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of the Federal Republic of Germany

Curriculum on Coastal and Marine Biodiversity and Protected Area Management

Module 6 Assessment and Monitoring of Coastal and Marine Biodiversity and Associated Issues

For Field-Level MPA Managers



Imprint

Training Resource Material:

Coastal and Marine Biodiversity and Protected Area Management for Field-Level MPA Managers

Module 1: An Introduction to Coastal and Marine Biodiversity and Ecosystem Services
Module 2: Coastal and Marine Biodiversity and Ecosystems Services in the Overall Environment and Development Context
Module 3: Mainstreaming Coastal and Marine Biodiversity into Overall Development and Environmental Planning
Module 4: Coastal and Marine Protected Areas and Sustainable Fisheries Management
Module 5: Governance, Law and Policies for Managing Coastal and Marine Ecosystems, Biodiversity and Protected Areas
Module 6: Assessment and Monitoring of Coastal and Marine Biodiversity and Relevant Issues
Module 7: Effective Management Planning of Coastal and Marine Protected Areas
Module 8: Communicating Coastal and Marine Biodiversity Conservation and Management Issues

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Curriculum on
Coastal and Marine Biodiversity and Protected Area Management

Module 6
**Assessment and Monitoring of
Coastal and Marine Biodiversity
and Associated Issues**

For Field-Level MPA Managers

Summary

This module has been designed to provide the required information on different coastal and marine ecosystems, critical marine habitats, their importance and assessment. It will also help participants in identification of species found in coastal and marine ecosystems. This will equip them with assessment methodologies of different critical habitats species. This module is delivered through different learning techniques, comprising class room session, and hands-on assessment practice in contained pool as well as open-water conditions. Hands on experience will be provided on all important topics covered in this module for better understanding of the coastal and marine habitats and the associated species. As a part of this module, exposure visits will be organized to beach, intertidal and mangrove ecosystems.

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Learning outcomes

After completing this module, the participants are able to

- Identify key coastal and marine ecosystem and species in India
- Describe the key assessment and monitoring methods used for coastal and marine habitats and species
- Appreciate the magnitude and distribution of coastal and marine biodiversity- a global overview, in India, and an in-depth understanding of their State
- Conduct under-water / coastal survey to monitor marine and coastal habitat features and species
- Report based on the monitoring data

Key messages

- While the focus on global and ecosystem processes is indeed imperative, controlled field experiments and carefully designed surveys and monitoring programs could be completely misinterpreted if analysis of data obtained via scuba is not also incorporated.
- Scuba created a scientific revolution by providing direct access to underwater habitats composing a large part of the biosphere. While there have been many important specific advances, we believe that the overarching benefit of scuba for marine population, community, and ecosystem ecology has been to facilitate the direct observation and manipulations of individual organisms and their surrounding conditions..
- Management of the marine environment is a matter of societal choice. It involves decision making in terms of allocating parts of three-dimensional marine spaces to specific uses to achieve stated ecological, economic and social objectives. People are central to this decision-making process and are the agents for change.

Key terms

Ecosystem; habitat; coral reef; mangroves; sea grass; seaweed; rocky shore biodiversity hotspots; methodology; assessment; monitoring; quadrats; transects; manta tow board; analysis; marine protected area; integrated coastal zone management.



6.1 Why assessment, monitoring, evaluation and review of MPAs

Effective management of a complex ecosystem under human pressure is not possible without science. The natural sciences are needed to understand the functioning of the ecosystem and the social sciences are needed to understand human-induced problems and how they can be solved. The science done for an MPA has to be driven by management needs.





6.2 Assessment Planning

Scientific data obtained from a monitoring programme in a marine protected area are often sought to gain a clear understanding of the functioning of the ecosystem. However, monitoring is expensive; and the management of large systems or Protected Areas with multiple objectives and many values, usually with limited resources, means that monitoring efforts must be carefully targeted and well designed. The particular indicators chosen for monitoring should, if possible, provide at least some information on as wide a range of values as possible – for example healthy populations of an animal with a large home-range will often say something as well about the overall health of the ecosystem. Because the specific objectives for management will be different for each protected area, the content of monitoring and evaluation programmes for assessing outcomes will be correspondingly diverse



To monitor status of any value, it is usually necessary to decide:

- What attributes will be considered;
- What indicators of this attribute will be measured/assessed; and
- Methods to be used in measuring the indicator.

