.aims.gov.au; www.gcrmn.org
For other similar methods see: Rogers *et al.* (1994).
For the radial arc transect method contact Deborah Santavy, santavy.debbie@epa.gov; Santavy *et al.* (2001).

For further information on disease see: Bruckner (2002);
www.icriforum.org/docs/man_priorities_coral_diseases.pdf
www.coral.noaa.gov/coral_disease/cdhc.shtml

Chain intercept transect

Programs that use this method:
- Caribbean Coastal Marine Productivity Program (CARICOMP) – coral communities methods.

Method description:
The use of chains to implement an LIT provides information on rugosity as well as percent cover.

Information obtained:
- Percentage cover (growth form and genus or species level depending on the skill of the observers);
- Spatial index.

Equipment required:
- 2 x 30 m tape measure;
- 1 x 10 m line marked at 1 m intervals;
- 2 x nylon line, 12 m-long;
- 1 x light chain with 1 cm link size and marked every 10 links;
- 20 x stakes;
- 100 nails;
- 1 x 2 kg hammer;
- 4 x star drills;
- 1 x underwater compass;
- 1 x 1 m rod.

Field personnel:
- 1 boat driver
- 2 observers (scuba divers). One must be experienced with this method.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

Parameters that can be surveyed using this method:
- ✓ Benthic communities

Scale:
- ✓ Medium

Monitoring level:
- ✓ Management

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ Potential for some damage

General procedures:
Coral reef community line intercept transect
- Lay 5 x permanently marked 10 m transects at 10 m depth at each of 2 areas of reef;
- Lay out a taught nylon line between stakes marking the start and end points of the transects. Lay out the chain so that it follows the contour of the reef. Hammer 2-3 inch nails at 1 m intervals along the chain to mark the position of the chain for future reference;
- Note the substratum and benthos at start and end points (by link number) along the transect. If a 2-3 m chain is used, re-deploy it as you move along the transect;
- Calculate the rugosity (length of chain used per 10 m transect).

Gorgonian survey
- Lay a tape measure along each 10 m transect and count and record the holdfast position of gorgonians whose branches or fronds cross above or below the transect line with the normal surge conditions on the reef.

Advantages:
- LIT and PIT give the best estimates of percent coral cover and diversity;
- Use of the chain enables rugosity or 'spatial index' of the reef, which is the ratio of reef surface contour distance to linear distance. As part of a long-term monitoring program, the spatial index provide a way to quantify changes in the structural complexity of the reef;
- Provides better estimates of live coral cover in shallow areas where tops of coral may be dead and counted as dead coral for LIT or PIT methods (p 33 and 36), otherwise CIT, LIT and PIT have been shown to provide comparable estimates of benthic cover (Rogers and Miller 1999);
- Information on the size of coral colonies is obtained. This is useful as an indicator of the stability of a coral community. A large average size indicates no recent disturbance, a small average size indicates recent disturbance and recolonisation (Meesters *et al.* 1996).

Limitations:

- Equipment intense;
- Even well-trained divers find it difficult to avoid causing some damage especially in areas with branching corals;
- Must be done by specially trained divers;
- Cannot be used to directly measure species density or colony size;
- Not suited to areas where stony corals are widely spaced and small;
- Impossible in areas dominated by delicate branching corals;
- Tedious and time consuming. It is not unusual to spend over an hour on a 10 m transect;
- It is impossible to position the chain in exactly the same location each time.

Training required:

- Must be done by observers who are trained in the method

Contact:
Dulcie Linton, dmlinton@uwimona.edu.jm
John Ogden, jodgen@marine.usf.edu

Reference:
For a copy of the manual see www.ccdc.org.jm/caricomp_main.html

Also see: CRAMP: cramp.wcc.hawaii.edu and Rogers *et al.* (1994) for similar chain intercept methods and Tim Mcclanahan at the Wildlife Conservation Society East Africa, tmcclanahan@wcs.org, for the line transect method (www.wcs.org).

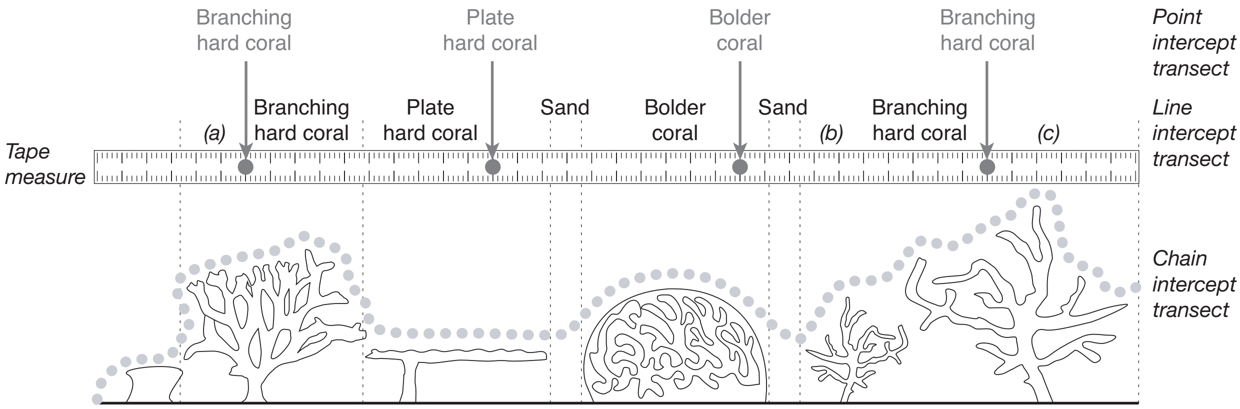

Figure 4. *A comparison of point intercept transect (PIT), line intercept transect (LIT) and chain intercept transect (CIT) on the same area of coral reef. PIT records objects under set points on the tape measure; LIT records the width of every object under the tape by noting the length where there is a change; and LIT records the number of chain links covering each object (or substrate type).*

Coral recruitment tiles

Major programs using this method:
- GCRMN (English *et al.*);
- Meso-American Barrier Reef System – Synoptic Monitoring Program (MBRS SMP).

Example 1. English et al.

Method description:
This involves placing frames of ceramic tiles onto the reef. These tiles are collected and newly settled coral recruits are identified.

Information obtained:
Abundance of new corals (identified to species or genus where possible) settling on the reef. Detail is less than the MBRS SMP method because it is difficult to identify all coral species or families.

Equipment required:
- Labelled, unglazed terracotta, flat tiles which are uniform on each surface; each approximately 12 cm^2 and 1 cm thick;
- Racks of wire mesh to hold tiles;
- Stainless steel wire or cable ties to attach tiles to racks;
- Binocular dissecting microscope.

Field personnel:
- Minimum of 2 experienced scuba divers (more may be required for heavy frames and tiles);
- 1 boat driver/surface watch.

Lab personnel:
- Observers trained by people experienced in monitoring coral recruitment;
- Data entry, analysis, interpretation and reporting.

Parameters that can be surveyed using this method:
- ✓ Benthic communities

Monitoring level:
- ✓ Management
- ✓ Research

Scale:
- ✓ Fine

Level of detail:
- ✓ Quantitative
- ✓ Detailed

Causes damage to the reef?
- ✓ Potential for some damage

Achievable precision:
- ✓ High

General procedures:
- Attach the racks securely to the bottom at 5 m depth. Avoid sand and rubble areas;
- Position racks so the tiles are inclined at 45° with the top facing the predominant swell or current;
- Attach 2-4 tiles to each rack approximately 20 cm above the bottom;
- 20-30 tiles are recommended for each site and each rack should be 0.5 to 1 m apart from other racks;
- Tiles must be labelled with an identification number prior to deployment and the location must be recorded;
- Tiles must be collected carefully and transported so that the surfaces do not rub;
- At the lab, tiles must be washed, dried in the sun and stored.

Advantages:
- Sampling of newly settled coral larvae using tiles reduces the effect of post-settlement mortality on observed recruitment;
- Racks to hold settlement plates are more easily relocated;
- Attachment and removal of plates onto racks is easier and quicker.

Limitations:
- Identification of juvenile coral to species level is difficult and sometimes not possible;
- Expensive and time consuming;
- Cumbersome equipment.

Training required:
- Lab identification experience.

Contact:
Clive Wilkinson, c.wilkinson@aims.gov.au

Reference:
English *et al.* (1997); www.aims.gov.au, www.gcrmn.org
For other references for recruitment methods see Rogers et al. (1994).

Example 2. MBRS SMP method

Method description:
This involves placing terracotta plates onto the coral reef. These plates are collected throughout the year, with coral recruits settled on them identified. This method forms part of category 2 for MBRS SMP. It is recommended that this level be conducted 4 times per year at high priority monitoring sites.

Information obtained:
Abundance of newly settled coral recruits. These can be identified to species level for some, but not all, species.

Equipment required:
- 100 (10 x 10 cm, and 1 cm thick) unglazed, individually numbered terracotta tiles with 50 at each depth per site;
- Pneumatic drill running off a scuba tank, with approx 4 cm masonry bit;
- Plastic wall anchors which are ~4 cm x 2 cm PVC plate that will hold ~5 mm screws. Into the wall anchor, screw a ~5 cm stainless steel hex-head bolt. The bolt with a flat and lock washer goes through a ~5 mm hole drilled into the plate. Below the plate, there should be a 1 cm long piece of ~12 mm PVC pipe;
- Plastic trays;
- Dissecting microscope.

Field and lab personnel:
See English *et al.* method

General procedures:
- Mount 50 tiles onto the wall anchors at each depth (2 and 10m) at the fore reef;
- Tiles should be placed 6 months prior to the main spawning event and collected soon after.

Advantages:
- Sampling of newly settled coral larvae using tiles will minimise the effect of post-settlement mortality on observed recruitment;
- Tiles mounted on base plates leaves the places affixed horizontally with a distinct upper surface that mimics the upper surface of the reef and an under-surface (separated from the base plate by spacers) that mimics cryptic space.

Limitations:
- Identification of juvenile coral to species level is difficult;
- Expensive and time consuming;
- Cumbersome equipment.

Training required:
- Experienced divers;
- Lab identification experience.

Contact:
Alejandro Arrivillaga, aarrivillaga@mbrs.org.bz or mbrs@btl.net

Reference:
Almada-Villela *et al.* (2003a); www.mbrs.org.bz

Coral recruitment quadrats

Major programs using this method:
Atlantic and Gulf Rapid Reef Assessment (AGRRA);
Florida Keys National Marine Sanctuary Coral Reef Monitoring Program (FKNMS CRMP).

Method description:
The AGRRA method involves searching for new coral recruits within quadrats. The FKNMS CRMP method photographs the quadrats to map coral recruits in the lab. See quadrats p 41, and permanent photo quadrats p 43.
Information obtained:
Abundance and identification of coral recruits. The level of detail collected is dependent upon personnel capacity.

Equipment required:
- AGRRA uses 25 x 25 cm quadrat;
- FKNMS CRMP uses 90 x 70 cm quadrats ('quadrats' p 19 for how to make them); and still camera equipment (English *et al.* permanent photo quadrat p 43).

Field personnel:
- 1 boat driver/surface watch;
- 2 observers (scuba divers). One must be experienced in the method.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
AGRRA method
- Following the benthic survey, swim in a haphazard fashion around the reef and place the quadrat on the substratum in areas lacking large (>25 cm diameter) sessile invertebrates;
- Count all small (maximum diameter 2 cm) stony corals within the quadrat. Record to genus if possible;
- Repeat 80 times.

Monitoring level:
- ✓ Management
- ✓ Research

Scale:
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ Potential for some damage

Achievable precision:
- ✓ High

FKNMS CRMP method
- Photograph 16 permanent quadrats beside the 30 m transect used for video monitoring method (p 38);
- Photographs are digitised in the lab (p 20 on 'photography and video in monitoring').

Advantages:
- No cumbersome tiles to set and collect;
- Provides abundance estimates of recruits that have survived the first year, thus giving a more reliable estimate of future coral species composition than recruitment tiles that look at newly settled recruits.

AGRRA methods
- Visual techniques are more reliable than photographic methods as recruits are cryptic (Edmunds *et al.* 1998).

FKNMS CRMP method
- Permanent record;
- The survivorship of individual recruits can be followed.

Limitations:
AGRRA method
- Experienced personnel with appropriate identification skills are necessary;
- Time consuming in the field.

FKNMS CRMP method
- Expensive equipment to buy and maintain;
- Time consuming and expensive in the lab;
- New recruits can be missed or difficult to identify from photographs.

Training required:
- Proper training and good eyesight are essential.

Contact:
AGRRA: Robert Ginsburg, agrra@rsmas.miami.edu
FKNMS CRMP: John Ogden, jodgen@marine.usf.edu

Reference:
AGRRA: www.coral.aoml.noaa.gov/agra
FKNMS CRMP: www.fknms.nos.noaa.gov/research_monitoring/zpr98.html#contents

Table 4. Summary of the main monitoring methods used in the Caribbean and Atlantic for benthic communities.

Monitoring level	Parameters measured	Method name	Reference and contact	Page
Community Broad Scale	Percent algal cover	General coral health - RECON methods	RECON, The Ocean Conservancy: www.oceanconservancy.org/dynamic/getinvolved/events/coral/coral.html	45
	General coral health	Coral Watch Health Chart	Coral Watch: www.vthrc.uq.edu.au/ecovis/CurrentRes.html#Prawns	46
	Coral bleaching	Bleaching observations	ReefBase: www.reefbase.org	31
Community Medium Scale	Percent cover	Point intercept transect	Reef Check: www.reefcheck.org ReefKeeper: www.reefkeeper.org	36
	General coral health	Invertebrate belt transect	Reef Check: www.reefcheck.org	64
Management Medium Scale	Percent cover	Point intercept transect	Mesoamerican Barrier Reef System Synoptic Monitoring Program: Almada-Villela *et al.*, 2003, mbrs.org.bz	36
	General coral health	Coral condition line transect	Mesoamerican Barrier Reef System Synoptic Monitoring Program: Almada-Villela *et al.*, 2003, mbrs.org.bz	51
	Coral bleaching	Rapid visual assessment	ReefBase: www.reefbase.org	47
	Coral disease	Coral-octocoral disease survey	Caribbean Coastal Marine Productivity: www.ccdc.org.jm/caricomp_main.html	49
	Structural complexity (rugosity)	Chain intercept transect	Caribbean Coastal Marine Productivity: www.ccdc.org.jm/caricomp_main.html Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	54
Management Fine Scale	Percent cover of algae	Coral condition, algae; Diadema survey (visual quadrat)	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/	51 41
	Algal biomass	Algal biomass survey	Caribbean Coastal Marine Productivity: www.ccdc.org.jm/caricomp_main.html Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	51
	General coral health	Coral condition LIT and quadrat	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/	51
	Coral growth	Rogers methods	Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	53
	Coral recruitment	Coral recruitment tiles	Mesoamerican Barrier Reef System Synoptic Monitoring Program: Almada-Villela *et al.*, 2003, mbrs.org.bz; Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	56
	Coral recruitment	Visual quadrats	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra	41
Research Medium Scale	Percent cover	Video transect	Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: www.fknms.nos.noaa.gov Virgin Islands methods: www.cpacc.org	38
	Biodiversity	Timed swim	The Nature Conservancy: www.nature.org; World Wide Fund for Nature: www.wwf.org; Conservation International: www.conservation.org	31

Research Fine Scale	Percent cover	Permanent photo quadrat	Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: www.fknms.nos.noaa.gov or Rogers *et al.*, 1994	43
	General coral health	Coral condition LIT & quadrat	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/	51,41
	Coral bleaching	Permanent photo quadrat	Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: www.fknms.nos.noaa.gov	43
	Coral growth	Permanent photo quadrat	Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: www.fknms.nos.noaa.gov	58
	Coral recruitment	Coral recruitment tiles	Reference 1:Mesoamerican Barrier Reef System Synoptic Monitoring Program: Almada-Villela *et al.*, 2003, mbrs.org.bz	56
		Visual and photo quadrats	Visual: Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra Photo: Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: www.fknms.nos.noaa.gov	58

Table 5. Summary of the main monitoring methods used to assess benthic communities in the Indo Pacific region (Middle East, Western Indian Ocean, South Asia, Southeast and East Asia, Wider Pacific Ocean).

Monitoring level	Parameters measured	Method name	Reference and contact	Page
Community Broad Scale	Percent cover & General coral health	Manta tow	Global Coral Reef Monitoring Network: English *et al.* 1997; www.gcrmn.org, www.aims.gov.au Philippines methods: (Uychiaoco *et al.* 2001) www.oneocean.org/download/_index.html	22 30
		General observations	Great Barrier Reef Marine Park Authority – Eye on the Reef. Contact: Andrew Chin, a.chin@gbrmpa.gov.au or Robin Aiello, robin.aiello@iig.com.au	
	General coral health	Coral Watch Health Chart	Coral Watch: www.vthrc.uq.edu.au/ecovis/CurrentRes.html#Prawns	46
Community Medium Scale	Percent cover	Point intercept transect	Reef Check: www.reefcheck.org	36 64
	General coral health	Invertebrate belt transect		
	Coral bleaching	Bleaching observations	Reef Check: www.reefcheck.org; Great Barrier Reef Marine Park Authority www.gbrmpa.gov.au; ReefBase: www.reefbase.org	47
Management Broad Scale	Percent cover	Manta tow	English *et al.* 1997	22
		Timed swim	ReefBase: www.reefbase.org; Commission de l'Ocean Indien: Conand *et al.* 1999, Conand *et al.* 2000, www.coi.intnet.mu/	31

Management Medium Scale	Percent cover	Line intercept transect	English *et al.* 1997	33
		Point intercept transect	The Nature Conservancy: www.nature.org; Alison Green, agreen@tnc.org	36
	Coral bleaching	Rapid visual assessment	ReefBase: www.reefbase.org	47
	Structural complexity (rugosity)	Line transect method Chain intercept transect	Wildlife Conservation Society East Africa: www.wcs.org Hawaii Coral Reef Assessment and Monitoring Program: cramp.wcc.hawaii.edu	33 54
Management Fine Scale	Percent cover General coral health	Visual quadrat	Commission de l'Ocean Indien: Conand *et al.* 1999, Conand *et al.* 2000, www.coi.intnet.mu/	41
		Tagging corals	English *et al.* 1997:	53 56 22
	Coral recruitment	Coral recruitment tiles		
Research Broad Scale	Percent cover	Manta tow		
Research Medium Scale		Video transect	English *et al.* 1997; Australian Institute of Marine Science: www.aims.gov.au, Page *et al.* 2001 Hawaii Coral Reef Assessment and Monitoring Program: www.cramp.wcc.hawaii.edu	38 24
	Biodiversity	Timed swim	The Nature Conservancy: www.nature.org World Wide Fund for Nature: www.wwf.org Conservation International: www.conservation.org Australian Institute of Marine Science: www.aims.gov.au	31
	Coral bleaching	Video transect	Great Barrier Reef Marine Park Authority: www.gbrmpa.org ReefBase: www.reefbase.org	47
	Coral disease	Belt transect & timed swim	Australian Institute of Marine Science: (Bass and Miller 1998), www.aims.gov.au	31 38
	Structural complexity	Chain intercept transect	Hawaii Coral Reef Assessment and Monitoring Program: CRAMP: cramp.wcc.hawaii.edu	54
Research Fine Scale	Percent cover	Permanent photo quadrat	English *et al.* 1997	43 53 43 56
	General coral health	Tagging corals		
	Coral bleaching Coral growth	Permanent photo quadrat		
	Coral recruitment	Coral recruitment tiles		

6: Macro-invertebrates

Invertebrate species diversity

See 'species diversity' on fish page 88.

