Methods

Method 1

Select the Scale of Coral Reef Monitoring Programs

Before starting monitoring, it is essential to select the most appropriate scale for the program. This will depend on whether you are managing a small or large MPA, whether you are experiencing short-term or long-term impacts, as well you must consider what are the available resources in trained people, money, equipment and time. These will decide whether:

- to conduct monitoring over a large or small spatial scale (=area); and
- to commit to a long-term or a short-term monitoring program;
- the level will be **community**, **management** or **scientific** (see No. 2. Resource Status and Long-Term Trends, p 4), based on available financial resources and human expertise.

These decisions are important to ensure that the program is sustainable, able to answer the questions posed, and to ensure that the program is achievable with available resources

Large-scale Monitoring is used to assess major disturbances like tropical storms, crown-of-thorns starfish predation, coral bleaching, coral diseases and sediment pollution over large areas. Monitoring is important to understand the impacts of these disturbances on reefs and determining the nature and rates of recovery. Standard monitoring protocols are available to compare areas before and after the disturbances, or compare similar areas that have and have not been affected (see No. 2. Resource Status and Long-term Trends, p 4).

Small-scale Monitoring applies when a MPA is very small or it is predicted that a disturbance will only have local impacts, like those listed for short-term monitoring. Frequently changes in MPA status can be detected over a small-scale if the resources available to a manager are limited e.g. not enough people or no boats to survey distant reefs. Specific examples include damage from tourist divers around a resort or platform or ship groundings on a coral reef.

Long-term Monitoring is the most common form of monitoring to provide data and information on the status and long-term trends of the coral reefs and also the coral reef user communities. This information is essential for performance evaluation and adaptive management. The major monitoring parameters usually include:

- assessing corals and other benthic organisms for changes in bottom cover;
- determining whether there are changes in the major species or life forms;
- assessing total fish populations with an emphasis on the number and size of key target fisheries species;
- monitoring fish catches, prices, preferences and catch per unit effort;
- assessing income distribution amongst fisher communities.

Short-term Monitoring programs are less common, but can assist managers detect changes from industrial or tourism developments, sediment increases from deforestation, impacts of a ship wreck on a coral reef (see Case Study 14, p 40). A short-term study of 2 to 4 years would be important if a manager needs to monitor changes from a development, like building a tourist resort.

Data Storage, Analysis, Accessibility and Reporting

Monitoring without adequate and careful handling of the data and information obtained is a waste of time and money. Unfortunately, many monitoring programs have failed because the data have been lost or stay in filing cabinets in the same format as when collected. Diving to collect the data can be fun; but there is often less enthusiasm for processing the data.

MPA managers should seek advice on how to store, analyse, and report all data obtained from monitoring. The whole process should be planned in advance with a budget allocation to ensure that the data are correctly stored, analysed and made accessible.

The critical steps for data management are:

1. Plan the data system before collection. Develop a protocol for collecting and storing the data in the field, transferring into the computer and into the home base. Develop a data entry program that is compatible with the receiving database;
2. Take field notes at the time of sampling (who collected the data, methods used, problems encountered). Put these notes into the database for interpretation later. Taking a portable computer into the field is a good idea;
3. As soon as possible, the data collected should be entered into the database and backed up to ensure that there is a second set if the first is lost; if this is delayed, the data may be difficult to interpret;
4. After entry, it is essential to check the data point by point to avoid data transcription errors. This is best done with the help of a second person;
5. Soon after data entry and checking, preliminary analyses should be performed to verify that there are no serious errors and also to give feedback to the monitoring team and other stakeholders. This is best done through graphic presentation of the data using a data analysis package. AIMS in Australia produced ARMDES for this purpose and this is being updated by ReefBase for global distribution by the GCRMN;
6. Preliminary analysis may show that there is a need to change the sampling methods. This may be through more samples, more frequent samples, or it may show that observers are not identifying some categories or species correctly;
7. All data should be permanently archived into to another computer and a backup copy maintained elsewhere;
8. The global database, ReefBase based at the WorldFish Center in Penang Malaysia can provide permanent storage of primary and summary data. Permanent storage is strongly recommended.