Table 1: Example of monitoring attributes, indicators and methods

Value	Attributes	Indicators	Method
Population of an endangered animal	Breeding success	Number of breeding females at sites x,y,z	Counting nests
		Mortality rate	Tag and recapture
Integrity of an indigenous art	Visibility of artwork	Vibrancy and clarity compared with the previous years	Photo-monitoring and analysis
	Disturbance level of site	Evidence of graffiti, trampling and soil compaction	Photo-monitoring and soil compaction measures
Level of cooperation with local community	Proportion of community supporting the protected area	Number of incursions by local people recorded	Patrol database
		Report of positive progress at meetings	Subjective quarterly reports reviewed

[Source: Hockings et. al. 2006]

6.2.1 Assessing ecological integrity and threats status¹

Most Protected Areas are managed to conserve a range of natural values, including ecosystem function and services, biodiversity at all levels from landscape and ecosystem through species and population to genetic; and human-wildlife interactions. Monitoring and evaluating ecological integrity and threats to it is a significant topic of research and discussion at present. While every protected area has its own values and objectives, some organizations have standardized the issues and areas to be measured in each park. For example:

- Is the park losing native species?
- Are selected indicators within acceptable ranges?
- Are herbivores and predators playing their role?
- Are biological communities at a mix of ages and spacing that will support native biodiversity?
- Are productivity and decomposition operating within acceptable limits?
- Is the system cycling nutrients within acceptable limits?
- Are key physical processes supporting biodiversity?
- What are the key stressors we are concerned about?

To answer such questions and to evaluate the achievement of ecologically-related objectives, monitoring information based on solid science is highly desirable. To obtain such information, indicators are chosen for each value, objective or question, and methods to measure and report on these indicators are developed. The Nature Conservancy's Conservation Action Planning methodology has been used to measure ecological integrity in many different systems. The process is summarised in Figure on the next page.

Ratings are often used to report on the status of indicators and outcomes in a 'report-card' format which can easily be understood by managers. These ratings (usually poor/fair/good/very good or A,B,C,D) need to be built on a solid foundation. See a case of Marine National Park and Sanctuary, Jamnagar State of Gujarat, India here: <http://gujenvi.nic.in/PDF/gok%20report%202015.pdf>

¹ [Source: Hockings et. al. 2006]