Key macro-invertebrates

Commercial species

Reef managers find it useful to monitor both target invertebrates (that are fished for food or curios to determine if fishing pressure on the reef is sustainable), and coral predators. Special surveys are available to monitor aquarium species.

Keystone species

It is also useful to monitor **keystone species,** which can have ecological impacts on the reef. These include the crown-of-thorns starfish (*Acanthaster planci* or COTS) and *Diadema.* There are specific broad to medium scale methods to assess urchins and damselfish on Caribbean reefs. For more information contact Brian Keller, brian.keller@noaa.gov. *Drupella* are coral predatory gastropods that may occur in high enough numbers to considerably reduce coral cover.

Table 6. Which invertebrate monitoring method should you choose?

Monitoring category & scale	When should you choose this method?	Page
Broad scale	**Site selection and to cover a large area in short time**	
General observations	**Commercial inverts:** Estimates general abundance of invertebrates; provide low precision but valuable data to raise awareness of recreational divers.	22, 30
Manta tow	**Keystone and commercial species:** To count large species e.g. COTS, *Diadema* or giant clams; cost-effective as covers large areas in short time.	22
Medium scale	**Smaller area, more detail and more precise than broad scale methods. More time consuming and expensive than broad-scale methods.**	
Timed swim	**Species diversity:** To count all the obvious species to decide ones to include in visual census.	31
Invertebrate belt transect	**Commercial inverts:** information on population structure of target species; experienced observers of abundance; more experience and repeated training required for size estimations. Special MAQTRAC method was designed for aquarium trade species; requires experienced observers of abundance, with special training for size estimations. **Keystone species:** COTS, *Drupella* and *Diadema* counted on belt transects for coral health e.g. disease, bleaching and general invertebrates; Reef Check for non-professionals; or Lincoln-Smith for management and research. If *Diadema* populations are particularly important i.e. populations recovering after mass disease in Caribbean, specific methods may be appropriate.	64, 68
Fine scale	**Useful for asking detailed, small-scale questions about small invertebrates, e.g. *Drupella* snails. More time consuming and expensive than medium-scale surveys.**	
Quadrats	**Keystone species:** To get precise abundance estimates *Drupella* if these are major coral predators; these snails are small and hard to get precise estimates on larger belt transects, which provide indications of numbers only.	43
Collection and CIT	**Keystone species – *Diadema*:** To get precise size structure of urchin populations that is related to habitat complexity with urchin population size structure.	70

Belt transect

Programs that use this method:
- Reef Check;
- Australian Institute of Marine Science Long-term Monitoring Program (AIMS LTMP);
- Various Pacific monitoring programs (Lincoln-Smith transect);
- Reef Check MAQTRAC Program.

Example 1. Reef Check method
Method description:
This involves a pair of observers swimming along the belt transect and counting the target invertebrate species as well as special features on the reef, such as coral health or physical damage.

Information obtained:
Abundance estimates of key macro-invertebrates as well as a measure of physical damage and coral health. A single survey provides a snapshot of the status of target key macro-invertebrates and impacts on a regional/global scale. To achieve higher precision to detect local changes, teams can make more replicates and increase the monitoring frequency (e.g. 4 x per year).

Equipment required:
- Transect tape (100 m). See Reef Check PIT p 36;
- 5 m cross lines or PVC poles to help estimate belt width.

Monitoring level:
- ✓ Community

Scale:
- ✓ Broad
- ✓ Medium

Level of detail:
- ✓ Quantitative
- ✓ Semi-quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Low
- ✓ Medium

Field personnel:
- 2 observers (scuba or snorkel divers;
- 1 boat driver/surface watch.

Lab personnel:
- Observers should enter data into Excel spreadsheet immediately after the dive and send the data to Reef
- Check Headquarters. Results should also be interpreted and reported locally.

General procedures:
- See Reef Check point intercept transect for method to lay the transect;
- A buddy pair swims along each of the 4 x 20 m transect segments and records target invertebrates as well as coral health characteristics and the presence other coral damage or trash along a 5 m belt transect. Each observer surveys half of the belt (2.5 m wide);
- 3 options for checking belt width are: observers carry a 2.5 m long PVC pipe; lay cross lines at the start of each replicate to provide a reference to estimate belt width; measure the distance from your flipper to your fingertips (approx. 2 to 2.5 m) to judge the belt width.

Advantages:
- Cost effective, especially when using volunteer observers;
- Education and raises awareness at same time;
- Provides a global snapshot of coral reef health;
- Repeat surveys can be done as a local monitoring program.

Limitations:
- Surveys should ideally be repeated up to 4 times per site and up to 4 times per year for meaningful data for local comparisons. This adds to the expense.

Training required:
- Experienced recreational divers can learn the methods in a single day.

Contact: rcheck@ucla.edu

Reference: www.reefcheck.org/methods/instructions.asp
Other similar invertebrate surveys

For a modification of the Reef Check belt transect for Philippines coral reefs see Uychiaoco *et al.* (2001); www.oneocean.org/download/_index.html

Example 2. AIMS LTMP method

Method description:
This is a 2 m belt transect that observers search for disease, predation scars, predators and bleaching.

Information obtained:
Total counts are made of the following:
- Crown-of-thorns starfish (COTS; total count in 3 size classes) and feeding scars;
- *Drupella* and feeding scars;
- White syndrome disease scars;
- Blackband disease scars;
- Incidence of other disease and unknown scars;
- Estimate of bleaching as a percentage of live coral cover on the transect.

Monitoring level:
- ✓ Research

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ High

Equipment:
- 50 m transect tapes;
- Digital underwater camera if possible.

Field personnel:
- 1 Observer experienced with this method plus a buddy (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
Fixed transect searches
- This survey follows the fish census along the 5 x 50 m long transects (AIMS LTMP fish visual census, p 79). The observer pairs the video transect diver (AIMS video transect p 38) and swims along each transect searching a 2 m belt for coral mortality, disease, COTS and *Drupella.* Photographs are taken of unidentifiable diseases for identification later.

See p 31 for 'AIMS timed swim' for how to conduct this method on non-permanent monitoring sites.

Advantages:
- Quick and easy assessment of key macro-invertebrates and coral health indicators;
- Can be performed at the same time as a benthic line transect so the buddy is not redundant.

Limitations:
- Observers must be able to search quickly to keep up with the video photographer when surveys are done together (AIMS LTMP video transect p 38).

Training required:
- Identification of target species and coral health indicators

Contact:
Hugh Sweatman, h.sweatman@aims.gov.au

Reference:
Bass and Miller (1998); www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop1/mon-sop1-11.html

Example 3. Lincoln-Smith transect

Method description:
This method is widely used in the Pacific to determine the abundance of key macro-invertebrates that are harvested for food.

Information obtained:
Abundance estimates of key invertebrate species e.g. giant clams, sea cucumbers, pearl oysters, trochus and false trochus to give a comparison with abundances of harvested species.

Monitoring level:
- ✓ Management
- ✓ Scientific

Scale:
- ✓ Medium

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Equipment required:
- 50 m transect tape
- 2 m wide T-bar

Field personnel:
- 2 observers trained (1 to lay the transect and 1 to count);
- 1 boat driver/surface watch.

Lab personnel:
Data entry, analysis, interpretation and reporting.

General procedures:
- Haphazardly lay 6 x 50 m long transects at 2 depths of shallow reef flats of 0.5 to 3.5 m, deep slopes at 15 to 22 m;
- The tape is laid into the existing current so that the survey is easier to conduct.

Shallow habitat
- Count and estimate the length of target invertebrates along a 2 m belt, which is measured using the T-bar. Sea cucumbers are measured from the mouth to the anus, clams are measured along the top of the shell and trochus are measured across the widest point of the shell base and pearl oysters from the apex to the hinge of the shell;
- Replicates are placed 10 to 15 m apart.

Deep habitat
- Transects are laid along coral, rubble and sand slopes. Sea cucumbers and goldlip and blacklip pearl oysters are counted and measured along a 50 m long and 5 m wide belt transect.

Advantages:
- Easy to do;
- Transect depths and widths take account of the preferred habitats of the different target invertebrates, and their size and abundance.

Limitations:
- Experienced divers should be used because of the depth of the deep transect.

Training required:
- Identification of target invertebrates and measurements.

Reference:
Lincoln-Smith *et al.* (2001);
www.gbrmpa.gov.au/corp_site/info_services/publications/research_publications/rp69/

Example 4. MAQTRAC method
Programs that use this method:
- Reef Check's MAQTRAC program

Method description:
This involves a pair of observers swimming along the belt transect and counting and measuring the target invertebrate species as well as noting impacts on the reef, such as coral health or physical damage.

Information obtained:
Counts and size measurements of target invertebrates

Equipment required:
Underwater slate with attached ruler
Tape measures

Field personnel:
- 2 observers trained in the methods; one observer can conduct the substrate survey (Reef Check PIT p 36), while the other conducts the invertebrate survey;
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

Monitoring level:
- ✓ Research

Scale:
- ✓ Medium
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ High

General procedures:
- A pilot study should be done to determine the required number of replicates for adequate precision;
- Surveys conducted along the same belt transect as the MAQTRAC fish transect (5 m wide);
- Count all target species of key macro-invertebrates and coral species;
- Make length estimates for all individuals, this includes a measurement along the longest part, and the aspect perpendicular to this for species with radial symmetry. An additional measurement should be made of the height of coral colonies;
- Record a qualitative estimate of the percentage of the coral colony that is dead;
- Identify and measure scars along the longest aspect and perpendicular to the longest aspect. Grade the scars with the following criteria:
    - '1' for fresh scars with no re-growth;
    - '2' for scars covered with moderate re-colonisation by algae and/or sessile invertebrates; and
    - '3' for a previously known scar that is completely overgrown and difficult to differentiate from the surrounding habitat.

Advantages:
- Detailed and precise assessment of the impacts of the aquarium trade if sufficient replicates are monitored.

Limitations:
- Time consuming;
- May require many replicates for rare species or complex communities;
- High level of expertise.

Training required:
- Advanced species identification.

Contact:
rcheck@ucla.edu
See p 82, 100 for more information on MAQTRAC

DIADEMA BELT TRANSECT

Status of populations of *Diadema antillarum*

Programs that use this method:
- Atlantic and Gulf Rapid Reef Assessment (AGRRA);
- Caribbean Coastal Marine Productivity Program (CARICOMP).

Method description:
These methods involve counting the abundance and measuring the size of the *Diadema antillarum* along a belt transect. We recommend these surveys are done at the same sites as benthic communities surveys.

Information obtained:
- Abundance of *Diadema*;
- Density ;
- Size structure.

Equipment required:
- 1 m PVC stick or transect tape marked each 10 cm.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

Example 1. AGRRA method
General procedures
- This belt transect is conducted with the AGRRA coral condition, algae and *Diadema* survey; p 51.
- Using the 1 m measuring device for scale, swim a belt transect along each of the 6 x 10 m lines. Count every *Diadema* within 0.5 m either side of the line.

Parameters that can be surveyed using this method:
- ✓ Invertebrates

Monitoring level:
- ✓ Management

Scale:
- ✓ Medium

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Example 2. basic CARICOMP method
General procedures:
- This belt transect is conducted with the CARICOMP coral communities method; p 49;
- Mark the rod so that you can measure 50 cm either side of the transect line;
- Swim back along the transect and record the total number of *Diadema* and other urchins encountered.

Example 3. CARICOMP Diadema status method (more detailed than the basic method)
This method consists of a snorkel survey followed by a scuba survey.
a. Snorkel method
- Count the number of urchins in 2 x 15 minute snorkel surveys per reef;
- Separate urchins into 2 size classes: < 5 cm test diameter (juveniles) and > 5 cm test diameter (adults);
- Record observations about the spatial heterogeneity of the habitats.

b. Scuba survey. Select 3 sites
- Divide the front reef and slope, and also if there is a well-developed back reef, into 3 depth intervals (0-5 m, 5-10 m and >10 m);
- At each depth, place at least five 10 x 2 m belt transects. Use random number tables to select the exact transect placements;
- Count the number of urchins in each size category along the belt transect.

Advantages:
- Easy to implement.

Limitations:
- Random number tables can be logistically difficult to use because coral reefs have irregular shapes (see 'permanent versus haphazard sample methods' p 13).

Training required:

- Implementation of this method

Contact:
AGRRA: Robert Ginsburg, agrra@rsmas.miami.edu
CARICOMP: Dulcie Linton, dmlinton@uwimona.edu.jm and John Ogden, jogden@marine.usf.edu

Reference:
AGRRA: http://www.coral.aoml.noaa.gov/agra/
CARICOMP: www.ccdc.org.jm/caricomp_main.html
CARICOMP have a method for collecting and measuring *Diadema* which is recommended if *Diadema* have been depleted and precise information on population structure is required.

COLLECTION OF *DIADEMA*

Programs that use this method:
- Caribbean Coastal Marine Productivity Program (CARICOMP).

Method description:
This is conducted after the Diadema snorkel and scuba belt transects and involves collecting and measuring urchins at sites where chain intercept transects have been conducted.

Information obtained:
- Size structure of different urchin populations
- Relates habitat complexity with urchin population size structure

Parameters that can be surveyed using this method:
- ✓ Invertebrates

Monitoring level:
- ✓ Management

Scale:
- ✓ Fine

Level of detail
- ✓ Quantitative

Causes damage to the reef?
- ✓ Yes

Achievable precision:
- ✓ Medium to high

Equipment required:
- Large plastic basket;
- Barbeque tongs and fork;
- Two pointed compass;
- Ruler glued to a slate or another measuring devise;
- Chain 2-3 m in length.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- Following the CARICOMP belt transect urchin survey (p 68), determine the rugosity of each transect (see CIT p 54);
- Collect a minimum of 200 urchins of all sizes along each depth interval;
- Using the tongs, pick individual urchins from the basket, turn them upside down and measure the oral test diameter using a two-pointed compass. Measure the compass distance using the metric scale on your slate.

Advantages:
- Precise estimate of urchin abundance and size (measurements of size are more precise than estimates).

Limitations:
- Time consuming;
- Ecological impact of urchin collection;
- Some coral damage is unavoidable with the use of a chain, more so in branching coral habitats. The ecological impact of collecting urchins is unavoidable (see chain transects for limitations related to chain use).

Training required:
- Chain transects require specialist training

Contact:
Dulcie Linton, dmlinton@uwimona.edu.jm and John C. Ogden, jogden@marine.usf.edu

Reference:
http://www.ccdc.org.jm/caricomp_main.html

Table 7. Summary of the main monitoring methods used in the Indo-Pacific region for Invertebrates (Middle East, Western Indian Ocean, South Asia, Southeast and East Asia, Wider Pacific Ocean).

Monitoring level	**Parameters measured**	**Method name**	**Reference and contact**	**Page**
Community Broad Scale	COTS specific methods (or giant clams)	Manta tow	Global Coral Reef Monitoring Network: English *et al.*, 1997, www.gcrmn.org, Philippine methods: Uychiaoco *et al.* 2001; www.oneocean.org/download/_index.html	22
Community Medium Scale	General abundance	Belt transect	Reef Check: www.reefcheck.org Philippine methods: Uychiaoco *et al.* 2001; www.oneocean.org/download/_index.html	62
Management Broad Scale	COTS specific methods & giant clams	Manta tow	Global Coral Reef Monitoring Network: English *et al.*, 1997, www.gcrmn.org,	22
Management Medium Scale	Pacific belt methods	Belt transect	Lincoln Smith *et al.* 2001: www.gbrmpa.gov.au/corp_site/info_services/publications/research_publications/rp69/	62
Research Broad Scale	COTS specific methods	Manta tow	Global Coral Reef Monitoring Network: English *et al.*, 1997, www.gcrmn.org, Australian Institute of Marine Science: Bass and Miller, 1998, www.aims.gov.au	22
Research Medium Scale	General abundance	Belt transect	Australian Institute of Marine Science: Bass and Miller, 1998, www.aims.gov.au	62
	Aquarium invertebrate abundance	Aquarium invertebrate belt transect	MAQTRAC (Reef Check): www.reefcheck.org	65
	Drupella specific	Scuba search	Australian Institute of Marine Science: Bass and Miller, 1998, www.aims.gov.au	63
	Pacific belt methods	Belt transect	Lincoln Smith *et al.*, 2001: www.gbrmpa.gov.au/corp_site/info_services/publications/research_publications/rp69/	62
Research Fine Scale	Drupella specific	Visual quadrat	Commission de l'Ocean Indien: Conand *et al.* 1999, Conand *et al.* 2000, coi.intnet.mu/	41

Table 8. Summary of the main monitoring methods used in the Caribbean and Atlantic for Invertebrates.