ReefBase (www.ReefBase.org) is the accepted global information system for coral reef conservation and management and was developed by the WorldFish Center, Penang Malaysia. It offers a range of information, tools and resources for managers, students and scientists relevant to managing reefs for sustainable use and production. ReefBase stores all records of coral bleaching worldwide. It currently has over 6,000 records in its database, which can be accessed as reports, graphs and maps. All data from Reef Check and the GCRMN are stored here. The AIMS LTMP (see Case Study 9 p 30) shows how data can be reported with their results on the www.aims.gov.au/reef-monitoring.

Method 3

Ecological Monitoring Methods for Coral Reefs

These are commonly used methods for very basic coral reef ecological monitoring. The ecological methods have been developed over more than 30 years, whereas most of the socio-economic methods for coral reefs have only been developed during the last 10 years and are still under active development.

Ecological assessments are used to monitor the status and long-term trends of biological and physical parameters associated with coral reefs. Standard protocols for surveying tropical marine resources, including coral reefs are in English *et al.* (1997).

Physical parameters to measure

- Depth, bathymetry and reef profiles – these are critical in developing maps for management plans and selecting sites for monitoring;
- Currents – general measures of current directions and speeds are important for predicting the flows of pollution or new larvae;
- Temperature – measures of water temperature at different locations on coral reefs. These are important when monitoring for coral bleaching;
- Water quality - the amount of sediments, nutrients and pollutants in the water to assist in assessing pollution. Sediment can be measured in basic sediment traps;
- Visibility – how far one can see under water (i.e. penetration of light for photosynthesis);
- Salinity – this should only be measured when large flows of freshwater have occurred to determining the level of stress to corals.

Biological Parameters to Measure:

- Percentage cover of corals, sponges, algae and non-living material (i.e. dead coral, rock and sand) – this measures the area of living corals and also detects dead corals which may indicate stress;
- Species composition and size structure of coral communities – measure either the species or genera or life-form categories depending on available expertise;
- Presence of newly settled corals and juveniles – this measures coral recruitment and potential for recovery;
- Numbers, species composition, size and structure of fish populations (including measures of biomass) – particular emphasis is placed on target fish for fishers or aquarium collectors;
- Juvenile fishes, especially target species – this uses similar methods as above but at smaller scales;
- Populations of organisms of special interest such as giant clams, crown-of-thorns starfish, sea urchins etc.
- Extent of coral bleaching, species or genera of corals showing bleaching and the amount of bleaching in the coral colonies;
- Extent and type of coral disease – measured as above, and can include measures of broken or damaged corals.

Methods to measure parameters

Broad scale surveys: These are used to assess broad changes in coral reef communities over large areas looking for the general structure and health of the reefs as well as track large-scale disturbances (i.e. crown-of-thorns starfish or coral bleaching and disease)

- Manta tows – involves towing an observer behind a motor powered boat around the perimeter of a reef for timed interval (usually 2 minutes) and recording major reef components e.g. coral cover, anchor and blast damage, giant clams, crown-of-thorns starfish etc.
- Timed swims or random swims – involves swimming over the coral reef, usually within a selected depth range, and recording major categories as above. This is particularly useful in searching for the presence of large fish and doing biodiversity presence/absence surveys (a special example is Method 3 for large fish; p 54)

Benthic surveys: These are used to assess changes in individual coral reef community health (or prevalence of disease) over time at smaller scales and generally in more detail.

- Transect lines (tape measures, chains or ropes with knots) – involve monitoring indicators at intercept points or at set intervals along the transect line. The most appropriate lines are 50m fibre glass tapes similar to the ones used by builders. Assessments are usually done by recording data on underwater paper or slates;
- Belt transects (including video monitoring) – involve assessing populations along a belt either side of a transect line, and can be a 1m to 10m wide belt depending on the target (see note below);

- Quadrats (large and small) - involve monitoring indicators in specific sized quadrants, varying from small squares of 10 to 20cm to the most common 1m sides, up to 10m long sides. Assessments can be made of random smaller squares inside the quadrats or by photographing the quadrats and counting what is under fixed points;
- Settlement plates – usually unglazed tiles attached at 45^{o} near a coral reef and assessed microscopically for settled coral colonies.