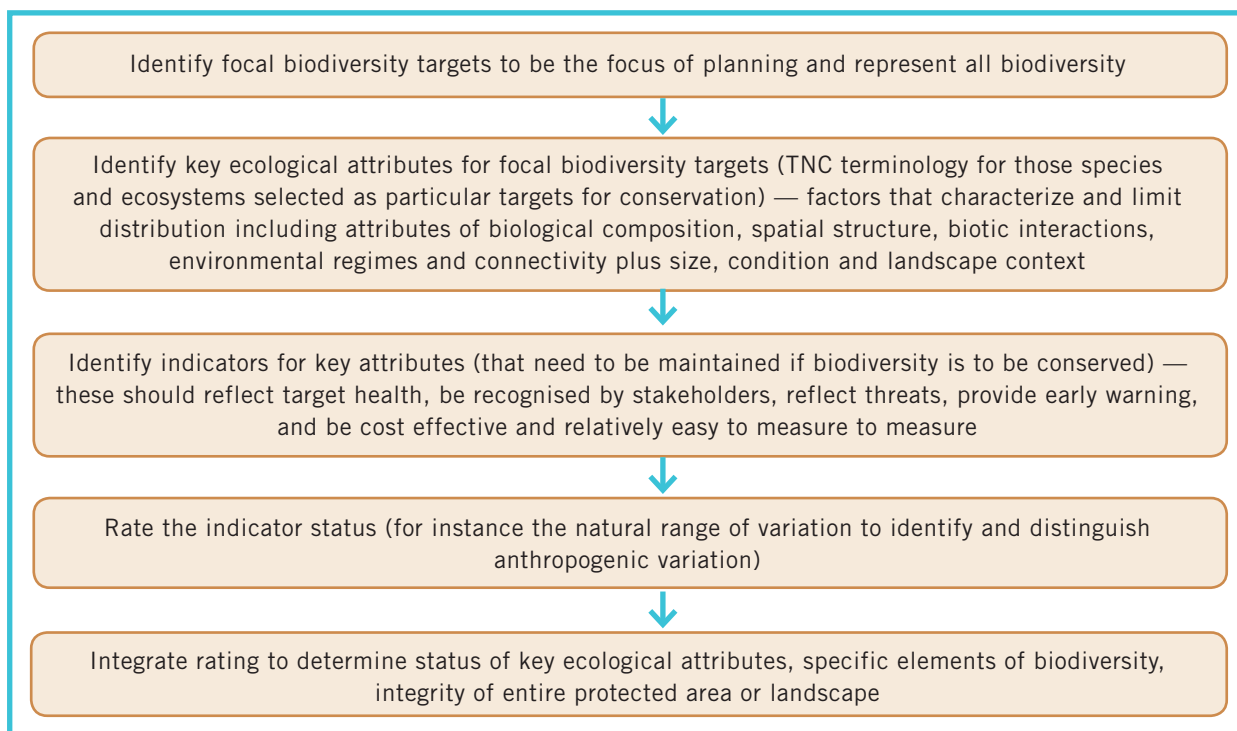


Figure 1: The Nature Conservancy's Conservation Action Planning methodology for Monitoring Ecological integrity