Monitoring level	**Parameters measured**	**Method name**	**Reference and contact**	**Page**
Community Broad Scale	General abundance	Coral health survey	RECON, The Ocean Conservancy: www.oceanconservancy.org/dynamic/getinvolved/events/coral/coral.html	45
Community Medium Scale	General abundance	Invertebrate belt transect	Reef Check: www.reefcheck.org	64
Management Medium Scale	Diadema specific methods	Diadema belt transect	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/; Caribbean Coastal Marine Productivity Program: www.ccdc.org.jm/caricomp_main.html	68
Research Medium Scale	General abundance	Aquarium invertebrate belt transect	Suggest: MAQTRAC (Reef Check): www.reefcheck.org	65

7: Fishes

A coral reef manager must know what is happening to the fishes and other targeted species harvested from reefs, because the purpose of management is to safeguard the fisheries of the local people and the associated biodiversity. However, monitoring the fishes is probably the hardest task as many of them are highly mobile and counts can vary enormously from day to day. There are many methods to assess fish populations. Other target species are covered in the section on 'Invertebrates' p 63.

Fisheries monitoring methods include monitoring both the fisheries and their impacts on fish populations, including target and non-target species. Fisheries monitoring usually focuses on monitoring catch, effort, catch per unit effort and biological characteristics of the key fisheries species. This is called **fishery dependent monitoring** and the information can be used to monitor trends in the fishery and expected yield under different types of fishing pressure; see Samoilys (1997); Russ (2002) for more information. Another important assessment is to monitor fish catches at local ports or markets; these methods are not covered here and can be found in the Socio-economic manuals of Bunce *et al.* (2000) and (2002).

In this section we focus on **visual census methods.** These types of methods are used to monitor fishing impacts on target species, called **fishery independent monitoring**. The specific methods you should use will depend on the size and mobility of the target species you want to monitor.

Obtaining reliable estimates of fish populations is difficult so observers need extensive and on going training. Populations of fishes may fluctuate widely because recruitment of young fish into the adult population is highly variable and because many fish are highly mobile. This means that **estimates of abundance** are usually highly variable (estimates have high variance). Schooling species are particularly difficult to estimate as they may either be present in large numbers or absent. The structural complexity of coral reefs and the mobility, diversity and abundance of reef fishes also makes censusing difficult. While qualitative observations may be possible on large numbers of species, fewer species should be recorded for quantitative observations (Wells 1995). Likewise less experienced observers should be expected to count fewer target fish than more experienced observers. The best way to reduce the variance in complex areas is to perform more counts, e.g. many small samples, rather than trying to improve the precision of a few large counts (Bohnsack and Bannerot 1986).

It is possible to do a fish census on snorkel, but scuba allows surveys to be done at more depth ranges and many of the key fisheries species may be more abundant in deeper water. Although it is difficult to obtain reliable information on abundance and population size-structure, presence - absence data can be useful to determine if fish are moving away from impacted areas to more favourable places.

What affects accuracy and precision of fish counts?

- Diver movements;
- Diver visual capabilities e.g. water visibility;
- Spatial scale of sample methods relative to extent of fish movements, or the size of the area being counted compared to the movement range of many fishes;
- The range of ecologically different fish species counted in a census;
- Swimming speed - more fish will be seen by a diver who swims slowly.

Fish monitoring methods

Fish species diversity

You may want to survey species diversity as a part of a baseline study when commencing a monitoring program or to monitor them continuously. Surveys of species diversity may also help decide which species to include in the monitoring program. Questions include:

- What fish species occur at this site?
- What is the relative abundance of key target species at this site?

Monitoring coral reef species diversity requires a high level of technical expertise, i.e. a different expert is required for each taxon. If you do not have the technical expertise, it may be necessary to fund overseas experts to

How often should you conduct a visual fish census?
The frequency of fish monitoring will depend on your program objectives. If you want to detect seasonal changes, doing a census every month or every 3 months is necessary. Monthly surveys are useful to establish a baseline. If the aim is to detect long-term changes, we recommend you conduct these censuses annually and in the same month each year. However at the start, you may want to census fish over several consecutive days to establish the short-term variability.

conduct these surveys. Standard methods for species diversity have been developed and are used by a number of international non-government organisations (NGOs). See Donnelly *et al.* (2003) at http://www.komodonationalpark.org/ or contact one of the major NGOs: The Nature Conservancy at www.nature.org, the World Wide Fund for Nature at www.wwf.org and Conservation International at www.conservation.org.

What types of fish census methods are available?
1. **Belt transects** provide diversity estimates and cover a large area per census; (widely used for abundance and size estimation);
2. **Stationary visual census** focuses on the relative abundance and frequency of occurrence of all species at the site (widely used on patch reefs);
3. **Plotless methods** (rapid visual census) involve a roving diver swimming randomly and counting fish to provide more compete information on total species richness.

General fish monitoring

Food fish or target species
Monitoring fish that are important for food is useful to determine if fisheries are sustainable. This is called fishery independent monitoring and is valuable if done in conjunction with fishery dependent monitoring (see above).

Fish spawning aggregations
Monitoring spawning aggregations helps to:
- Determine how populations of target fish respond to seasonal or total closures;
- Measure impacts of management regulations (such as closures);
- Assess trends (declines/recovery) in aggregation populations;
- Provide predictive power for other sites/species;
- Provide some insight into reproductive biology;
- Maintain field presence to deter poaching; and
- Define multi-species versus single species aggregation sites.

Fish recruitment
Recruitment of coral reef fish is highly variable, which means that the number of new adults entering the population each year is variable. Counting the number of new recruits can help you estimate future adult populations.

Indicators of reef health

Butterflyfish (Chaetodontidae) are easily recognised by experienced and less-experienced observers. Many species rely on healthy coral to live, therefore the abundance of those that eat coral (coralivores, e.g. *Chaetodon fascialis*) provide a general indication of coral reef health. The usefulness of this approach has been questioned by some scientists who argue that if you want to detect changes in coral cover, then monitor coral cover directly (Jones and Kaly 1995).

Which fish monitoring methods should you choose?

Monitoring category & scale	When should you choose this method?	Page
Broad scale	**General overview of families and abundance over a large area in a short time.**	
Towed diver (manta tow)	**Food and large fish abundance:** To obtain a general estimation of abundance. Cannot be used for small, reef-hugging or cryptic species, or for reliable size estimates.	76
Medium scale	**Smaller area, more precise information and can include size and species information.**	
Roving diver	**Species diversity:** To count all species in an area; helps decide the species to include in a visual census.	78
Fish belt transect	**Food fish:** To measure the population structure of target fish requires experienced observers; more experience and repeated training is required for size estimation; **Aquarium fish:** Provides information on fish populations targeted by the aquarium trade; requires experienced observers of abundance; more experience and repeated training is required for size estimations; **Spawning aggregations:** As above; experience in estimating abundance of schooling fish is necessary; **Fish recruitment:** To determine the number of new recruits to the reef.	79 82 91 84
Stationary plot	**Food fish:** Stationary methods work better for patchy reefs and total fish counts, but are not suitable for complete species lists as small and cryptic species are missed; these methods also avoid problems associated with moving divers and cumbersome transect tapes; experienced observers needed to count fish and estimate tunnel size; **Spawning aggregations:** As above; experience in estimating abundance of schooling fish is necessary.	86 91
Butterflyfish method	**Indicators of coral health:** Change in coral eating fish abundance indicates coral reef health; easy for non-specialist observers, however results should be treated carefully.	89
Herbivory methods	**Herbivory:** Useful for serious over-fishing of herbivores. http://mgg.rsmas.miami.edu/agrra/	—

How wide should the belt transect be?

A higher percentage of individuals are missed on wider transects so it is important to use the width suitable to the type of fishes you want to census and the experience of the workforce e.g.:

- 1 m wide is best for small fish recruits;
- 2-5 m wide transects are commonly used for medium to larger species. Some methods use 4-5 m belts to survey the larger, more mobile species, e.g. surgeonfishes (Acanthuridae), small parrotfish (Scaridae) and small groupers (Seranidae) can be monitored using 50 x 5 m belt transects; smaller, less mobile species, like damselfish (Pomacentridae), can be monitored on a 2 m belt. Different methods are required to monitor large, uncommon and particularly vulnerable fisheries species, e.g. sharks, large wrasses (Labridae) (e.g. napoleon wrasse, *Cheilinus undulatus*), parrotfishes (particularly the humphead parrotfish *Bolbometapon muricatum*) and groupers like the Nassau grouper (*Epinephelus striatus*). These counts can be made by consecutive swims along the same transect or by one observer counting larger fish and another counting the smaller fish.

Towed diver (manta tow)

Programs that use this method:

- NOAA Fisheries Pacific Islands Fisheries Science Center Coral Reef Ecosystem Division (CRED)

Method description:
Towed-diver surveys involve towing two scuba divers behind a boat at a constant speed (~1.5 knots). Each diver manoeuvres a towboard connected to the boat by a bridle and towline and outfitted with survey equipment including digital still or video cameras. The towed-diver fish surveys can be used to conduct rapid assessments of large areas of reef in a short period of time, which can be critical when working at remote sites. Compared to traditional dive surveys, which have limited spatial coverage, the towed-diver surveys are more effective at estimating abundance and density of large mobile fishes. We recommend that the video component of this method only be used for research level monitoring with sufficient funding to buy and maintain equipment. Management and community level monitoring can use the visual part of this method for rapid or large fish surveys. We recommend that habitat type be noted during visual surveys where video is not used.

Information obtained:

- Fishes larger than 50 cm total length during the *in situ* diver surveys;
- Fishes larger than 20 cm total length during the digital video analysis;
- Fish habitat classification (physiographic zone, habitat type, and rugosity);
- Fish diversity (larger, more mobile fishes only).

Field equipment:

- 60 m long, 10 mm diameter low-stretch towing line;
- Towing bridle affixed to towboard;
- Towboard with fitted cut outs or mounts to attach cameras and other instruments (data sheets and pencil are attached to the towboard);
- Digital video camera;
- Depth and temperature recorder (e.g. SBE39);
- Waterproof watch with countdown function to signal intervals for visual assessment;
- Separate waterproof watch as backup and to monitor dive time;
- Depth gauge bottom timer (e.g UWATEC);
- Magnetic switch telegraph system;
- GPS unit in boat to geo-rectify survey track (e.g. Garmin 76);
- Depth sounder in boat to maintain constant towing depth.

Fish size classes used.

Code	Length category (cm)
1	20-34
2	35-49
3	50-74
4	75-99
5	100-149
6	150-199
7	200-249
8	250-299
9	300 and over

Lab equipment:

- Video player and s-video cable;
- High-resolution professional monitor;
- ArcView GIS.

Field personnel:

- Efficiency is improved when there are two teams so that surface team and dive team can switch roles at the end of each survey.

Lab personnel:

- Analysts experienced in the identification of coral reef fishes to species level, and estimating size class and abundance.

Field general procedures:

- Deploy divers and start surface GPS recording;
- After the divers reach the bottom, they coordinate the start of the survey with each other using hand signals and with the surface support team using the telegraph;
- The start entails activating the stopwatch and camera, recording the time on the datasheet, and commencing the survey (if a camera is used);
- The boat coxswain maintains tow speed of ~1.5 knots; currents and sea conditions may require a change in vessel speed;
- Divers attempt to manoeuvre the towboard 1 meter above bottom;

- The survey is divided into 5 minute segments, which include a 1 minute circle survey and a 4 minute transect. During the circle survey, all fishes larger than 50 cm total length are recorded in a 360° scan. During the tow survey the diver visually surveys fishes in a 5 m belt and 10 m in front;
- At the end of the survey (50 minutes, which is ~2 km), the diver with the telegraph alerts the surface support team and divers ascend to begin the safety stop.

Lab general procedures:
- View 40% of the tape for fishes 20-50 cm total length and view 100% of the tape for fishes > 50 cm total length;
- Tapes are viewed in 10 x 5 minute segments and fishes are recorded within a 10 m wide belt;
- Fishes are identified to species level, where possible and sizes are estimated in size categories;
- Habitat classification and rugosity are classified from each 1 minute segment.

Advantages:
- A large area is covered in a short time;
- Fishes occupying different habitats, e.g. patch reef, sand flats, rubble zones and the transitions between them are observed in a single tow;
- Compared to traditional dive surveys, which have limited spatial coverage, the towed-diver surveys are more effective at estimating abundance and density of large mobile fishes;
- Rare or uncommon fishes not encountered during conventional surveys are more likely to be observed during towed-diver surveys because of the larger area;
- The towed-diver video analysis permits more detailed assessment of larger fishes, including the ability to count the numbers of individuals better within large aggregations of fishes observed during the *in situ* surveys;
- Towed-diver surveys are suitable for remote locations that can be visited infrequently;
- Towed divers can survey areas that are unsuitable for roving divers due to strong current, surge, or poor anchorage;
- Use of alternating surface and dive teams increases surveys per day;
- An archived visual record can be re-sampled or re-analysed. This video is also useful to describe benthic characteristics i.e. physiographic zones, habitat types, and rugosity;
- A GPS receiver on the towing boat allows geo-referencing the survey track, linking imagery to location.

Parameters that can be surveyed using this method:
- ✓ Fishes

Monitoring level:
- ✓ Research
- ✓ Management
- ✓ Community

Scale:
- ✓ Broad

Level of detail:
- ✓ Quantitative and Qualitative.

Causes damage to the reef:
- ✓ No

Achievable precision:
- ✓ Low

Limitations:
- Requires experienced divers trained in specific hazards of manoeuvring towboards;
- Field equipment is expensive and requires regular maintenance, therefore this method is only suited to research projects with large budgets;
- Costly and time-consuming to analyse imagery;
- Reduced taxonomic resolution of analysed imagery relative to free-swimming diver fish survey methods;
- Cryptic fishes are easily overlooked.

Field training required:
- Certified scuba divers trained in safely manoeuvring towboards;
- Operation of small boats, GPS units, digital video;
- Size determination and identification of fishes to species;
- ArcView GIS

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Reference:
www.crei.nmfs.hawaii.edu/eco/tow_board.html

Fish roving diver technique

Programs that use this method:
- Reef Education and Environmental Foundation (REEF);
- Atlantic and Gulf Rapid Reef Assessment (AGRRA);
- Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS SMP);
- Caribbean Coastal Marine Productivity Program (CARICOMP).

Information obtained:
- Information on abundance of all fish species recognised and presented as Log10 index of abundance;
- Species presence/absence and frequency of occurrence (among observers);
- Relative abundance per site can be obtained by multiplying the index score by frequency of abundance.

Field personnel:
- 1 boat driver/surface watch
- Minimum of 2 observers (scuba divers). At least 1 diver must be able to identify all fish species in the area.

General procedures:
- Usually conducted between 10.00 and 14.00 hours following belt transects (or concurrently if sufficient observers);
- One survey conducted per site;
- Swim around the site (keeping to a 200 m diameter of the start) for 30 minutes and record all fish species observed;
- Approximate the density of each species using logarithmic categories: Single (1 fish), Few (2-10), Many (11-100), or Abundant (>100 fishes).

Advantages:
- Rapid;
- Minimal equipment required;
- Wide spatial area coverage is possible;
- Cumulative frequency data are statistically useful;
- Plotless methods are good for species lists;
- Particularly useful for large fish that are wary of divers, cryptic species and roving pelagic fishes that require an intensive search of the reef;
- Length estimations helped by use of two laser beams (if this is within your budget); 4 laser pointers positioned 10 cm apart and project red laser dots outwards (Colin *et al.* 2003).

Parameters that can be surveyed using this method:
- ✓ Fishes

Monitoring level:
- ✓ Community
- ✓ Management

Scale:
- ✓ Medium
- ✓ Fine

Level of detail:
- ✓ Semi-quantitative.

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Limitations:
- Limited by the diver identification skill and effort; requires searching all potential fish habitats;
- Each dive is the sampling unit and may cover a wide range of depths, and habitats depending on site topography and habit patchiness. Volunteers concentrate on popular dive sites and are not randomly distributed among habitats. Therefore, there is no control for the following:
  - Spatial area covered per sample (difficult to compare abundances/sightings between surveys);
  - Number of micro-habitats covered per sample;
  - Site selection;
  - Time of sampling.
- Diver training and skill vary greatly between novices and experts, although REEF tests divers and categorises them into skill levels so that data are sorted by skill levels;
- Abundance estimates constitute an index that requires large numbers of samples for comparative studies and cannot be converted into absolute abundance estimates.

Training required:
- Random swims are necessary to ensure the observer is familiar with all fish species in the area;
- Observers who are part of the REEF program must perform tests that categorise them into skill levels;
- Observers must have detailed knowledge of different fish habits and habitats.

Reference: REEF: www.reef.org/; MBRS SMP: www.mbrs.org.bz; AGRRA: www.coral.aoml.noaa.gov/agra/
CARICOMP: www.ccdc.org.jm/caricomp_main.html
Also see Jones and Thompson (1978); Kimmel (1985); Rogers *et al.* (1994); Almada-Villela *et al.* (2003).

Fish belt transect

Programs using this method:
- Australian Institute of Marine Science Long-term Monitoring Program of the Great Barrier Reef;
- Global Coral Reef Monitoring Network, English *et al.*;
- Reef Check;
- Reef Check program's MAQTRAC method;
- Large fish belt transect method;
- English *et al.* fish recruitment method.

Method description:
These methods aim to count (quantify) the abundance and community composition of fish on a transect (for more information see 'belt transects' p 75). 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.