Tools for recording data

- Plastic Slates or underwater paper – plastic material that is resistant to water. Slates are heavier but can be used many times after cleaning. Underwater paper is lighter and can be washed and stored as a permanent record of the data;
- Photo transects or quadrats – this requires the use of an underwater camera (or pairs of cameras) which can either be the standard film type or newer digital cameras. The photographs can become a permanent record of the site provided they are archived correctly. It is essential to extract the data within a few days of taking the photographs, or else the task can become too large and memory about the site can fade;
- Video cameras – these permit surveys over large areas when limiting time underwater is important. These should only be used for monitoring when there is an existing system of analysis already established and the monitoring is well trained to record the data within several days to weeks of survey. A video provides a permanent record (provided that they are well archived) of a site for later comparison if un-anticipated events occur.

Other Methods

There are many other measures one can take of coral reefs, but all monitoring is time consuming and MPA managers have to select parameters that they need to employ that will provide useful data that can be analysed to show the status and trends in the coral reef resources in the MPA. Where possible all monitoring should be conducted inside MPAs and outside at comparable sites as well to assess differences between managed and unmanaged situations. Methods are listed in **Appendix 2.**

Reference

English S, Wilkinson C, Baker V (Eds). (1997). Survey Manual for Tropical Marine Resources, 2nd Edition. Australian Institute of Marine Science, Townsville. 390pp (ISBN 0 642 25953 4).

Method 4

Socio-economic Monitoring Methods for Coral Reefs

Socio-economic assessments are used to monitor the status and long-term trends of social, economic, cultural and political parameters associated with coral reefs. Standard protocols are available for coral reef socio-economic assessment and monitoring in Bunce et al., 2000 and Bunce et al. 2002.

Socio-economic monitoring aims to understand human behaviour and how people interact with coral reefs. It is not possible to separate human activities and ecosystem health, especially when coral reefs are very important in many peoples' livelihoods. Socio-economic monitoring can measure the motivations of resource users as well as the social, cultural, and economic conditions in dependent communities. Socio-economic data can help mangers determine what stakeholder and community attributes can play a vital role in successful management. The most frequently used socio-economic parameters include:

method 4

Social parameters to measure

- Household Demographics – includes the age, gender, education level, religion, literacy, etc.;
- Employment – measures how people earn money or gather food. A special emphasis is on assessing people directly using marine resources, especially fishers;
- Cultural / heritage impacts – measures what areas or reef resources are of special interest to communities for cultural or religious purposes;
- Traditional uses and activities – determines how communities used and managed reef resources in the past. This is used to compare with current practices;
- Social networks and interactions – this is important in determining who are the key decision makers and how decisions are made in the community;
- Community infrastructure – details how communities are governed and how they relate to higher levels of government;
- Local perception of reef management and management success – this is essential for managers to understand and target methods of influencing perceptions in favour of resource conservation;
- Level of understanding of human impacts to reefs – measures whether communities are aware of their damaging activities and concerned about sustainability;
- Level of understanding and cooperation of MPA regulations – managers need this information to develop education programs to increase support for MPA management.

Economic parameters to measure

- Individual and household income – this is essential if the goals are to improve people's livelihoods. A special measure is reef associated activities;
- Catch data – measures what is extracted, where caught and where consumed or sold;
- Use of all products (sustenance vs. economic) – this includes all aspects of harvesting from coral reefs including animals, plants, rock and sand, as well as cultural items;
- Number and type of markets – this follows the flow of fisheries products in and out of the community;
- Fishing effort and changes over time – measures how much effort is put into harvesting from coral reefs and how effort has changed with increases or decreases in resource stocks;
- Local perceptions on extractive vs. non-extractive value of reef – assesses how communities value coral reef for both products and for cultural and aesthetic values;
- Level of reef use by outsiders, including fishers, and a special measure is the value of tourism and the value that tourists place on a healthy coral reef.