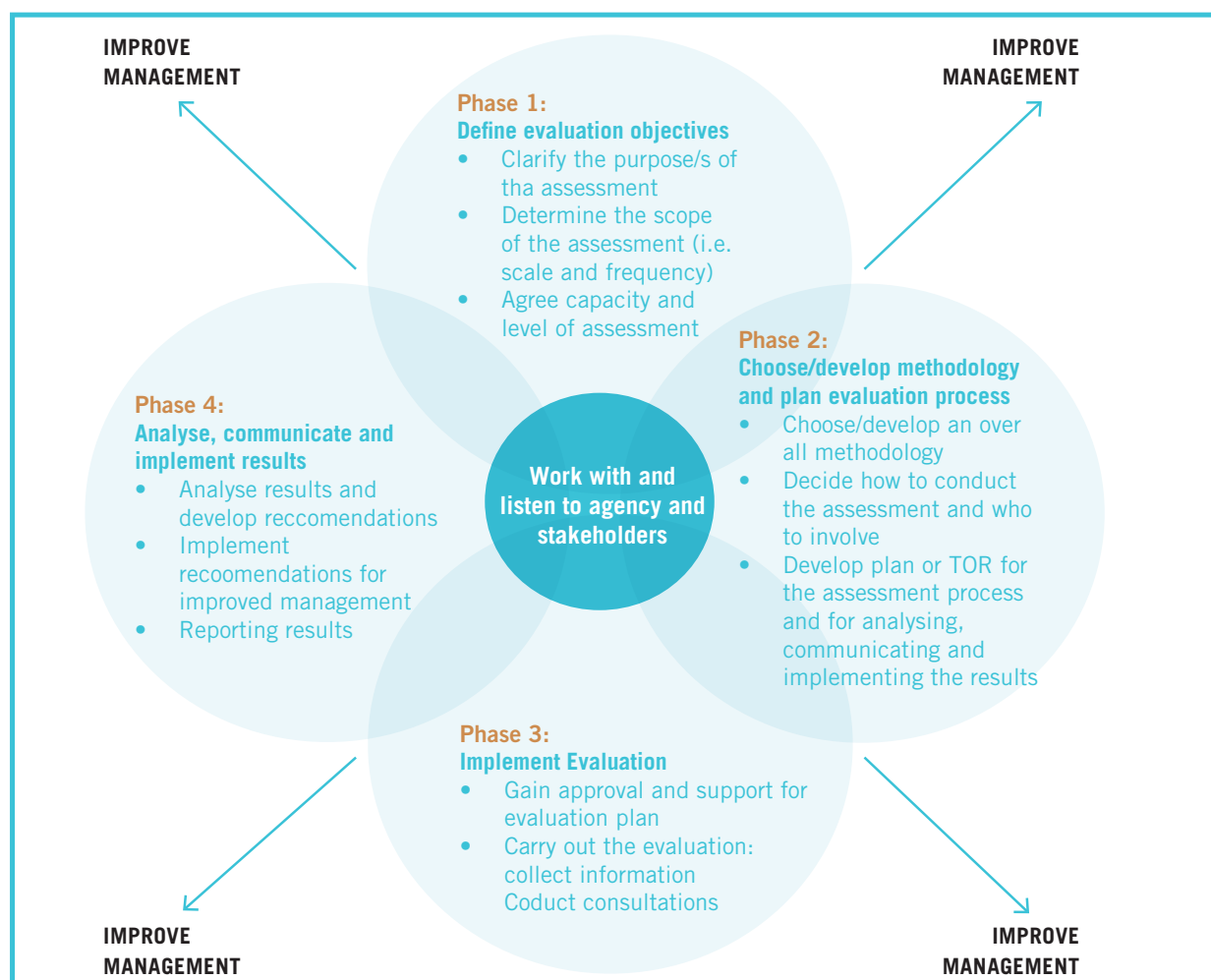


Figure 2: The four major phases of the assessment process (Source: Hockings et.al 2006)

6.2.2 Assessing the status of social and cultural values²

Cultural heritage values and objectives relate to both material culture (art sites, buildings, traditional roads and pathways, etc.) and non-material aspects such as people's connections to land, ceremonies, stories, songs, dances and ways of life.

While cultural values, especially the non-material aspects, are not always easy to define, they can be recorded, have associated indicators, and be assessed and rated in much the same way as the ecological values discussed above. For example, condition attributes and indicators for an ancient building might relate to the extent to which its structure remains whole and safe, while an Indigenous group's stories might be evaluated (preferably by the group themselves) in terms of their transmission to and adoption by the younger generations.

In both cases, an 'acceptable range of variation' can be defined and the assessment can rate whether the conservation objectives have been achieved. Social, economic and institutional indicators are typically not as well developed and not as commonly utilized as biological and physical indicators in natural protected area management. However this may change and it is interesting to note, for instance, that the UNESCO World Heritage Centre is considering extending the type of assessments undertaken in natural World Heritage sites to their cultural equivalents. Of particular importance to local and Indigenous communities are the recognition and maintenance of traditional rights and land tenure, the existence of effective dispute resolution mechanisms, involvement in management decision-making processes, and the incorporation of traditional ecological knowledge into planning.

If there are no specific objectives defined in a management plan or other documentation, international standards and conventions on human rights can be a good starting point for developing community and cultural indicators. The subsistence values of protected area resources such as non-timber forest products are frequently under-recognised in management planning and effectiveness evaluations. The monitoring and assessment of social, economic and institutional indicators in protected areas should also be linked with broader landscape issues, and closer linkages with sustainability frameworks such as State of Environment reports are needed.

A better integration of social, economic and institutional indicators across a range of programmes will enable a better understanding of impacts on protected areas and of broader regional trends outside protected areas.

6.3 Difference between inventory, assessment and monitoring

Inventory: Establish baseline

It is essential for the inventory to collect baseline information to describe the ecological character of the ecosystem, pressures and associated risks of adverse change in ecological character, and monitoring activities, which can include both survey and surveillance that provides information on the extent of any change. All these are important and interactive data gathering exercises. They should be considered as linked elements of this overall integrated framework which, when implemented, provides for identification of key features of the character of Protected Areas.

Assessment: Status, trends and threats

The identification of the status of, and threats to, the ecosystems as a basis for the collection of more specific information through monitoring activities.

Monitoring

Monitoring is the process of analysing the degree of change in status, trends and threats, including the emergence of new threats in the ecosystem. This is to collect specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management.