Field personnel for all belt surveys:
- 1 observer and 1 tape layer;
- 1 surface watch/boat driver.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

Parameters measured using this method:
- ✓ Fishes

Monitoring level:
- ✓ Community
- ✓ Management
- ✓ Research

Scale:
- ✓ Medium

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Example 1: AIMS LTMP method (research monitoring)
Method description:
The aim is to instantaneously estimate the abundance of fish within a given area (belt transect). Size estimations can be added to this method if desired.

Information obtained:
Abundance of target fish populations
Physical parameters:
- Cloud cover is measured using the Beaufort scale;
- Wind strength (p 79):
- Sea state (p 95);
- Underwater visibility.

Equipment required:
- Tape measures (5 x 50 m);
- Spare tape measure to calibrate estimates of belt width.

General procedures:
- Conduct this survey between 09.00 and 16.30 hours in the winter and between 08.30 and 17.00 in summer;
- First the cloud cover, wind and sea state are recorded (see information obtained above);
- Surveys are conducted along the 5 x 50 m permanent transects used for the AIMS LTMP. These transects are set between 6 and 9 m on the reef slope;
- Horizontal water visibility is recorded on entry;
- The observer swims ahead of the tape layer and uses the permanent stakes that are positioned every 10 m to guide their direction. Swim the transect twice; the first time count more mobile, larger fish on a 5 m belt; the team swims back along the transect counting less mobile fish (e.g. Pomacentridae) in a 1 m belt;
- Observers must look ahead to the next stake and count the fish by spending the same amount of time on each part of the transect for each group of target fish. The mobile fish should be counted first, followed by smaller, slower more cryptic species;
- Only fish in the 1+ year age class are counted because of the temporal variability in the 0+ age class.

Advantages:
- Laying the tape behind the fish counter reduces the disturbance to fish.

Limitations:
- Observers cannot collect adequate data on species composition, abundance, frequency of occurrence and biomass at the same time;
- Transects are impossible to use on some reefs due to complex habitat features, governmental regulations or 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 damaged by ship groundings, or reefs with different habitat types and habitat heterogeneity (patchiness), characteristic of Caribbean reefs.

Bohnsack and Bohnsack (1986) designed the 'stationary visual method' to solve problems with belt transect methods p 86).

Training required:
- Fish identification and abundance estimates and detailed knowledge of different fish habits and habitats; size estimation training if required.

Contact:
Hugh Sweatman, h.sweatman@aims.gov.au

Reference:
Halford and Thompson (1994); www.aims.gov.au
Other references: Brock (1954); Brock (1982); Jokiel *et al.* (2001); www.cramp.wcc.hawaii.edu/Overview/3._Methods/3._Site_Survey_Protocol/Reef_Fish_Monitoring/

Example 2: Global Coral Reef Monitoring Network, English et al. method (management and research monitoring)
Method description:
The aim is to simultaneously estimate the abundance and size of fish in a given area (belt transect).

Information obtained:
A reconnaissance dive is used to detect differences in reef fish assemblages at different sites using abundance categories. This provides baseline data for zoning, management and monitoring. The visual fish census on the belt transect provides abundance counts and size estimations of individual fish to determine the standing stock and population size structure of specific species. Experienced observers can make actual counts, but for less experienced observers or for numerically abundant fish, abundance categories should be used.

Abundance categories used for counting fishes.

Log 4 Abundance Category	**Number of fishes**
1	1
2	2-4
3	5-16
4	17-64
5	65-256
6	257-1024
7	1025-4096
8	4097-16384

Equipment required:
- Tape measures (5 x 50 m);
- Spare tape measure to calibrate estimates of belt width;
- Fish models to practice fish length estimations (English *et al.* 1997).

General procedures:
Reconnaissance dive
- Conducted during daylight hours;
- List the dominant species for inclusion in belt transect counts. This minimises the time needed to write species names on data sheets, thereby improving the observer's ability to record fishes continually. The species for inclusion should be selected using the following criteria:
    - Visually and numerically dominant, without cryptic behaviour;
    - Easily identified underwater;
    - Associated with the reef slope.
- A core group of species appropriate for coral reef assessment should be used to:
    - Quantitatively estimate abundance and size structure of species that are favoured **'targets'** of fishermen, e.g. Serranids, Siganids, Acanthurids, Lutjanids, Lethrinids, Haemulids, Balistids;
    - Quantitatively estimate the abundance of fishes along the same 50 m line used for the line intercept transect (p 33);
    - Semi-quantitatively estimate the relative abundance of other species belonging to major trophic categories (planktivores, algal grazers, and coral feeders), e.g. Pomacentrids, Acanthurids, Caesionids, Scarids, Siganids, Labrids, Mullids and other species that are **'visually obvious',** e.g. Chaetodontids**.**

Belt transect
- Conducted during daylight hours along 3 of the same transects as the line intercept (p 33) but the fish census transects must be 50 m long at 2 depths (3-5 m and 8-10 m);
- Wait for 5 to 15 minutes after laying the line before counting to allow fishes to resume normal behaviour;
- Swim slowly along the transect recording fish encountered in a 5 m belt and 5 m tunnel above the transect;
- Count the actual numbers of target species seen within the transect strip and estimate the size (in cms) of each of these fish;

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.
- One diver makes the census within the transect area while the dive buddy swims behind the observer and makes general observations of the reef environment and fish assemblages;
- 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.

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;
- The use of abundance categories reduces the power to detect small changes.

Training required:
- Fish identification, counting and length estimation. See English *et al.* (1997) for details on training to estimate length of fishes. This should be repeated every 6 months.

Contact:
Sue English, s.english@aims.gov.au

Reference:
English *et al.* (1997);

Example 3. Reef Check method (community monitoring)
Method description:
This method is designed for use by volunteer divers or snorkellers.

Data obtained:
Abundance of key target fish.

Equipment required:
- Transect tape (100 m);
- PVC pole to estimate belt width (optional).

General procedures:
- Lay out a 100 m transect tape at each of 2 depths, 2-6 m and 6-12 m;
- Wait for 15 minutes;
- Transects are 20 m by 5 m wide and 5 m high;
- Observer swims slowly along the transect line and stop every 5 m to count target species. The observer then waits for 1-3 minutes before continuing to the next stop point. This process is repeated 3 times until 20 m of the transect has been surveyed. Here the observer skips a 5 m section before beginning a new 20 m section of transect. One complete transect consist of 4 replicate 20 m segments for a total survey length of 80 m.

Advantages:
- Simple to use by a non-professional workforce, therefore cost-effective;
- One full survey is sufficient to gain a snapshot of target fish abundance when compared on a regional or global scale. Increased surveys in time and space are required to gain a more precise picture of abundance and changes through time at the local site scale.

Limitations:
- More replicates and more frequent surveys are required to acquire a more reliable indication of local fish abundance and changes. Increased replication increases cost.

Training required:
- Identification of target species (to family and species level for the most common species). Training can be done in one day.

Contact:
rcheck@ucla.org

Reference:
www.reefcheck.org

Example 4. Reef Check Program's MAQTRAC method (research monitoring)
Method description:
This method is designed to determine the impact of the aquarium trade on fish populations. The objective is to obtain a sufficient sample size of fish indicator species to be able to compare statistically and distinguish differences between fish collection and control sites.

Data obtained:
Species level abundance and size information.

Equipment required:
- Transect tape (100 m).

General procedures:
The number of transects necessary is dependent upon the density of fish in the area, size of sampling area and spatial heterogeneity of the sampling area. This usually means that a minimum of 5 and as many as 15 transects will be needed to achieve a sufficient sample size for most species.
- See Reef Check belt transect method above. The survey depth varies depending on where target fish are collected;
- To record abundance: if individuals of a size class in a group of fish are between 1-50 individuals, count every fish in that size class. Break the counts up by size classes. When there is a large school of fish, abundance estimates should be made by fitting an imaginary quadrat to the school that is a third or quarter of the size of the school and estimating the abundance of fish in the imaginary quadrat.

Timed swim

- Timed swims can be conducted beyond the 100 m transect (which is also used for Reef Check PIT and MAQTRAC invertebrate belt transects) instead of laying out another tape measure. Timed swims should be conducted as the primary survey technique when a species is not sufficiently abundant in belt transect surveys or in habitats that do not allow for a belt transect. Where a timed swim is the only means of obtaining abundance data, it is imperative to estimate the distance swum and record the time accurately.
- The survey is along the same 5 m belt path, but the transect length is measured by the time of the swim instead of a transect tape;
- Note the start and stop time (this is essential);
- Maintain a constant swim speed;
- When a stop is made to count a large school or to look into crevices, the clock must be stopped and then restarted when swimming recommences. This is an important step because density measurements may be obtained from the sample time and swim speed;
- Count all individuals of the target species and size in the same manner as on the transect surveys.

Advantages:

- The method is statistically robust if there are sufficient replicates. It therefore can be used to detect the impact of the aquarium trade on fish populations;
- The method is designed as a more detailed version of the Reef Check community monitoring method; therefore, data can be compared with community data.

Limitations:

- Difficult to determine if a statistically significant impact is ecologically significant;
- Time consuming and costly if many replicates are required.

Training required:

- Highly trained to species identification level and fish size estimation. Must have detailed knowledge of fish habitats to perform searches appropriately.

Contact:
rcheck@ucla.org

Reference:
www.reefcheck.org

Other fish methods can easily be altered for aquarium fish, however, many species are very small there is need to determine the optimum **sample method size** (p 107). See Russ and Choat (1988) for details on experimental design and analysis of fishery data.

Example 5. Large fish belt transect method (any monitoring level)
Method description:
Observers estimate the abundance of large, mobile fish along belt transects, e.g. grouper and napoleon wrasse.

Data obtained:
Abundance estimates of target species.

Equipment required:

- No special equipment.

General procedures:
Both these surveys are timed swims. It is helpful to estimate the distance the observers cover during survey times so that density estimates can be calculated and compared over time and between sites. Groupers tend to have cryptic behaviour and stay close to the bottom, or hide in caves or under overhangs and ledges. To ensure these are not overlooked, slower swimming speeds are required for visual censuses.

Long-swim technique for larger, mobile reef fishes

- Swim for 20 minutes at a standard speed at a constant 5 m depth along the reef front just below the crest (the crest must be visible);
- Record the number and size of all individuals of large target species observed within 10 m on either side of observer;
- For very large mobile species the appropriate transect dimension are 400 m x 20 m. For smaller fish, such as steephead parrotfish narrower transects (5 m either side) are required.

Grouper survey

- Swim at a speed of 6 metres per minute for 30 minutes;
- Search the substratum thoroughly, count and estimate the size of all individuals within a 5 m belt;
- A second observer should follow behind and record the numbers and sizes of any larger mobile groupers that are within 10 m either side.

Advantages:

- Long-swims enable larger areas to be covered in a limited dive time compared to small transects;
- Disturbance of fish by divers is minimised as no tapes are used before counting;
- These techniques are better suited to fishes that are sensitive to diver activity;
- Wider transects for conspicuous species are useful for counting larger fishes that do not allow close approach;
- Slower swim speeds with increased search intensity within a 5 m belt produces higher counts than other methods for more cryptic groupers;
- Long-swim methods are logistically simple and provide useful data in addition to the more established visual survey methods.

Limitations:

- Observers can be trained to swim at constant speeds but it is difficult in a current which alters the area covered.

Training required:

- Identification;
- Swimming at a constant speed.

Contact:
Rachael Pears, Rachael.pears@jcu.edu.au or Howard Choat, howard.choat@jcu.edu.au

Reference:
Samoilys (1997); Wilkinson *et al.* (2003).

Example 5. Fish recruitment method (management and research monitoring)

Method description:
This involves swimming along a narrow belt transect and counting newly settled fish recruits. This provides information on the composition of the new recruits, and the distribution and abundance of reef fish stock (species with conspicuous sedentary juveniles). This is used to predict the future abundance of adult populations as well as provide a temporal picture of changes in recruitment.

Equipment required:

- 50 m long fibreglass tape measure;
- 1 metre yardstick for a reference length. It is easier if this is attached to a handle making a T-bar.

Field personnel:

- 1 boat driver/surface watch;
- 2 observers (scuba divers). At least 1 of the divers must be able to identify the fish recruits in the area and be familiar with the size limits that discriminate the recruits from other year-classes.

Lab personnel:

- Data entry, analysis, interpretation and reporting.

General procedures:

- 3 x 50 m long transects should be laid randomly at a depth between 6-9 m below the reef crest;
- Transects should not overlap and must be separated by 10-20 m;
- Lay the transects in a straight line;
- If LIT is used at the recruitment sites, it is recommended that it is conducted along the entire 50 m length. The fish transects must be completed first;
- Wait 5-15 minutes before starting the counts to allow fish to resume to normal behaviour;
- Swim slowly along the transect and record fish seen within 1 m either side of the transect line;
- Count recruits by careful searching habitats along the transect. Count schooling species ahead of the diver;
- Transects should not be broken into smaller units as many species are uncommon to rare.

Advantages:
- Rapid and non-destructive;
- Simple and inexpensive;
- Minimal number of personnel and equipment.

Limitations:
- Requires well-trained and experienced observers;
- Visual census of fish recruits is limited to species with conspicuous sedentary juveniles;
- Not useful for pelagic species.

Training required:
- Detailed training and experience.

Contact:
Sue English, s.english@aims.gov.au

Reference:
English *et al.* (1997).

Fish stationary plot survey

Programs that use this method:
- Atlantic and Gulf Reef Rapid Assessment (AGRRA);
- Florida Keys National Marine Sanctuary Coral Reef Monitoring Program (FKNMS CRMP).

Method description:
Fish inside an imaginary tube are counted by a diver who is observing from outside the area. This method was designed to estimate fish community structure and is used to do stock assessments in USA along with traditional fishery-dependent data.

Information obtained:
Species diversity and community size structure.

Equipment required:
No special equipment.

Field personnel:
- 2 observers (1 of these must be trained in the methods, the other is a buddy);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- One observer counts the number of fish visually in an estimated 7.5 m radius tunnel for 5 minutes;
- Estimate and record the lengths for each fish counted.

Parameters that can be surveyed using this method
- ✓ Fishes

Monitoring level:
- ✓ Management
- ✓ Research

Scale:
- ✓ Medium
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Advantages:
Key advantages over transect methods include:
- It is easy to use and collect a large sample size;
- Minimal equipment is required;
- Minimum 'edge effect' error;
- No time wasted in laying out lines;
- Maximum bottom time (due to minimum air consumption);
- Provides spatial integrity if multiple habitat types are covered;
- Behavioural avoidance and attraction problems are minimised compared to a swimming diver because fishes tend to habituate to stationary divers and act more normally;
- Bias between observers swimming at different speeds and distances from the substrate is eliminated;
- Bias between observers looking in particular hiding places based on special personal knowledge about the fish is eliminated;
- Maximum size data are more sensitive to fishing and adult mortality effects while minimum sizes are sensitive to recruitment effects;
- Data are collected simultaneously on species composition, abundance, frequency of occurrence and individual lengths for all visually detectable species. These data on all major community parameters can be collected practically with this method;
- The methods of data collection have been extensively tested, refined, and are unchanged for the last 25 years;
- These techniques are particularly useful for discrete patch reefs or artificial reefs.

Limitations:

- This method is not suitable for crevice-dwelling, cryptic and very secretive fish and inefficient for studies concerning a few species or genera;
- It does not work well under high surge conditions, in strong currents, and under low visibility although correction factors can be applied to correct for low visibility. However, the method provides consistent and reliable data under a range of visibility conditions normally found on coral reefs;
- An index of abundance (density per sample) can be obtained from the data and is suitable for relative comparisons, however the precision of this method is subject to the ability of observers to estimate the tunnel diameter. If absolute abundance is required, empirically derived habitat-specific correction factors would need to be determined and applied. This is not a problem for most studies that only need to show relative changes or differences;
- The precision achieved is highly dependent on the skills of the diver to estimate the 7.5 m radius.

Improvements to stationary visual census method

- Significant improvements in estimates of the coefficient of variation (an estimate of precision) have been achieved by using a two stage random stratification for selecting 200 x 200 m sampling sites. These statistical improvements are described in detail in Ault *et al.* (2001); Ault *et al.* (2002). Major improvements in precision were achieved by not over sampling individual sites but distributing sample effort over more sites;
- Auto correlation of buddy pairs (who often see the same fish) is reduced and individual difference reduced by combining data from a buddy pair. Replication is provided by having a sample method sampled by a second buddy pair;
- A population size distribution can be generated using mean, maximum, and minimum sized as described by Meester *et al.* (1999).

Training required:

- Fish identification, counting, size estimation and tunnel estimation.

Contact:
Robert Ginsburg, rginsburg@rsmas.miami.edu or Phil Kramer, agrra@rsmas.miami.edu

Reference:
AGRRA www.coral.aoml.noaa.gov/agra/
FKNMS CRMP: http://www.fknms.nos.noaa.gov/research_monitoring/

The publications cited above can be viewed and downloaded at:
www.sefsc.noaa.gov/articlesandpublications.jsp. Also see Kimmel (1985); Bohnsack and Bannerot (1986).

Fish rapid visual census

Used to determine species diversity. Useful to determine which species to include in long-term monitoring.

Method description:
Observers conduct this survey at a constant speed for a fixed time instead of measuring the area with transect tapes. The method is useful to estimate relative abundance and is based on the assumption that the probability of encountering a species increases with its abundance. Therefore, the more common the species, the sooner the observer is likely to encounter it.

Information obtained:
Species diversity and relative abundance presented as frequency of occurrence.

How do you analyse and interpret the data?
- Species scores indicate the relative abundance of different species seen to each other;
- Species lists provide an estimation of the species diversity in an area.