Ecological parameters are closely linked to socio-economic ones, therefore both types of 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, particularly if there are seasonal changes in what fishers catch. Similarly ecological parameters reflect the natural state of the MPA, which will have impacts on socio-economic factors such as income and employment.

Six basic steps to socio-Economic monitoring

1. Advance preparation, including identifying purposes of the socio-economic monitoring, selecting the relevant indicators, defining the process to conduct socio-economic monitoring, identifying and consulting with stakeholders, and identifying the monitoring team;
2. Data collection through secondary sources
   - National census data - relevant data for selected indicators such as population and employment statistics. These data can be confirmed through surveys in communities;
   - Local government and council records - relevant data for selected indicators such as recreation

patterns or tourism patterns (in some countries religious institutions keep these data);
- Historical sources – includes compiling and reviewing relevant data from previous reports, assessments, and surveys. Many government departments keep these data, often in easily accessible formats.

3. Data collection through key informants
- Interviews – involves interviewing people who have specialized knowledge about indicator due to their experiences or knowledge;

4. Data collection through household interviews

5. Data collection through observation
- Observations – includes qualitative descriptions of what a researcher sees or hears while visiting a community,

6. Data analysis and communication – the same rules for data management as outlined in Method 2 apply for socio-economic data gathering. Planning is essential before starting.

Additional tools for data gathering

- Surveys (mail, phone, person) – involves distributing a survey to a randomly selected group of possible respondents to gain information regarding their knowledge on a subject or to provide feedback or comments;
- Focus / Discussion Groups – involves a selected group of individuals, perhaps key stakeholders, meeting to discuss;
- Public meetings – includes presentations by relevant stakeholders regarding an issue of concern and provides opportunity for community members to provide feedback or comments;
- Cost-benefit analysis - assesses the potential costs and benefits of a resource or activity in monetary terms to determine the most efficient use of resources;
- Multiple criteria analysis – assesses the potential costs and benefits of a resource or activity using multiple data types;
- Citizen juries – involves representative members of the public, acting as concerned citizens, making a decision on behalf of society on a given charge;
- Modelling – used to run simulations, predict effects, or identify effects that may not be intuitive.

Further details on these steps and guidelines on how to conduct socio-economic assessments for coral reefs are in 1. below and online at http://www.aims.gov.au/pages/reflib/smcrm/mcrm-000.html. This contains information on costs, frequency, indicators and a wealth of other information. Practical guidelines on how to conduct socio-economic monitoring for Southeast Asia are in 2. below and online at http://ipo.nos.noaa.gov/coralgrantsdocs/SocMonSEAsia.doc. These guidelines may require some modification for application in other areas and cultures.

References

Bunce L, Pomeroy B (2003). Socioeconomic Monitoring Guidelines for Coastal Managers in Southeast Asia: SOCMON SEA. GCRMN and World Commmission on Protected Areas, NOAA Washington DC, pp. 82.

Bunce L, Townsley P, Pomeroy R, Pollnac R (2000). Socioeconomic Manual for Coral Reef Management, 2nd edition. GCRMN and Australian Institute of Marine Science, Townsville pp.251 (ISBN 0 642 32205 8).

Method 5

A Rapid, Quantitative Survey Method for Large, Vulnerable Reef Fishes

Howard Choat and Rachael Pears

Introduction

MPA managers are often faced with the task of collecting information on the abundance and population size structure of large fish species targeted by reef fisheries. Underwater visual surveys are the most effective way to collect this information, particularly in remote locations. Larger species are particularly vulnerable to over-exploitation, and are often the first to be reduced by fishing in an area. They include sharks, napoleon wrasse *(Cheilinus undulatus),* large parrotfish (particularly the humphead parrotfish *Bolbometapon muricatum* and Pacific Steephead parrotfish *Chlorurus microrhinos),* and large groupers.