Field personnel:
- 1 observer and 1 buddy
- 1 boat driver/surface watch

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
- The observer swims randomly around a reef to locate and record as many fish species as possible;
- The swim should be limited to the specific habitat (depth, reef zone) to determine species richness;
- Species are only recorded once when first seen in the specific 10 minute time interval, for a total of five 10 minute intervals. The 10 minute search intervals allows the diver to obtain estimates of the relative abundance of each species in addition to presence or absence data derived from the species lists. The assumption is that the species occurring in early time intervals are the most abundant in the community;
- Fishes occurring in the first 10 minute interval receive a score of 5, those in the second interval 4, and so on with the fifth interval fish scoring 1. Species scores are summed to indicate frequency of occurrence;
- Repeat these counts 8 times per site.

Parameters that can be surveyed using this method?
- ✓ Fishes

Monitoring level:
- ✓ Management
- ✓ Research

Scale:
- ✓ Medium
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Advantages:
- Simple with low equipment requirements;
- Avoids time-consuming transecting methods;
- Useful for initial surveys of species diversity, and to select species to include in long-term monitoring according to their abundance; this will affect the reliability of data from the chosen transect length;
- Can be implemented on patch reefs if time intervals are stopped when swimming between reef areas.

Limitations:
- Data cannot be directly compared with coral cover or key macro-invertebrates data as different areas are examined;
- As with all fish census methods, species diversity is estimated as many cryptic species may be overlooked;
- The method over-emphasises the importance of widespread though rarer species (common for fish on coral reefs), while under-estimates patchy but abundant fishes.

Training required:
- Species identification and detailed knowledge of different fish habits and habitats.

Reference:
Jones and Thompson (1978); Kimmel (1985).

Butterfly fish method

Major programs using this method:
This method is used by researches in Hawaii. No major programs use this method.

Method description:
This method involves observing butterfly fish chasing and feeding behaviour to determine the abundance of food and habitat per butterfly fish pair. Percentage cover of benthic communities should also be determined. The concept is based on the assumption that coral-feeding butterflyfish will move away from a reef area when coral health deteriorates.

Equipment required:
- 30 m long brightly coloured propylene line approximately 1 cm in diameter and marked every metre;
- Underwater slate with 20 cm ruler attached.

General procedures:
- Should be implemented at a minimum of 2 study sites where one site is a control (no known anthropogenic disturbances);
- The basic level estimates fish abundance; the advanced level measures fish behaviour and territory size (resource dependent).

Abundance estimates
- Place up to 4 x 30 m transects on areas of high coral cover (not haphazardly);
- Swim slowly at 6 m per minute along the transect and record target butterfly fish abundance along a 10 m wide belt transect.

Monitoring level:
- ✓ Community
- ✓ Management
- ✓ Research

Scale:
- ✓ Broad
- ✓ Medium

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ Medium

Percentage cover of benthic communities
See 'percentage cover of benthic communities' (p 16). We recommend use of point intercept transect method as the easiest method for non-professionals (p 36).

Chasing behaviour (expected to increase as food becomes limited)
- Implemented after the abundance survey;
- This survey is conducted during 5 x 10 minute observation periods. The diver swims along the transect to the first pair of butterfly fish;
- The boundary of their territory is marked out (furthest edges where they move);
- Observe the fish behaviour for 10 minutes;
- Note each time the target pair chases a fish in an adjacent territory;
- Repeat for the same pair for 50 minutes of observations;
- These observations do not need to be implemented during one dive, but consecutive dives should be implemented as soon as safety requirements allow;
- Estimate the size of the target fish by noting the position of their beak and rear eyespot or tail on a coral when they are feeding, when they move away, measure the area with a ruler attached to the slate.

Feeding behaviour (to determine preferred food)
- Observe feeding behaviour for 3 x 10 minute periods;
- Note the number of bites on a particular species of coral;
- Calculate the numbers of bites per 10 minutes for each coral species.

Measuring territory size (expected to increase with food shortage)
- Mark the territory boundary (circular or oval) with colour-tagged nails;
- Stretch a measuring tape across the longest axis of the territory and anchor it at both ends with a small weight;
- While one diver holds one end of the second tape at each meter interval along the first tape, the second diver measures the distance to the boundary of the territory;
- The territory size is calculated by adding up all the values on the data sheet.

Field personnel:
- 2 observers;
- 1 boat person/surface watch.

Lab personnel:
- Calculate feeding behaviour and territory size measurements;
- Data analysis, interpretation and reporting.

Advantages:
- Simple and inexpensive;
- Can be implemented by individuals with no previous technical training;
- Sensitive to slowly changing conditions on the reef; coral-eating butterflyfish will enlarge their territory if the density of their food decreases, therefore observing territory size can indicate gradual coral decline that might not be significant from direct observations of coral cover;
- Stepwise design where more information can be added where resources and personnel capacity allow.

Limitations:
- It is easier to measure coral cover directly i.e. by doing the point intercept transect.

Training required:
- No formal scientific training is required but 1 or 2 key coralivores must be recognised per geographic location.

Reference:
Crosby and Reese (1996).

Fish spawning aggregations methods

Programs that use this method:
- Society for Conservation of Reef Fish Aggregations (SCRFA)

Method description:
This involves determining the location, season and size of spawning sites and conducting an underwater visual census to estimate abundance of spawning adults.

Data obtained:
- Aggregation density;
- Aggregating population size and sex structure;
- Temporal patterns in spawning activity and aggregation;
- Total number of fish at spawning site.

Equipment required:
Calibration rulers for estimating sizes.

Field personnel:
- 2 observers (scuba divers);
- 1 boat driver/surface watch.

Lab personnel:
- Data entry, analysis, interpretation and reporting.

General procedures:
There is a need to define the following:

1. Where are aggregations?
An aggregation is recognised by a 3 fold increase in density of spawning fish. For confirmation of spawning, direct 'signs of spawning' should also be identified, including:
- i. Undisputed spawning observations;
- ii. Females with hydrated eggs; and
- iii. Presence of post-ovulatory follicles in the ovaries of aggregating females.

Indirect signs include:
- i. Behaviour or colour pattern changes that are known to be associated only with spawning; and
- ii. Gonad somatic index(GSI) data, swollen abdomen and other proven indications of spawning.

2. What is the timing or season of the aggregation?
This information is obtained from fishers, observation of gravid fish in markets, increased numbers of fish in live holding pens and from gonad histology.

Parameters that can be surveyed using this method:
- ✓ Fishes

Monitoring level:
- ✓ Research

Scale:
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No (Underwater Visual Census)

Achievable precision:
- ✓ Medium

3. Where are the aggregations located?
Nautical charts, satellite imagery, aerial photographs and aerial reconnaissance are useful to assess potential aggregation sites from known bathymetric and oceanographic profiles for the species. Aggregations of local fishing boats synchronised with moon phase are a useful indication of spawning aggregations, and interviews with fishers are particularly helpful. Broad scale surveys on snorkel or manta-tow can also be useful although they are slow and labour intensive.

Conducting the monitoring
There are 3 monitoring methods that can be used:
- Underwater Visual Census (p 88) or Stationary Plot Fish Survey (p 86)
- Collection of fisheries dependent data; Domeier *et al.* (2002); Colin *et al.* (2003);
- Remote surveillance techniques.

Underwater Visual Census for spawning aggregations

Visual surveys within a path that traverses the aggregation site are recommended. For diver-shy species, stationary counts are recommended. Timed swims are not recommended because they do not provide quantitative data. The following criteria will determine which methods are applicable:

- Site depth;
- Density of fish;
- Currents (when strong currents or when fish may be wary of divers in close proximity. Stationary plots may be more appropriate here with a tethered observer to save energy).

Parameters measured:

- Number of fish per unit area;
- Size;
- Sex ratios;
- Behaviour;
- Location on site (mapping).
- Measure aggregation areas. Mark the border of the site while doing the survey and return to measure this later. Marks can include placing painted rocks or weights with floats;
- If possible, video the transect during the visual assessment in order to determine accurate abundance estimates; remote videos are useful for fish that avoid humans.

Advantages:

- Non-destructive method;

Limitations:

- Monitoring more than one aggregation site can require several teams of observers if aggregations occur at the same time, which is frequent with transient spawning fishes;
- Due to inherent variation in spawning aggregation location and timing both seasonally and during the aggregation itself, it is not possible to visit a site only once and expect survey data to be meaningful. Careful planning is essential;
- Because every spawning site is different, the survey methods suggested here should only be taken as guidelines;
- Since most aggregations occur where there is significant coral cover, often with an abundance of hiding places, fish that are hidden in crevices or under ledges will cause an underestimate of the actual numbers;
- Very difficult to validate the accuracy of any fish counts in aggregations so any interpretations must be made carefully. Repeated analysis of video is one option, but not without error and not suitable for all fish species;
- Size data must be interpreted with care, because estimates of minimum and maximum sizes are approximate;
- Determining sex is only possible for species that have obvious size or colour differences.

Training required:

- Trained for aggregation monitoring; contact the Society for Conservation of Reef Fish Aggregations (SCRFA);
- Observer bias, training in length estimation, recognition of species and spawning behaviour, disruption of fish behaviour by divers are factors to consider. Whenever possible, fishers and other stakeholders should be involved in observer training programs.

Reference:

See Domeier *et al.* (2002); Colin *et al.* (2003) for fisheries dependent data and remote surveillance techniques; www.scrfa.org/

The Nature Conservancy is developing a manual for monitoring grouper spawning aggregations in the Indo Pacific. See www.nature.org

Table 9. Summary of the main monitoring methods used for fishes in the Indo-Pacific region (Middle East, Western Indian Ocean, South Asia, Southeast and East Asia, Wider Pacific Ocean).

Monitoring level	Parameters measured	Method name	Reference and contact	Page
Community Medium Scale	General fish abundance	Fish visual belt census	Reef Check: www.reefcheck.org	82
	Large fish	Large fish belt transect	Samoilys 1997; Wilkinson *et al.* 2003	83
	Butterfly fish	Butterfly fish as reef health indicators	Crosby and Reese 1996: www.coral.noaa.gov/themes/butterfl.pdf	89
Management Medium Scale	Biodiversity & general abundance	Fish visual belt census & Roving diver technique	Global Coral Reef Monitoring Network, English *et al.*, 1997, www.gcrmn.org Jones and Thompson 1978; Kimmel 1985; Rogers *et al.* 1994; Almada-Villela *et al.* 2003	79 78
	Large fish	Large fish belt transect	Samoilys 1997; Wilkinson *et al.* 2003	83
	Biodiversity	Rapid visual belt census	Jones and Thompson, 1978; Kimmel 1985; Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	78
	Fish recruitment	Fish recruitment belt transect	Global Coral Reef Monitoring Network, English *et al.*, 1997, www.gcrmn.org	79
	General fish abundance & size	Fish visual belt census	Global Coral Reef Monitoring Network, English *et al.*, 1997, www.gcrmn.org	79
	Butterfly fish	Butterfly fish reef health indicators	Crosby and Reese 1996: www.coral.noaa.gov/themes/butterfl.pdf	89
	Fish spawning aggregations	Fish spawning aggregations visual census	Society for Coral Reef Fish Aggregations, Domeier *et al.* 2002; Colin *et al.* 2003: www.scrfa.org/	91
Management Fine Scale	Fish herbivory	Fish herbivory imaginary quadrats	Suggest: Atlantic and Gulf Rapid Reef Assessment, Steneck 1985: http://mgg.rsmas.miami.edu/agrra/	-
Research Medium Scale	Aquarium fish	Aquarium fish belt transect	MAQTRAC (Reef Check): www.reefcheck.org	82
	Large fish	Large fish belt transect	Samoilys 1997; Wilkinson *et al.* 2003	83
	Biodiversity	Rapid visual census	Jones and Thompson, 1978; Kimmel 1985; Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	26, 88
	Fish recruitment	Fish recruitment belt transect	Global Coral Reef Monitoring Network, English *et al.*, 1997, www.gcrmn.org	84
Research Fine Scale	Fish spawning aggregations	Fish spawning aggregations visual census	Society for Coral Reef Fish Aggregations, Domeier *et al.* 2002; Colin *et al.* 2003: www.scrfa.org/	91

Table 10. Summary of the main monitoring methods used in the Caribbean and Atlantic for fishes.

Monitoring level	Parameters measured	Method name	Reference and contact	Page
Community Medium Scale	Species diversity & general abundance	Roving diver technique	Reef Environmental Education Foundation: www.reef.org/	78
	General fish abundance	Fish visual belt census	Reef Check: www.reefcheck.org	79
	Large fish	Large fish belt transect	Suggest: Samoilys 1997; Wilkinson *et al.* 2003	83
Management Medium Scale	Species diversity & general abundance	Roving diver technique	Mesoamerican Barrier Reef System Synoptic Monitoring Program: www.mbrs.org.bz; Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/; Caribbean Coastal Marine Productivity Program: www.ccdc.org.jm/caricomp_main.html Jones and Thompson 1978; Kimmel 1985; Rogers *et al.* 1994; Almada-Villela *et al.* 2003	78
	General fish abundance & size	Stationary plot visual census	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/ Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: floridakeys.nos.noaa.gov/; Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html Kimmel 1985; Bohnsack and Bannerot 1986	86
	Large fish	Large fish belt transect	Suggest: Samoilys 1997; Wilkinson *et al.* 2003	83
	Species diversity	Rapid visual census	Jones and Thompson, 1978; Kimmel 1985; Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	88
Management Fine Scale	Fish herbivory	Fish herbivory imaginary quadrats	Atlantic and Gulf Rapid Reef Assessment, Steneck 1985: www.coral.aoml.noaa.gov/agra/	—
Research Medium Scale	General fish abundance & size	Stationary plot visual census	Atlantic and Gulf Rapid Reef Assessment: www.coral.aoml.noaa.gov/agra/; Florida Keys Marine National Sanctuary Coral Reef Monitoring Program: floridakeys.nos.noaa.gov/; Rogers *et al.* 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html Kimmel 1985; Bohnsack; Bannerot 1986	86
	Large fish	Large fish belt transect	Suggest: Samoilys 1997; Wilkinson *et al.* 2003	83
	Species diversity	Rapid visual census	Jones and Thompson, 1978; Kimmel 1985; Rogers et al. 1994: cars.er.usgs.gov/Coral_Reef_Ecology/coral_reef_ecology.html	88
	Fish spawning aggregations	Fish spawning aggregations visual census	Society for Coral Reef Fish Aggregations, Domeier *et al.* 2002; Colin *et al.* 2003: www.scrfa.org/	91

8: MonitoringPhysical Parameters

Monitoring physical parameters complements ecological monitoring where direct changes to the reef are measured. Monitoring the physical environment of coral reefs helps managers to determine the cause of reef degradation or recovery.

Categories discussed here are:

- Water and air temperature;
- Salinity;
- Wind strength and sea state;
- Water quality;
  - Turbidity;
  - Sedimentation.

Water and air temperature

Corals require a water temperature range between18 to 32°C. Temperatures above or below the local range can cause stress to corals. Global Climate Change is causing high sea surface temperatures in El Niño and also La Niña years, which stress corals and cause them to bleach. It is important to monitor water temperature fluctuations to help understand what temperature changes cause corals to bleach and eventually whether they recover or die.

Water temperatures are measured using a mercury thermometer enclosed in protective casing. Temperature readings should be taken in the air, and the water temperature just below the surface and at the depth of your survey. See the GCRMN recommended methods (English *et al.* 1997).

Salinity

Corals prefer a salinity range of 3.2% to 4.2%, and surface salinity can decrease when fresh water is added e.g. floods or pollution from industry, or increase if surface water evaporates. Changes may cause stress to corals therefore it is useful to monitor salinity using a refractometer. Water samples from the surface and survey depth can be collected in sealed plastic containers and the salinity measured on the surface. See GCRMN recommended methods (English *et al.* 1997).

Wind strength and sea state

This is useful when monitoring fish, as abundance of fish at a site changes according to the weather conditions. Categories for measurements are below.

Wind strength category	**Wind strength (knots)**
0	0
1	0-5
2	6-10
3	11-15
4	16-20
5	21-25

Sea state	**Description**
Calm	Mirror-like to small ripples
Slight	Large wavelets, crests breaking
Moderate	Many white caps forming
Rough	Large waves, 2-3 m, white caps

Water quality monitoring is technical and requires a high level of expertise. These methods are not described here; see MBRS SMP manual www.mbrs.org.bz for more information or Wilkinson *et al.* 2003 for explanation.

Water pollution from human land-use is a serious threat to coral reefs around the world, however water quality monitoring can be expensive and requires measuring those pollutants that are released into your area. These may include suspended sediment (below), nutrients (nitrogen and phosphorus compounds), toxic metals (e.g. lead, cadmium and copper), petroleum hydrocarbons (lubrication oils and fuels), pesticides, organochlorine wastes and organic matter.

Turbidity
Turbidity is the amount of suspended sediment and plankton in the water column. Turbidity is often higher following storms when sediments are resuspended in the water column or washed onto the reef from land. Secchi discs are commonly used to measure turbidity. The disc is split into 2 white and 2 black sections and attached to a length of rope with knots at metre distances. The disc is lowered into the water column and the turbidity is measured by the distance at which you can no longer see the disc. Secchi disc measurements should be taken on a clear day within 2 hours of noon (English *et al.* 1997).

Sedimentation
Sedimentation is the sediment load that arrives onto the reef. Sedimentation rates are measured using sediment traps. You can also look at the content of the sediments to determine influx of zooplankton (food for corals etc.).

Monitoring level:
- ✓ Management
- ✓ Research

Parameters that can be surveyed using this method
- ✓ Physical parameters

Scale:
- ✓ Fine

Level of detail:
- ✓ Quantitative

Causes damage to the reef?
- ✓ No

Achievable precision:
- ✓ High

Sedimentation traps

Programs that use this method:
- English *et al.* is the GCRMN recommended method;
- Meso-American Barrier Reef System – Synoptic Monitoring Program (MBRS SMP).

Method description:
This involves attaching a PVC sediment trap to the reef and left for up to 3 months to collect sediments settling on the reef. This method can be used to detect temporal change, for example, impact assessment.

Information obtained:
Measure of sedimentation rates. This is presented as weight of sediment (g) per unit time.

Equipment required:
- PVC pipe with a 5 cm internal diameter, 11.5 cm length and sealed at one end;
- Lid to seal the sediment trap before removal;
- 2-6 baffles at the top of the pipe to stop unwanted animals or objects getting into the tube;
- Drying oven (to 60°C);
- Balance to 1 mg sensitivity.

Field personnel:
- 1 boat driver/surface watch
- 2 scuba divers

Lab personnel:
- Lab technician to process samples;
- Data entry, analysis, interpretation and reporting.

General procedures:
- Hammer steel rods deep into the substratum;
- Attach 3 sedimentation traps to each rod 20 cm above the substrate;
- 4 sets are recommended at 3 m depth. If desired, place 2 additional sets either side of permanent benthic transects or quadrats (‘monitoring benthic communities’ p 27);
- Seal the traps before removal;
- Remove on a 1-3 monthly basis;
- In the lab, filter, dry (at 60°C) and weigh the sample to obtain the dry weight to the nearest milligram.

Advantages:
- Equipment is fairly cheap;
- Quantitative temporal data on sedimentation rates;
- Simple to deploy, collect and process.

Limitations:
- Traps cannot be left for long periods (over 3 months);
- Inefficient in currents with water velocity over 20 cm / second;
- Frequent visits to field sites to collect and replace traps.

Training required:
- Minimal field and lab training

Contact:
Sue English, s.english@aimls.gov.au

Reference:
English *et al.* 1997;
See: www.aims.gov.au and www.gcrmn.org

Also see the MBRS SMP protocol by Almada-Villela *et al.* 2003a; www.mbrs.org.bz and Rogers *et al.* (1994).

9: Monitoring Programs

How do you put a monitoring program together?

A program consists of a selection of monitoring protocols structured around methods that together provide information for effective reef management. The actual protocols and methods that you choose will depend upon the information needed for the specific reef, the size of the area, and the available resources of people, time, equipment and money. There are a number of major programs that use a selection of methods. It may help you to decide by looking at the methods in the major programs.

Major programs

There are major international efforts underway to conserve the coral reefs of the world against a range of damaging threats. These efforts include providing funds and expertise aimed at improving monitoring for all types of coral reefs. The International Coral Reef Initiative (ICRI) started in 1994 and formed the Global Coral Reef Monitoring Network (GCRMN) in 1995 to improve and implement coral reef monitoring in all parts of the coral reef world. One task of the GCRMN is to assist developing countries implement monitoring of reefs, especially in MPAs. Reef Check was formed in 1997 to facilitate volunteer and community monitoring. Another ICRI network is ICRAN (International Coral Reef Action Network) which is stimulating coral reef management, again with a focus on MPAs. They are focusing on key demonstration sites where there is already effective management and monitoring with the aim of assisting nearby regions. There are also regional monitoring programs: CORDIO; AGRRA; CARICOMP.

Data from all monitoring programs can be lodged in the global database, ReefBase, which contains data and considerable information on reefs all over the world (www.reefbase.org). This information is reported in the GCRMN '*Status of Coral Reefs of the World*' reports every 2 years. The use of either Reef Check or GCRMN methodology provides the added advantage of obtaining assistance from these global coral reef monitoring programs, as well as better recognition as part of a global program. Thus it is possible for all MPA managers to link into global and regional networks and gain the benefit of the experience in monitoring methods, protocols, database analyses and reporting in these programs. In turn, your data and experience can contribute to the global effort to conserve coral reefs.

Global Coral Reef Monitoring Programs

- Global Coral Reef Monitoring Network – Management and Research monitoring, p 99;
- Reef Check – Community Monitoring, p 100.

Major regional coral reef monitoring programs

- Atlantic and Gulf Rapid Reef Assessment (AGRRA)
- Caribbean Coastal Marine Productivity Program (CARICOMP)
- Coral Reef Degradation in the Indian Ocean (CORDIO)
- Commission de l'Ocean Indien (COI)
- Mesoamerican Barrier Reef System – Synoptic Monitoring Program (MBRS SMP)
- Florida Keys National Marine Sanctuary Program (FKNMSP)
- NOAA Fisheries Pacific Islands Fisheries Science Center Coral Reef Ecosystem Division (CRED)
- RECON (Reef Condition) of the Ocean Conservancy

The tables on pages 108 to 111 describe the methods used in the major global programs and many of the regional and national monitoring programs.

The Global Coral Reef Monitoring Network

Program description:

The Global Coral Reef Monitoring Network (GCRMN) is an operational unit of the International Coral Reef Initiative (ICRI) reporting on the status of coral reefs and raising awareness on the need for urgent action. The GCRMN is in partnership with ReefBase, Reef Check, and consists of people, governments, institutes and NGOs monitoring coral reefs in 80 countries. It is also a partnership of other monitoring programs including:

- Reef Check;
- Coral Reef Degradation in the Indian Ocean (CORDIO);
- Caribbean Coastal Marine Productivity Program (CARICOMP);
- Atlantic and Gulf Rapid Reef Assessment (AGRRA); and
- Other monitoring programs.

Monitoring level:
- ✓ Management
- ✓ Research

The GCRMN seeks to encourage and coordinate three overlapping levels of monitoring: community, management and research; and functions as a network of independent Regional Nodes that coordinate training, monitoring and databases within participating countries and institutes in regions based on the UNEP Regional Seas Programme.

Protocols used:
- English *et al.* for the Indo-Pacific region (English *et al.* 1997);
- Protocols used by GCRMN partners.

An example of a GCRMN recommended program:

Benthic communities:
- Line intercept transect, 5 x 20 m transects at 3-5 m depth per site; for percent cover estimates, p 33;
- Tagging coral colonies; for detailed information on specific corals affected by bleaching, disease or to measure growth, p 53;
- Coral recruitment tiles; to obtain information on the recovery potential of a reef, p 58.

Invertebrates
- Manta tow, minimum of 9 x 2 minute tows per site; measures the abundance of large invertebrates, such as COTS, giant clams or *Diadema* over a large area; also useful for bleaching studies and site selection, p 22.

Fishes
- Fish belt transects 3 x 50 m in tunnel 5 m wide and 5 m high; for abundance and size estimates of target and ecologically important species p 79;

Physical parameters:
- Sedimentation traps; p 96;
- Water quality. p 96

Scope of program
- Program support;
- Regional database; data are submitted to ReefBase www.reefbase.org
- Standard database format recommended; English *et al.* 1997;
- Standard coding system and data sheet template;
- Data analysis and publication.

Public participation, education and awareness
High. This is achieved at all levels, communities through Reef Check, to managers and scientists through the GCRMN network.

Management support:
The GCRMN assists monitoring by providing manuals, some equipment, databases, training, problem solving and help with finding funds for monitoring. A major product of the GCRMN is the 'Status of Coral Reefs of the World' report that is produced every 2 years; www.aims.gov.au/pages/research/coral-bleaching/scr2002/scr-00.html.

Contact details:
Clive Wilkinson, c.wilkinson@aims.gov.au

Reference: www.gcrmn.org

Reef Check

Program description:

Reef Check was developed in 1996 as a volunteer, community-based monitoring protocol designed to measure the health of coral reefs on a global scale. The aims of Reef Check are to:

- **Educate** the public and governments about the value of coral reefs and the crises facing them;
- **Create** a global network of volunteer teams, trained and led by scientists, that regularly monitor and report on reef health using standard methods;
- **Facilitate** collaborative use of reef health information by community groups, governments, universities and businesses to design and implement ecologically sound and economically sustainable solutions;
- **Stimulate** local action to protect remaining pristine reefs and rehabilitate damaged reefs worldwide.

Monitoring level:
✓ Community

Reef Check is the only global-scale, volunteer-based organisation that measures reef health using standard methods. Teams that can only survey one site should chose the 'best' site with few human impacts; if several sites can be surveyed, they should include representative of the most impacted, moderate and least impacted

Protocols used:

- Reef Check (community monitoring)
- MAQTRAC (research monitoring of the aquarium trade)

An example of a Reef Check program

Any anecdotal information (site description survey).

Benthic communities

- Reef Check point intercept transect; measures the percent cover of benthic communities, p 36;

Key macro-invertebrates

- Reef Check belt transect; measures the abundance of key invertebrates and impacts such as coral bleaching, disease, physical damage and trash.

Fishes

- Reef Check fish belt transect; measures the abundance of key families and species, p 79.

Scope of program:
Global; active in over 60 tropical countries and territories

Program support

- Regional database;
- Standard database
- Standard coding system and data sheet template
- Data analysis and publication

Public participation, education and awareness: High. Participants in Reef Check programs develop a sense of stewardship, and the programs focus on building a global community of reef stakeholders at the grass roots level for better reef management.

Management support:
Reef Check is creating a **web-based interactive database** with ReefBase to assist teams and coral reef managers with data entry and compare with previous data submitted by other teams. The database will also include management recommendations based on local and regional Reef Check data.

Additional information:
Reef Check and the Marine Aquarium Council (MAC) designed an intensive monitoring protocol called 'MAQTRAC' (p 82) to study the effects of aquarium collection on reef health. This monitoring aims to improve collection practices and fish survival rates from the point of collection through to retail sale, and raise awareness among marine aquarium fishermen.

Contact details:
Rcheck@ucla.org, www.reefcheck.org

Atlantic and Gulf Rapid Reef Assessment

Program description:

The Atlantic and Gulf Rapid Reef Assessment (AGRRA) has developed the most extensive regional database on coral reef condition at 720 reef sites in 34 areas in the western Atlantic (Caribbean, Gulf of Mexico, Florida, Bahamas, Brazil). The goals of the AGRRA Project are to:

- Complete a regional assessment of the health of coral reefs throughout the Western Atlantic;
- Analyse the results and develop a database to establish a practical scale of comparative reef condition at multiple spatial scales;
- Promote the transfer of this information to a wider audience including the general public, resource managers, government officials, policy makers, tourist operators, and students;
- Collaborate with colleagues throughout the western Atlantic to establish periodic monitoring of representative reef sites.

Monitoring level:
- ✓ Community
- ✓ Management

Initially, the AGRRA program protocols were not intended to distinguish between cause and effect of reef condition but designed to develop hypotheses on trends of reef decline, particularly across large spatial scales. AGRRA was intended to be a one-time assessment, but now many sites are being re-assessed using these methods as part of regional monitoring. These protocols have been adopted in on-going monitoring programs with the results being widely used by reef scientists and managers.

Protocols of AGRRA:
Benthic communities
- Many line transects for cover, size and condition of coral species (≥25 cm maximum diameter) especially disease, bleaching, predation, overgrowth and mortality, p 33, 51;
- Multiple quadrats on transects for algal abundance (macroalgae, crustose corallines), p 41;

Invertebrates
- Belt transect for *Diadema* abundance (useful in Caribbean following disease with increased algal populations), p 68.

Fishes
- Multiple belt transects for abundance and size of target fishes, number of damselfish lawns;
- Roving diver survey for inventory of most common species, p 78;

Program support:
Standard database template
- Regional database for results of AGRRA surveys
- Standard coding system
- Standard data sheet template
- Data analysis and publication

Public participation, education and awareness:
Formal and informal reporting and publication of results; training of foreign participants in monitoring, report writing, translating educational materials, financial support for field work, outreach with school children and talks; presentations at scientific meetings.

Management support:
Regional training workshops provided

Contact details:
Robert Ginsburg, rginsburg@rsmas.miami.edu
http://mgg.rsmas.miami.edu/agrra

Caribbean Coastal Marine Productivity Program

Program summary:
Two-tier, long-term monitoring of the productivity, structure and functions of coastal ecosystems.

Program description:
The Caribbean Coastal Marine Productivity (CARICOMP) Programme is a regional scientific study of land-sea interaction processes, to monitor for change, and provide appropriate scientific information for management. The Program focuses on understanding the productivity, structure and functions of 3 important coastal ecosystems: mangroves; seagrasses; and reefs. Scientific monitoring of these ecosystems is performed on a daily, weekly and twice annual basis throughout the region using the same monitoring protocol. The long-term monitoring capability of CARICOMP can provide base-line data on Caribbean coastal biodiversity and also document threshold responses of ecosystems to global change including human impact and climate change.

An example of a CARICOMP program:
Benthic communities
- Chain Intercept Transect; CIT, p 54; ;
- Belt transect; to determine the incidence and type of coral disease, p 49;

Monitoring level:
- ✓ Community

Invertebrates
- Belt transect; to determine the abundance of *Diadema*, p 68;
- Collecting *Diadema;* to determine the size-frequency distribution, p 70.

Fish
- Roving Diver Technique; to determine species abundance,p 78.

Program support:
Standard database template
- Regional database for CARICOMP
- Standard coding system
- Standard data sheet template
- Data analysis and publication

Public participation, education and awareness:
Low; principally through reporting of scientific results: operates in marine stations.

Management support:
Reporting of results

Contact details
Dulcie Linton, dmlinton@uwimona.edu.jm

John C. Ogden, jogden@marine.usf.edu, www.ccdc.org.jm/caricomp_main.html

Coral Reef Degradation in the Indian Ocean

Program description:

Coral Reef Degradation in the Indian Ocean (CORDIO) is a regional, multidisciplinary program developed to investigate the ecological and socio-economic consequences of the mass coral bleaching in 1998 and subsequent degradation of coral reefs in the Indian Ocean. This program also coordinates the East African and South Asian Nodes of the GCRMN.

Methods used:

Survey manual for tropical marine resources (English *et al.* 1997)
Reef Check
Commission de l'Ocean Indien (COI).

Program support:

- ❍ Regional database
- ❍ Standard database
- ❍ Standard coding system
- ❍ Standard data sheet template
- ❍ Data analysis and publication

Monitoring level:

- ✓ Community
- ✓ Management
- ✓ Research

Public participation, education and awareness:

Medium; considerable community involvement in other projects.

Management support:

Provision of guidance for management and public awareness

Contact details:
www.cordio.org

Program Co-ordination: Olof Linden, olof.linden@cordio.org and David Souter, david.souter@cordio.org

East Africa: David Obura, david.obura@cordio.org

Islands States: Rolph Payet, rolph@seyshelles.sc

South Asia: Jerker Tamelander, jerker.tamelander@cordio.org

Commission de l'Ocean Indien/Indian Ocean Commission

Program description:

Commission de l'Ocean Indien (COI) established a regional network in 1998 to monitor coral reefs in the South West Indian Ocean islands (Comoros, Madagascar, Mauritius, Réunion and Seychelles). IOC acts as the regional node of the GCRMN for the South West Indian Ocean.

Methods used:

English *et al.* with local adaptations.

Rapid assessments
Snorkel timed swims – broad-medium scale p 31, and Reef Check methods.

Monitoring level:
- ✓ Management
- ✓ Research

Program support
- Regional database(CoReMo II)
- Standard database (CoReMo II)
- Standard coding system
- Standard data sheet template
- Data analysis and publication

Public participation, education and awareness:
- Low. Achieved through reporting of results. Currently planning new stakeholder training in community level monitoring.

Management support:
Provision of regional-scale information on reef health, Low at the local level

Contact details:
COI Secrétariat Général, Recif_members@coi.intnet.mu

References:
coi.intnet.mu/
Conand *et al.* 1999; Conand *et al.* 2000.

Mesoamerican Barrier Reef System – Synoptic Monitoring Program

Program summary:

Long-term, four-tier regional monitoring program

Program description:

The Mesoamerican Barrier Reef System – Synoptic Monitoring Program (MBRS SMP) was designed for long-term monitoring to include physical and biological components reflected in the core themes of: Coral reef ecology; Marine pollution; and Physical oceanography

The MBRS SMP has 4 categories with different detail collected by each method:

- Category 1 is baseline level monitoring, using the smallest set of parameters of all program categories. It is expected that more sites can be monitored using these techniques and these sites can be monitored more frequently e.g. between 2 and 6 times per year;
- Category 2 is medium-term analyses to track changes in coral mortality and water quality over short time scales; more sites are being added;
- Category 3 is annual monitoring designed to track long-term changes;
- Category 4 is rapid assessment designed to assess the affects of specific disturbances at impact sites.

Monitoring level:
- ✓ Management
- ✓ Research

An example of an MBRS SMP program:

Benthic communities:
- Point intercept transect; to determine % cover of benthic organisms below every 25 cm; records coralline algae, turf algae, macroalgae, sponges, gorgonians, specific coral genera, dead corals (recent and long dead), bleached and diseased coral, p 36;
- Recruitment plates; to determine the recovery potential of a reef, p 56;

Invertebrates:
- *Diadema* survey; to determine the abundance of Diadema, based on AGRRA methods, p 68.

Fishes:
- Fish belt transect, based on AGRRA methods, p 79.

Physical parameters:
- Sedimentation traps; to determine sedimentation rates, p 96;
- Water quality, sediment and tissue pesticide levels; PAH metabolites in bile; cholinesterase activity in muscle; nutrient concentration and total and faecal coliform concentration in water.

Program support:
- Data management
- Standard web-based database template
- Regional database for MBRS SMP Regional Environmental Information System REIS
- Standard coding system and data sheet template
- Data analysis and publication

Public participation, education and awareness:
Low. Achieved through reporting of results.

Management support:
Reporting of results

Contact details:
Alejandro Arrivillaga, aarrivillaga@mbrs.org.bz or mbrs@btl.net, www.mbrs.org.bz;

Methods www.mbrs.org.bz/dbdocs/tech/SMPMan03.pdf

Reef Condition (RECON) Monitoring Program.

Program description:

The Ocean Conservancy developed Reef Condition (RECON), a volunteer, low-tech, rapid monitoring program, to document overall reef status and the health of key reef organisms in the tropical Western Atlantic. RECON is focused on important stressors (e.g. diseases, algal overgrowth) in the wider Caribbean region, and was designed to allow high spatial and temporal coverage. Survey sites are selected by experienced RECON divers and classified by reef type, orientation, structural complexity and dominant framework corals to facilitate between-site comparisons. RECON complements the REEF fish program, Reef Check, and other reef monitoring programs. When RECON divers work in small teams, repeat dives are needed to provide sufficient data for statistical analysis. The goal is for rapid reporting of findings to reef managers or scientists.