These methods are about determining patterns of abundance of a number of larger reef fish species that are targeted by fisheries in many countries. The first step is to develop modified counting methods that account for the characteristics of key target species, including both large and mobile, or cryptic species. The methods used to count fishes need to be carefully chosen to suit the biology and behaviour of the species and the reef locality. Many reef fish species have some of the following attributes: large size; high mobility; relative rarity; patchy or clumped distributions; camouflage; and fairly cryptic behaviour. Therefore such fisheries species may be poorly counted by established visual survey protocols for reef fishes (e.g. small belt transects in Method 3, p 50).

Methods

Here we outline the modified counting methods for: 1. large, mobile reef fishes; and 2. medium and large groupers.

1. **Large, mobile reef fishes**

   When present, sharks, napoleon wrasse and humphead parrotfishes tend to be large and conspicuous in their behaviour, since they tend to swim above the bottom. They can be counted using a long-swim technique, aimed at covering a large area in a short time with minimal diver disturbance. This approach is necessary as these species are mobile, usually have clumped distributions, and may show diver negative or positive behaviour. The long-swim technique consists of 20 minute timed swims with a standardised swimming speed over a depth of approximately 5m along the reef front (just below the reef crest, so that you can see the reef crest, flat and slope where these species tend to occur). Record the size and number of all individuals of these species observed within 10m either side of the observer on underwater paper. For very large mobile species, the appropriate transect dimensions are 400m x 20m. Steephead parrotfish can be counted using the same methodology, although narrower transects (5m either side) are required for this smaller species.

2. **Groupers**

   Most species of groupers are cryptic in behaviour and tend to stay close to the bottom, or hide in caves or under overhangs and ledges. As groupers are often well camouflaged they are easily overlooked, therefore, counting these species requires a modification of the above technique to improve detection rates. These species can be surveyed using slower swimming speeds of approximately 6 metres per minute (to allow the observer to search the substratum more thoroughly) for 30 mins, counting and estimating the size of all individuals within a 5m wide band. The main observer actively searches for groupers within the band, and must be experienced in the underwater detection and identification of the local species. A second observer should swim slightly behind the main observer to record numbers and sizes of any larger mobile groupers that are within 10m either side. This collects information on species such as the brown-marbled grouper (*Epinephelus fuscoguttatus*) that do not usually allow close approach by divers. More visible roving grouper species (e.g. members of the genus *Plectropomus* or *Epinephelus*) can be counted using the methodology for sharks, wrasses, and parrotfishes.

   The information is of added value if raw count data are converted to density estimates to compare abundances over time and among places. First, you need to determine the area of each count by estimating the distance of the swim multiplied by the width of the count. The distance is estimated by measuring swimming speed over measured distances. The distance travelled can also be estimated from the surface if you have a GPS available. Divers can be trained to judge the fixed width by eye (fish within this distance from the swimmer are included in the count). Counts are then converted to a standard density (number, either per ha or 8,000m^2) for comparing densities among areas.

Prior to commencing a count program, divers should calibrate swimming speeds (usually the distance covered in 5 mins) and the accuracy of their width estimates (5-10m each side of the swim line) using tape measures. Observers must be well trained in the survey techniques, underwater identification of local species, and fish size estimation. The divers counting the fish should be the only people in or near the area to ensure that the fish are not attracted or chased away. The procedure for each count must be standardized to achieve consistency and dive safety considerations are paramount. Further useful information on visual survey methods is in the references.

Conclusions

The long-swim techniques have been tested in many countries including the Seychelles, and have proved to be suitable for counting many larger reef fishes. Advantages of these methods:

- 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 is useful for counting larger fishes that do not allow close approach;
- slower swim speeds with increased search intensity within a 5m wide band 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.

Long-swim techniques are an improvement over small and narrow transects for counting some large, vulnerable fishes. However, the choice of counting method should be matched to the main species of interest. Groups of species with similar attributes may be counted together, but attempts to count all species at once are unlikely to produce useful results. Fish counts focused on fisheries species can provide a rapid assessment of the status of coral reef fishes and valuable long-term monitoring data for MPA and fisheries management.

References

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Method 6

Water Quality Monitoring in Coral Reef Systems

Jon Brodie

Introduction

Damage to coral reef systems from land-based pollution is one of the world wide issues facing the continued existence of reefs. Well known examples of reefs damaged by water pollution include the Kaneohe Bay, Hawaii, where sewage discharge caused major losses on the coral reefs offshore, and Jakarta Bay, Indonesia where pollution from over 10 million people has been a major factor in the death of virtually all corals in the bay. Even very large reef systems such as the Florida Keys, USA and the Australian Great Barrier Reef have been damaged and continue to be threatened by land-based pollution.

To detect reef damage due to poor water quality, monitoring of reefs using standard 'reef health' methods may be used. However, it is often very difficult to separate the potential causes of reef damage and change e.g. coral reefs may be damaged by bleaching, destructive fishing, natural change, cyclones and coral disease. If it is suspected that water quality is an issue, then a monitoring program to measure ***sources*** of the pollutants, their ***transport*** to the reef areas and thus the ***exposure*** of the reefs to pollutants should be established. Such a monitoring program will complement the monitoring program set up to detect ***biological effects*** on the reef system.

Methods

Sources and loads

Generally land-based pollutants are delivered to the marine environment from a point source. The point source may consist of a pipe carrying sewage effluent or industrial wastewater or more commonly the source will be a river, stream or drain carrying pollutants from the catchment area. As samples can be taken from all of these at a single point, monitoring is relatively straightforward, in principle. The following important categories have to be considered in the design of the monitoring program:

1. **The pattern of flow**
   Effluent pipes often have fairly regular flows and so can be monitored at any time. In contrast, rivers and streams, especially in the tropics, have very variable flows and most pollutants are transported in the wet season. Therefore the sampling of rivers and streams must be concentrated at this time;
2. **Pollutants to be measured**
   There is usually a large range of possible pollutants from a catchment or wastewater discharge, thus it is essential to narrow the range of pollutants measured to include those most likely to be the cause of the problem. Pollutants which can stress coral reefs include suspended sediment, 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. It is very expensive to sample and analyse for all these materials, therefore it is essential to target for analysis those pollutants which may be causing the problem and have a known source in the catchment area;
3. **Estimate loads**
   The actual amount (mass) of pollutant being discharged is important to know as well as the concentration of the pollutant in the water. To measure loads it is necessary to know the volume of the discharge as well as the concentration of the pollutant at a number of times during the discharge event;
4. **Catchment source identification**
   To attempt to manage the pollutants, it will probably be necessary to identify the actual source areas or activities within the catchment, which result in the majority of the pollutants. This may involve monitoring 'up the catchment' as well as at the river or stream mouth. 'Proxy' data may also be of use such as the amount of pesticide sold in the catchment, fertiliser use data and sewage treatment plant discharges into the river.

Transport and exposure

As pollutants are discharged into the marine environment from an outfall or river, there are processes that occur to decrease the concentration of the pollutant. These processes include sedimentation, evaporation and biological and chemical transformations as well as simple dilution through mixing with seawater. It is often important to know whether there is sufficient pollutant (either load or concentration) reaching the reef systems to cause biological effects.

Monitoring pollutants in the marine environment, whether in the water column or in sediment or organisms is far more complex than monitoring point source discharges. The three-dimensional nature of the seawater body means that many samples are required to characterise what is happening. Therefore a rigorously designed sampling program is necessary to generate conclusive results. Hydrodynamic modelling may be of use in predicting transport, dilution, dispersion and sedimentation, but such models are also complex and need expert design.

Biological effects

The coral reef monitoring program must include indicators, which are relatively specific to show water quality impacts. Many traditional reef monitoring indicators such as coral cover and fish counts are not very useful in detecting water quality impacts. Indicators such as coral recruitment, recruit survivorship, algal abundance and dynamics, immunoassay methods and photosynthetic performance (PAM) may be more useful indicators for many pollutants.

Conclusions

Monitoring must not only focus on a change in the system, but also on the causes of the change. If pollution is to be managed then the sources of the pollutants must be identified and quantified. Thus an integrated water quality monitoring program should measure sources, transport and effects so that an assessment of management options can be made. The effectiveness of management activities to solve water quality problems can also be tested with such an integrated program of monitoring.

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