RECON volunteers monitor:

- size, percent mortality, and bleaching in large (> 25 cm) coral colonies;
- identity of major stresses to these corals;
- % cover of corals and macroalgae;
- relative abundance of algal functional groups and identity of major macroalgae;
- density of *Diadema* sea urchins, spiny lobsters (*Panulirus* spp.) and queen conch (*Strombus gigas*);
- relative density of new coral recruits;
- obvious stresses to corals, gorgonians, zoanthids, sponges (bleaching, disease, algal overgrowth); and
- obvious human impacts (abandoned fishing gear, other debris, and anchor scars).

Protocols of RECON:

Preselected massive stony corals

- Size and condition of colonies (≥25 cm maximum diameter) especially partial mortality, bleaching, disease, predation, and overgrowth, p 45.

Benthic communities and Invertebrates

- Line transects for stony coral and macroalgal cover, p 45;
- Belt transects for *Diadema* abundance, spiny lobsters and queen conch, abundance of macroalgae, information on bleaching, disease and obvious human impacts, p 68.

Monitoring level:
✓ Community by volunteers

Program support:

- Standard training materials (currently print; CD in revision)
- Standard database template (in revision);
- Standard coding system;
- Standard data sheet template;
- Data analysis, publication and website (in development).

Public participation, education and awareness:

- Medium in Caribbean

Management support:
Local diver and instructor training workshops provided

Contact details:
Email: Seba Sheavly ssheavly@oceanconservancyva.org
www.oceanconservancy.com/recon

Appendices

1: How to do a pilot study?

What sample size and number do you need to gain maximum precision at least cost? Andrew and Mapstone 1987 suggest that a minimum of 3 sampling-unit sizes should be assessed in a pilot study. If multiple habitats or locations are to be sampled, the procedure should be repeated in more than one area to account for spatial variation (Mapstone and Ayling 1993).

To determine your optimum sample method you could follow a similar procedure to that provided in the example below:

To determine sample method size:

- Select a number of sites on your reef of interest;
- Select a number of random locations within this site to place your sample method (e.g. a transect);
- Conduct your sampling using a range of sample method sizes. If you are using a transect, conduct the sampling with a long transect (e.g. 50 m) then take the data from the first 10 m, 20 m and so on to compare the precision between different sample method sizes; avoid taking multiple contiguous small units from the sample large transects (pseudoreplication) because samples must be independent for statistical analyses;
- Calculate the mean precision and standard error (SE) for your data from the range of transect lengths;
- Plot the mean precision +/-SE against transect length;
- The transect size with the highest precision (lowest number) is the best for sampling length;

To determine how many replicates to use:

- Sample a few more replicates than you think you will use; (the standard methodsin this book give an idea of how many replicates might be enough). Calculate the SE or P for your replicates in cumulatively increasing number. Plot a graph to show the number of transects against a range of precision (e.g. 0.5, 0.2, 0.1, 0.05 and 0.01). You should aim for a precision of 0.05;
- The point where the slope of the graph levels out is the least cost for maximum precision.

$$SE = \frac{s}{x}$$

$$P = \frac{s}{\sqrt{n}}$$

SE = standard error; s = standard deviation; $\bar{x}$ = mean; n = sample size; P = precision (as P gets smaller, precision increases); From Kingsford 1988

In addition to sample method size and number of replicates, the shape may need to be assessed in some situations. Concerns include the influence of border effects, for example with round versus square units and where broad areas are being searched, organisms may be missed and this is a major concern in transect counts for fish and other cryptic or mobile animals (Kingsford 1988).

Other useful references:
Sale and Sharp 1983; Downing and Anderson 1985; Andrew and Mapstone 1987; Oxley 1997

2: Generic monitoring equipment

Typical monitoring equipment:

- Tide tables;
- Underwater slates (large enough to fix data sheets onto them e.g. A4);
- Data sheets (printed on underwater paper). These can be attached to the slate using electrical tape or rubber bands;
- Several pencils;
- Scuba gear or Snorkel gear;
- Radio;
- First Aid equipment that is suitable for snorkel or scuba diving;
- Boat, outboard engine;
- GPS (it is essential to note the system your GPS uses e.g. WGS 84);
- Dive flag and surface marker buoy.

Table 11. The major coral reef monitoring programs and the methods employed in regions (more than one country).

Geographic region	Program name	Methods used	Reference	Contact	Page
Global	Global Coral Reef Monitoring Network (GCRMN)	GCRMN recommended methods include English *et al.* & other major programs below	www.gcrmn.org	Clive Wilkinson, c.wilkinson@aims.gov.au	99
Global	Reef Check	Reef Check methods	www.reefcheck.org	Gregor Hodgson, gregorh@ucla.edu	101
Global	ReefBase	Repository for all coral reef monitoring methods	www.reefbase.org	Jamie Oliver, j.oliver@cgiar.org	-
Indian Ocean	Coral Reef Degradation in the Indian Ocean (CORDIO)	Reef Check, COI, GCRMN recommended English *et al.* methods	www.cordio.org	olof.linden@cordio.org; david.souter@cordio.org; Rolph Payet, rolph@seyshelles.sc; jeanpascal.quod@cordio.org	103
Indian Ocean	Commission de l'Ocean Indien (COI)	COI methods and *English *et al.* methods	www.coi.intnet.mu/	COI Secrétariat Général, Recif_members@coi.intnet.mu	104
Caribbean	Atlantic and Gulf Rapid Reef Assessment (AGRRA)	AGRRA methods	www.coral.aoml.noaa.gov/agra/	Robert Ginsburg, rginsburg@rsmas.miami.edu; agrra@rsmas.miami.edu	101
Caribbean	Caribbean Coastal Marine Productivity Program (CARICOMP)	CARICOMP methods	www.ccdc.org.jm/caricomp_main.html	Dulcie Linton, dmlinton@uwimona.edu.jm; John Ogden, jogden@marine.usf.edu	102
Caribbean	Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS SMP)	MBRS SMP methods (similar to CARICOMP and AGRRA)	www.mbrs.org.bz	Alejandro Arrivillaga, aarrivillaga@mbrs.org.bz or mbrs@btl.net	105

Table 12. A selection of National coral reef monitoring programs and the methods as provided by respondents to the Questionnaire

Geographic region/country	Program name	Monitoring level	Methods used	Reference and contact	
Tanzania	Chumbe Island Coral Park monitoring program	Community	Reef Check methods	www.reefcheck.org	Carol Daniels, info@chumbeisland.com
		Management	❍ English *et al.*	English *et al.*, 1997; www.gcrmn.org	
		Research	General coral health: Radial arc method	Santavy *et al.* 2001	
	Frontier	Community	Frontier methods	www.frontier.ac.uk	frontier@raha.com
	Wildlife Conservation Society	Research	WCS line transect & circular invertebrate method	www.wcs.org	Tim McClanahan, tmcclanahan@wcs.org or crcp@africaonline.co.ke
India	Status surveys of coral reefs in India	Management	❍ English *et al.*	English *et al.*, 1997, www.gcrmn.org	K. Venkataraman, dugong@md2.vsnl.net.id, venkyszi@hotmail.com
Iran	Monitoring of the Iranian Coral Reefs in N Persian Gulf	Community	Reef Check methods & Manta tow	www.reefcheck.org; English *et al.*, 1997,	Mohammad Reza Shokri, mrshok@hotmail.com
Indonesia	COREMAP	Community	Reef Check methods	www.coremap.or.id	
	Komodo National Park Coral Reef Status Monitoring	Management	Benthos: Komodo timed swim and point intercept transect	www.komodonationalpark.org	Andreas Muljadi, amuljadi@cbn.net.id, ah_Muljadi@yahoo.com Peter Mous, pmous@tnc.org
Philippines	Coastal Resource Management Project (CRMP)	Community	CRMP and Reef Check methods	Uychiaoco *et al.* 2001 www.oneocean.org/download/_index.html	
	Coral Cay Conservation (CCC)	Community	CCC and Reef Check methods	www.coralcay.org www.reefcheck.org	
Malaysia (Sabah)	Coral Reef Monitoring of Tunku Abdul Rahman Park	Management	Benthos: TRAP transects and quadrats	Simon Wilson, simon.wilson@adelphi-env.com	
Taiwan	Survey on the Status of coral Reefs in Taiwan	Community	Reef Check methods	www.reefcheck.org	Chang-feng Dai, corallab@ccms.ntu.edu.tw
	Status of the coral reefs in the Gulf of Thailand and the Andaman Sea	Community	Reef Check methods	www.reefcheck.org	Chang-feng Dai, corallab@ccms.ntu.edu.tw
		Management	❍ English *et al.* methods	English *et al.*, 1997, www.gcrmn.org	Sakanan Plathong, psakanan@ratree.psu.ac.th
Samoa	Long-term Monitoring Program for the Coral Reefs of American Samoa	Research and management	Benthos: Pacific point intercept transect	Choat and Bellwood 1985; Green 1996b; Green 1996a; Green 2002	Samoa program: Alison Green, agreen@tnc.org or Fishes methods: Howard Choat, howard.choat@jcu.edu.au
			Invertebrates: Belt transect	Green 1996b	
			Fishes: a.Samoan fish visual census; b.Large fish belt transect; c.Fish recruitment	a. Green 1996b; b.Samoilys 1997; Wilkinson *et al.* 2003; c.Green 1996b	

Central Pacific		Research and management	As above	As above Dave Fisk, davefisk@ipasifika.net	
Hawaii	Hawaii Coral Reef Assessment and Monitoring Program (CRAMP)	Research	Broad scale: Rapid Assessment technique (RAT)	Jokiel *et al.* 2001 www.cramp.wcc.hawaii.edu	
			Benthos: Photo quadrats Video transects		
			Fishes: Visual census		
Northwestern Hawaiin Islands	NOWRAMP Remote Area REA Protocol	Research	NOWRAMP methods	Maragos and Gulko 2002 www.hawaiianatolls.org/research/NOWRAMP2002	Jim Maragos Jim_Maragos@r1.fws.gov
Northern Mariana Islands	CNMI Nearshore Coral Reef Monitoring Program	Research	Benthos: CNMI photo point intercept transect	Houk 2001 www.deq.gov.mp/MMT/Reef.htm	Peter Houk, deq.biologist@saipan.com
			Invertebrates: CNMI belt transect		
			Fishes: CNMI belt transect		
			Physical parameters: CNMI sediment traps		
	Marine Sanctuaries Monitoring and Assessment	Management	*English *et al.* methods	English *et al.*, 1997, www.gcrmn.org	Micheal Trianni, mstdfw@itecnmi.com
New Caledonia	Mining impact monitoring program	Management	*English *et al.* methods	English *et al.*, 1997, www.gcrmn.org	Sarramegna Sebastien, ssarramegna@falconbridge.nc
Fiji	Coral Cay Conservation (CCC)	Community	CCC & Reef Check methods	www.coralcay.org www.reefcheck.org	
USA (Florida)	Florida Keys Marine National Sanctuary Coral Reef Monitoring Program	Community	Benthos: Coral spawning & ReefKeeper point intercept	Spawning: www.fknms.nos.noaa.gov Point intercept: www.reefkeeper.org	Point intercept: Alexander Stone, reefkeeper@earthlink.net Spawning: Alina Szmant, szmanta@uncwil.edu
			Invertebrates: Spiny lobster monitoring Queen conch Sea urchins	Lobster: John Hunt, john.hunt@fwc.state.fl.us Conch: Bob Glazer bob.glazer@fwc.state.fl.us Urchins: Brian Keller (Sea Stewards), brian.keller@noaa.gov	
			Fishes: Roving Diver Technique (Reef Environmental Education Foundation)	www.reef.org	reefhq@reef.org
		Research	Benthos: Video transect	John Ogden, jogden@marine.usf.edu	
			Invertebrates: Urchin and damselfish	Brian Keller, brian.keller@noaa.gov	
			Fishes: Fish cleaner station methods	Brian Keller, brian.keller@noaa.gov	

USA, Broward County Florida	Broward County Biological Monitoring Program	Research	Benthos: a.Broward photo belt transects Fishes: b.Broward belt transect; c.Stationary plot visual census Physical parameters: d.Broward sediment traps	a.Gilliam *et al.* 2003 b.Bohnsack and Bannerot 1986 c.Eric Myers, emyers@broward.org d.Lou Fisher, lfisher@broward.org	
USA, Flower Garden Banks	Long-term Monitoring of the Flower Garden Banks (FGB) National Marine Sanctuary	Research	Benthos: FGB photo transect and video transect methods Invertebrates: FGB belt transect Fishes: Stationary visual technique	Sanctuary: http://flowergarden.noaa.gov/ Technical reports: http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html & http://mmspub.mms.gov:81/search.html	James Sinclair, James.Sinclair@mms.gov
San Andres	CORALINA	Community	a.Reef Check methods b.Reef Environmental Education Foundation methods c.RECON methods	www.coralina.org/ a.www.ReefCheck.org b.www.reef.org c.www.oceanconservancy.org	Elizabeth Taylor, oralsai@col1.telecom.com.co
		Management	a.Caribbean Coastal Marine Productivity Program methods b.SIMAC methods (INVEMAR) Rapid Ecological Assessment methods	a.www.ccdc.org.jm/caricomp_main.html b.www.invemar.org.co	
Colombia	National Monitoring System for the Coral Reefs of Colombia (SIMAC)	Community	Reef Check methods	www.reefcheck.org	Jaime Garzón Ferreira, Alberto Rodríguez Ramírez, www.invemar.org.co
		Management	CARICOMP methods	www.ccdc.org.jm/caricomp_main.html	
Costa Rica	Monitoreo del Caribe Sur de Costa Rica	Management	CARICOMP & AGRRA methods	www.ccdc.org.jm/caricomp_main.html www.coral.aoml.noaa.gov/agra/	Jorge Cortes, jcortes@cariari.ucr.ac.cr
Netherlands Antilles	Porto Mari Reef Ball Project	Community	Reef Check methods	www.reefcheck.org	Paul Spiertz, paul@portomari.com
Brazil	Projeto de Monitoramento dos Recifes Brasileiros	Community	Reef Check methods	www.reefcheck.org	Beatrice Padovani Ferreira, beatrice@ibama.gov.br
Caribbean	Reef Condition Monitoring Program (RECON)	Community	General coral health: RECON methods	www.oceanconservancy.org/dynamic/getInvolved/events/coral/coral.htm	Seba Sheavly, ssheavly@oceanconservancyva.or
	ReefKeeper	Community	Benthos: ReefKeeper point intercept transect	www.reefkeeper.org	Alexander Stone, reefkeeper@earthlink.net
	Sea Stewards	Community	Sea Stewards methods	Mary Enstrom, menstrom@tnc.org	

*GCRMN recommend English *et al.* methods

References

Almada-Villela, PC, PF Sale, G Gold-Bouchot and B Kjerfve (2003a). Conservation and Sustainable Use of the Mesoamerican Barrier Reef Systems Project (MBRS). In Manual of methods for the MBRS Synoptic Monitoring Program: Selected methods for monitoring physical and biological parameters for use in the mesoamerican region. Belize City, Belize City, MBRS Coordination Unit: pp. 155.

Almada-Villela, PC, PF Sale, G Gold-Bouchot and B Kjerfve (2003b). Manual of Methods for the MBRS Synoptic Monitoring Program: Selected Methods for Monitoring Physical and Biological Parameters for Use in the Mesoamerical Region. Belize City, MBRS Coordination Unit: pp. 155.

Andrew, NL and BD Mapstone (1987). Sampling and the Description of Spatial Patterns in Marine Ecology. Oceanographic Marine Biology Annual Review 25: 39-90.

Aronson, RB (2001). The Limits of Detectability: Short-Term Events and Short-Distance Variation in the Community Structure of Coral Reefs. Bulletin of Marine Science 69: 331-332.

Ault, JS, SG Smith, GA Meester, J Luo and JA Bohnsack (2001). Site Characteristics for Biscayne National Park: Assessment of Fisheries Resources and Habitats. NOAA Technical Memorandum NMFS-SEFSC-468: pp.165.

Ault, JS, SJ Smith, GA Meester, J Luo, JA Bohnsack and SL Miller (2002). Baseline Multispecies Coral Reef Fish Stock Assessment for Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487: pp. 117.

Bass, DK and IR Miller (1998). Crown-of-Thorns Starfish and Coral Surveys Using the Manta Tow and Scuba Search Techniques. Long-term Monitoring of the Great Barrier Reef. Standard Operations Procedure Number 1, www.aims.gov.au/pages/research/reef-monitoring/methods.html.

Bohnsack, JA and SP Bannerot (1986). A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes. NOAA Technical Report NMFS 41: 1-15.

Brock, RE (1982). A Critique of the Visual Census Method for Assessing Coral Reef Fish Populations. Bulletin of Marine Science 18: 297-276.

Brock, VE (1954). A Preliminary Report on a Method of Estimating Reef Fish Populations. Journal of Wildlife Management 18: 297-308.

Brown, E, E Cox, BN Tissot, K Rodgers, W Smith, P Jokiel and S Coles (2000). Evaluation of Benthic Sampling Methods Considered for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawai'i, http://cramp.wcc.hawaii.edu/overview/3._methods.

Bruckner, AW (2002). Priorities for Effective Management of Coral Diseases, U.S. Department of Commerce. NOAA Technical Memorandum NMFS-OPR-22: pp. 49.

Bruckner, AW and RJ Bruckner (1997). The Persistence of Black-Band Disease in Jamaica: Impact on Community Structure. Proceedings, 8th International Coral Reef Symposium, Panama, 601-606.

Bunce, L, P Townsley, R Pomeroy and R Pollnac (2000). Socioeconomic Manual for Coral Reef Management, Global Coral Reef Monitoring Network and Australian Institute of Marine Science Townsville Australia: pp. 251.

Carleton, JH and TJ Done (1995). Quantitative Video Sampling of Coal Reef Benthos: Large Scale Application. Coral Reefs 14; 35-46.

Choat, JH and DR Bellwood (1985). Interactions Amongst Herbivorous Fishes on a Coral Reef: Influence of Spatial Variation. Marine Biology 89: 221-234.

Cohen, J (1988). Statistical Power Analysis for the behavioural sciences (2nd Edition). Hillsdale. New Jersey: L. Erlbaum Association.

Colin, PL, YJ Sadovy and ML Domeier (2003). Manual for the Study and Conservation of Reef Fish Spawning Aggregations, Society for the Conservation of Reef Fish Aggregations Special Publication No. 1 (Version 1.0).

Conand, C, P Chabanet, J-P Quod and L Bigot (1999). Guidelines: Coral Reef Monitoring in the South-West Region of the Indian Ocean. Indian Ocean Commission and the Regional Environmental Programme, Mauritius: pp. 27.

Conand, C, P Chabanet, J-P Quod and L Bigot (2000). Manuel Methodologique Pour Le Suivi De L'etat De Sante Des Recifs Coralliens Du Sud-Ouest De L'ocean Indien. Commission Ocean Indien, Mauritius: pp. 27.

Crosby, MP and ES Reese (1996). A Manual for Monitoring Coral Reefs with Indicator Species: Butterflyfishes as Indicators of Change on Indo-Pacific Reefs. Silver Spring, MD, Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration: pp. 45.

Domeier, ML, PL Colin, TJ Donaldson, WD Heyman, JS Pet, M Russell, Y Sadavoy, MA Samoilys, A Smith, BM Yeeting and S Smith (2002). Transforming Coral Reef Conservation: Reef Fish Spawning Aggregations Component. Working Group Report: pp. 85.

Donnelly, R, D Neville and PJ Mous, Eds. (2003). Report on a Rapid Ecological Assessment of the Raja Ampat Islands, Papua, Eastern Indonesia, held October 30 - November 22, 2002, The Nature Conservancy Southeast Asia Center for Marine Protected Areas, Sanur, Bali Indonesia: pp. 249, www.komodonationalpark.org

Downing, JA and MR Anderson (1985). Estimating the Standing Biomass of Aquatic Macrophytes. Canadian Journal of Fisheries and Aquatic Science 42: 1860-1869.

Edmunds, PJ, RB Aronson, DW Swanson, DR Levitan and WF Precht (1998). Photographic Versus Visual Census Techniques for the Quantification of Juvenile Corals. Bulletin of Marine Science 62: 937-947.

English, S, C Wilkinson and V Baker (1997). Survey Manual for Tropical Marine Resources. Townsville, Australia, Australian Institute of Marine Science, Townsville Australia: pp. 378

Gilliam, DS, RE Dodge, RE Spieler, MS Jordan and AV Jaime (2003). Marine Biological Monitoring in Broward County, Florida. Year 3 Annual Report. Prepared for Broward County Board of County Commissioners., Department of Planning and Environmental Protection, Biological Resources Division. Fort Lauderdale, Florida: pp. 62.

Green, AL (1996a). Spatial, Temporal and Ontogenetic Patterns of Habitat Use by Coral Reef Fishes (Family Labridae). Marine Ecology Progress Series 133: 1-11.

Green, AL (1996b). Status of the Coral Reefs of the Samoan Archipelago. Report to the Department of Marine and Wildlife Resources. PO Box 3730, Pago Pago, American Samoa. 96799: 120.

Green, AL (2002). Status of Coral Reef on the Main Volcanic Islands of American Samoa: A Resurvey of Long-term Monitoring Sites (Benthic Communities, Fish Communities, and Key Macroinvertebrates). A Report Prepared for the Dept of Marine and Wildlife Resources. Pago Pago, American Samoa. 96799: 133.

Green, EP, PJ Mumby, AE Edwards and CD Clark (2000). Remote Sensing: Handbook for Tropical Coastal Management. Paris, UNESCO Publishing: pp. 316, http://www.unesco.org/csi/pub/source/rs.htm

Halford, AR and AA Thompson (1994). Visual Census Surveys of Reef Fish. Standard Operational Procedure Number 3. Long-term Monitoring of the Great Barrier Reef. Townsville, Australian Institute of Marine Science. Townsville Australia: pp 22, http://www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop3/fishsop.pdf

Hallacher, L. E. and B. N. Tissot, 1999. Quantitative Underwater Ecological Survey Techniques: A coral reef monitoring workshop. Chapter13 in: Maragos, J. E. and R. Grober-Dunsmore (eds.). Proceedings of the Hawai'i Coral Reef Monitoring Workshop, Dept. of Land and Natural Resources, Honolulu, HI. http://www.coralreefnetwork.com/quest/methods.htm

Hodgson, G (2003). Reef Check Instruction Manual, Reef Check Foundation, http://www.reefcheck.org/infocenter/publications.asp

Houk, P (2001). State of the Reef Report for Saipan Island, Commonwealth of the Northern Mariana Islands. Saipan, CNMI, Division of Environmental Quality. http://www.deq.gov.mp/MMT/Saipan%20Final%20Report.pdf

Jokiel, PL, EK Brown, A Friedlander, SK Rodgers and WR Smith (2001). Hawaii Coral Reef Initiative Coral Reef Assessment and Monitoring Program (Cramp) Final Report 1999-2000. HCRI and NOAA Technical Report. Silver Spring, MD: pp. 66.

Jones, GP and UL Kaly (1995). Criteria for Selecting Marine Organisms in Biomonitoring Studies. Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. RJ Schmitt and CW Osenberg. San Diego, Academic Press: pp. 39-56.

Jones, RS and MJ Thompson (1978). Comparison of Florida Reef Fish Assemblages Using a Rapid Visual Technique. Bulletin of Marine Science 28: 159-172.

Kaly, UL and GP Jones (1997). Minimum Sampling Design for Detecting the Magnitude and Scale of Human Impacts on Coral Reefs. Proceedings, Eighth International Coral Reef Symposium, Panama: pp. 1479-1484.

Kimmel, JJ (1985). A New Species-Time Method for Visual Assessment of Fishes and Its Comparison with Established Methods. Environmental Biology of Fishes 12: pp. 23-32.

Kingsford, MJ (1988). Analytical Aspects of Sampling Design. Studying Temperate Marine Environments: A Handbook for Ecologists. MJ Kingsford and C Battershill. Canterbury, Canterbury University Press: pp. 49.

Lincoln-Smith, MP, J Bell, P Ramohia and KA Pitt (2001). Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Termination Report. Great Barrier Reef Marine Park Authority Research Publication No. 69; ACIAR Project No. FIS/1994/117; ICLARMN Contribution No. 1609: pp. 72.

Mapstone, BD and AM Ayling (1993). An Investigation of Optimum Methods and Unit Sizes for the Visual Estimation of Abundances of Some Coral Reef Organisms. A report to the Great Barrier Reef Marine Park Authority, Townsville Australia: pp. 71.

Maragos, J and D Gulko (2002). Coral Reef Ecosystems of the Northwestern Hawaiian Islands: Interim Results Emphasizing the 2000 Surveys. U.S. Fish and Wildlife Service and the Hawai'i Department of Land and Natural Resources. Honolulu, Hawai'i. www.hawaii.edu/ssri/hcri/files/nwhi_report_1of4.pdf

Marshall, P and H Schuttenberg, Eds. (2004). A Reef Managers Guide to Coral Bleaching, National Oceanic and Atmospheric Administration (NOAA), Great Barrier Reef Marine Park Authority (GBRMPA) and The World Conservation Union (IUCN). (in press).

Meester, GA, JS Ault and JA Bohnsack (1999). Visual Censusing and the Extraction of Average Length as a Biological Indicator of Stock Health. Naturalista sicil XX111 (Suppl.)(205-222).

Meesters, EH, I Wesseling and RPM Bak (1996). Partial Mortality in Three Species of Reef-Building Corals and the Relation with Colony Morphology. Bulletin of Marine Science 58: 838-852.

Oxley, WG (1997). Sampling Design and Monitoring. In: English et al, Survey Manual for Tropical Marine Resources. Townsville, Australian Institute of Marine Science: pp. 307-326.

Page, C, G Coleman, R Ninio and K Osborne (2001). Long-term Monitoring of the Great Barrier Reef Standard Operational Procedure Number 7, Australian Institute of Marine Science, Townsville Australia pp. 45. http://www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop7/sop7-2001a.html

Rogers, CS, G Garrison, R Grober, ZM Hillis and MA Franke (1994). Coral Reef Monitoring Manual for the Caribbean and Western Atlantic. St. John, USVI, Virgin Islands National Park: pp. 106.

Rogers, CS and J Miller (1999). Coral Bleaching, Hurricane Damage, and Benthic Cover on Coral Reefs in St John, U.S. Virgin Islands: A Comparison of Surveys with the Chain Transect Method and Videography. Proceedings of the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration. Bulletin of Marine Science 69: 459-470.

Russ, GR (1996). Do Marine Reserves Export Adult Fish Biomass? Evidence from Apo Island, Central Philippines. Marine Ecology Progress Series 132: 1-9.

Russ, GR (2002). Marine Reserves as Reef Fisheries Management Tools: Yet Another Review. San Diego, Academic Press. pp. 421-443.

Russ, GR and AC Alcala (1996). Marine Reserves: Rates and Patterns of Recover and Decline in Abundance of Large Predatory Fish. Ecological Applications 6: 947-961.

Russ, GR and JH Choat (1988). Reef Resources: Survey Techniques and Methods of Study, South Pacific Commission/Inshore Fishery Research/WP.10.

Sale, PF and BJ Sharp (1983). Correction for Bias in Visual Transect Censuses of Coral Reef Fishes. Coral Reefs 2: 37-42.

Samoilys, MA (1997). Manual for Assessing Fish Stocks on Pacific Coral Reefs, Department of Primary Industries, Queensland.

Santavy, DL, E Mueller, EC Peters, L MacLaughlin, JW Porter, KL Patterson and J Campbell (2001). Quantitative Assessment of Coral Reef Diseases in the Florida Keys: Strategy and Methodology. Hydrobiologia 460: 39-52.

Segal, PF and CB Castro (2001). A Proposed Method for Coal Cover Assessment: A Case Study in Abrolhos, Brazil. Bulletin of Marine Science 69: 487-496.

Steneck, RS (1985). Adaptations of Crustose Coralline Algae to Herbivory: Patterns in Space and Time, Pages 352-366. In Toomy D and M. Nitecki (eds). Paleoalgology. Springer - Verlag. Berlin.

Tomkins, PA, DK Bass, DA Ryan and H Sweatman (1999). Video Identification of Benthic Organisms: How Accurate Is It? Proceedings of the International Conference on Science. Aspects of coral reef assessment and monitoring, and rest., April 14-16, 1999, Ft Lauderdale, FL.

Underwood, AJ (1994). On Beyond BACI: Sampling Designs That Might Reliably Detect Environmental Disturbances. Ecological Applications 4: pp. 3-15.

Underwood, AJ (1995). Detection and Measurement of Environmental Impacts. In: Coastal Marine Ecology of Temperate Australia, University of NSW Press.

Uychiaoco, AJ, SJ Green, MT Dela Cruz, PA Gaite, HO Arceo, PM Alino and AT White (2001). Coral Reef Monitoring for Management, University of the Philippines Marine Science Institute, United Nations Development Programme Global Environment Facility-Small Grants Program, Guiuan Development Foundation, Inc., Voluntary Service Overseas, University of the Philippines Center for Integration and Development Studies, Coastal Resource Management Project, and Fisheries Resource Management Project: pp. 110

Vogt, H, ARF Montebon and MLR Alcala (1997). Underwater Video Sampling: An Effective Method for Coral Reef Surveys? Proceedings, 8th International Coral Reef Symposium, Smithsonian Tropical Research Institute, Panama: 2, pp. 1447-1452

Wells, SM (1995). Reef Assessment and Monitoring Using Volunteers and Non-Professionals. Publication of Rosenstiel School of Marine and Atmospheric Science, University of Miami, USA: pp. 57.

Wilkinson, C (2002). The Status of the Coral Reefs of the World: 2002. Townsville, Australia, Australian Institute of Marine Science and the Global Coral Reef Monitoring Network: pp. 378.

Wilkinson, C, A Green, J Almany and S Dionne (2003). Monitoring Coral Reef Marine Protected Areas. A Practical Guide on How Monitoring Can Support Effective Management of MPAs. Townsville, Australia, Australian Institute of Marine Science and the IUCN Marine Program: pp. 68

Zar, J (1999). Biostatistical Analysis, Upper Saddle River, New Jersey: Prentice-Hall.

Glossary of terms

The definitions below are those that we use throughout this book.

Accuracy	An accurate measurement is one that gives the correct value (without error or within an acceptable level of error), e.g. if 32% hard coral cover is recorded and the survey is accurate, then the actual coral cover on your reef is 32% (with an error range of +/- 2-5%).
Benthos	The animals and plants attached to the reef bottom.
Community monitoring	The monitoring level that involves the collection of lower detail information; this means a larger area can be covered for less cost and less time. This usually involves data collectors with a lower level of expertise.
Dependent replicate	A replicate is considered dependent of another if it is very close, e.g. < 5 m, or overlapping with another.
Ecological monitoring	Ecological monitoring includes the natural environment (biological and physical) e.g. the fish, coral or sedimentation.
Habitat	This is a particular reef zone; a particular depth and type of reef community structure or particular mix of animals and plants found together on the reef.
Haphazard site selection	This is a form of non-random sampling. First the habitat you want to survey is found, and then the position of the sampling is selected. The exact sample position is chosen by convenience, e.g. it is easy to find again for monitoring, there is sufficient area of chosen habitat to place all replicates, or it is easy to get to, such as near a mooring.
Independent replicate	A replicate is considered independent of another when the animals and plants inside of it are not influenced by other replicates. This means that replicates need to be separated by some distance, e.g. 5-10 m. This distance is specified in the method protocol.
Management monitoring	This level adds more detail than community monitoring and will cost more, take more time and reduce the area covered. Management monitoring protocols are aimed at providing the best information for MPA management.
Method	A method is the description of how the information is collected, e.g. line or point intercept transect.
Method family	A method family is the type of method, e.g. transects, quadrat or timed swim.
Monitoring	This is where surveys are repeated over time.
Monitoring level	This is the level of detail and the level of personnel expertise used to collect information. The definitions used in this book are **community monitoring**, **management monitoring** and **research monitoring**.
Monitoring program	A monitoring program consists of series of monitoring protocols that together provide a manager with the information needed to manage reefs.
Nested sampling design	Nested designs have multiple levels, e.g. replicate samples, sites and location where the replicates are unique to a particular site, which is unique to a particular location.
Parameters	These are the 'thing(s)' that you are measuring, e.g. hard coral or algae.
Precision	Data are precise when the same or very similar results are obtained when the survey is repeated immediately. Precision is more important than accuracy in coral reef monitoring. If methods provide precise data then differences in the results from one survey to the next can be interpreted as actual environmental change.
Protocols	Protocols are the selections of methods and how they are used to gain information at a site. This will include numbers of replicates, lengths of transect lines, specific information gathered, e.g. animals or plants to be counted or measured

Pseudoreplication	This is where the area contained within the replicate samples is not sufficiently distant in space to be considered independent.
Qualitative information	This is a subjective description of the object of interest and is difficult to use for comparative studies e.g. coral cover is described as 'medium' by one observer and 'low' by another because their concepts of 'medium' and 'low' are different. Qualitative information is useful to support quantitative information e.g. photographs of reef change can support trends illustrated on a graph. The public will relate better to photographs than graphs.
Quantitative information	This is when the subject of interest (e.g. coral cover) is expressed as a number (e.g. 32% coral cover). Quantitative information is standardised and therefore comparable.
Random site selection	This is where bias is completely removed from the selection process and sites are selected by chance. Different sites should have equal chance of being selected using random selection methods. Random methods can be logistically difficult to implement because of the complex and spatially variable nature of coral reefs. We recommend you use stratified haphazard methods.
Replicates	Replicates are the number of separate samples used to survey one site. Scientists are interested in the mean number of animals or plants from all replicates surveyed at one site as well as the variability between the replicates.
Representative	This means characteristic or typical. A representative sample includes an area of reef that is characteristic of the area of reef being described with monitoring information.
Research monitoring	This level provides very detailed data, but it is expensive, takes more time, requires more expertise to assess a smaller area, and is usually designed to answer a specific question.
Rugosity	This is a measure of the amount of coral surface area in relation to linear area. Branching coral reef habitats will have a higher rugosity (structural complexity) than encrusting coral reef habitats.
Sample	A sample is the area in which you count the animals and plants e.g. along a transect or inside a quadrat. The sample areas chosen for monitoring will depend on what type of information required and the parameters being counted.
Sample method	This is the size and shape of the sampling method e.g. transect length and number, duration of a timed swim or quadrat size.
Sampling	Measuring a part of the environment.
Scale	This is either broad (low detail), medium (medium detail) or fine (high detail).
Site	A monitoring site is the area of coral reef selected for monitoring and where data are required i.e. where the methods are used to gather sample data.
Socio-economic monitoring	This is monitoring the way humans use and interact with natural resources e.g. fish catch statistics in a particular area; fish prices in the markets; or community perceptions on resource management.
Spatial heterogeneity	This is where the reef (animal and plant) community and substrate is variable in space.
Spatial index	This is the ratio of reef surface contour distance to linear distance. A high index indicate a surface of high rugosity.
Structural complexity	This is a measure of the amount of coral surface area in relation to linear area. Branching coral reef habitats will have a higher structural complexity (rugosity) than encrusting coral reef habitats.
Substrate	This includes the animals and plants that are attached to the reef bottom, as well as the non-living parts of the reef, e.g. rock or dead coral.
Survey	This is data collection at a monitoring site on one occasion.
Variables	These are the 'thing(s)' that you are measuring, e.g. hard coral or algae.
Zone	This is a particular reef habitat, i.e. a particular depth and type of reef community structure or particular mix of animals and plants found together on the reef.