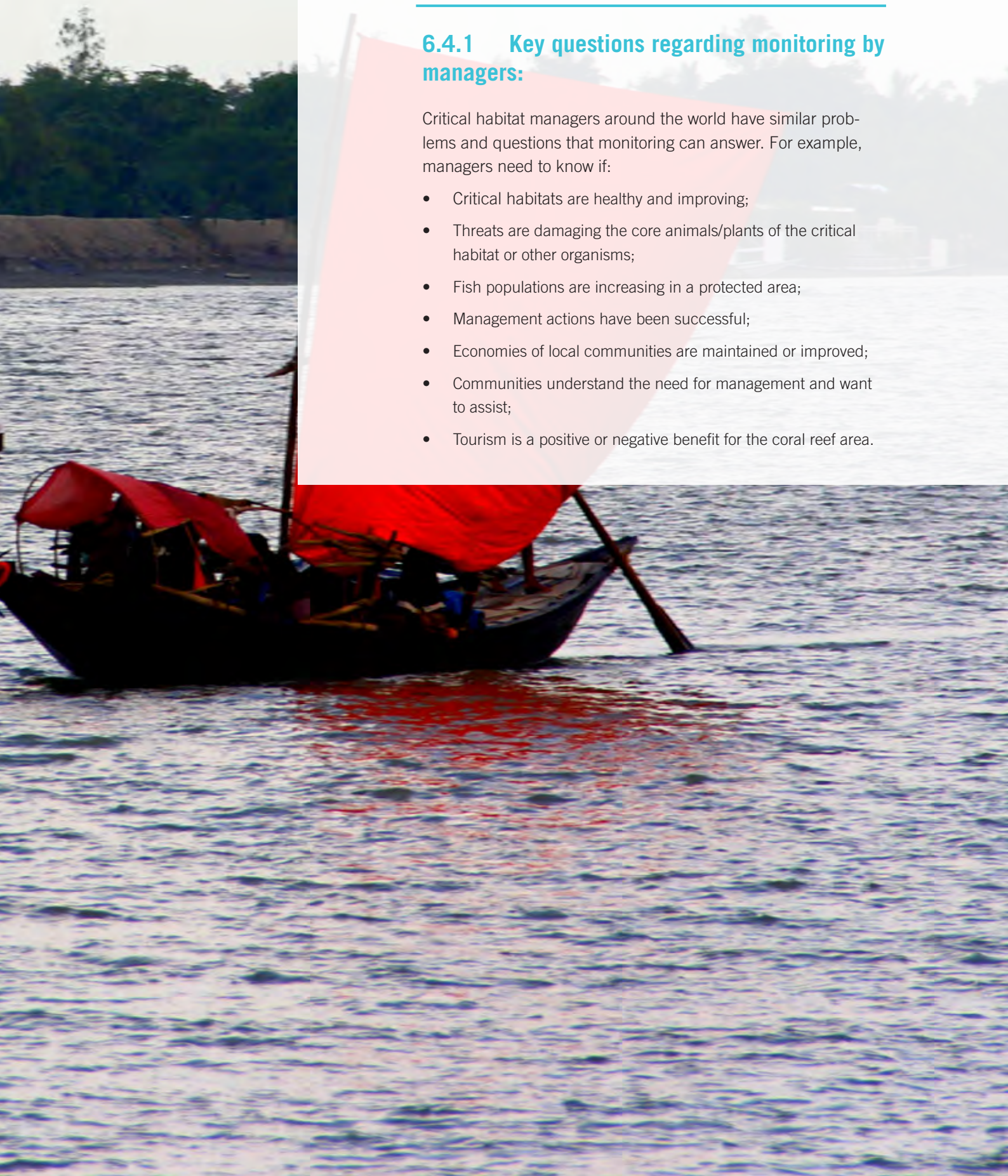


6.4 Critical Habitat Assessment & Monitoring

6.4.1 Key questions regarding monitoring by managers:

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

- Critical habitats are healthy and improving;
- Threats are damaging the core animals/plants of the critical habitat 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.

And some specific questions on the monitoring:

- 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 coastal or marine 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 section represent the ones most commonly used on critical habitats around the world. Our advice is to use the standard and frequently used methods to monitor your critical habitat because these have been extensively tested. Using standard methods also means that you will be able to compare the status of your critical habitat with other critical habitat at regional and global scales.

6.4.2 What is monitoring³?

Monitoring is the gathering of data and information on a ecosystems or on those people who use critical habitat resources. Monitoring should be repeated on a regular basis, preferably over an extended period of time. Ideally a critical habitat 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, sea grass beds, mangroves, wetlands;
- Understanding the status of critical habitat key communities, fish populations and fishing practices;
- 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 critical habitat manager has to select which variables (things to measure) to be included into a monitoring program. In this section, the term monitoring includes both the initial baseline survey and continued monitoring.

6.4.3 Some Important Definitions

There are lots of terms used when talking about monitoring. We use the same definitions throughout the section 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;

3 Source: Wilkinson et. al., 2003

- Ecological monitoring is monitoring the natural environment, e.g. the fiji sh 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 fiji sh;
- 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.

6.4.4 How can monitoring help the MPA managers in effective management of their MPAs⁴?

A major goal of a critical habitat 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 a protected or managed coastal or marine area, through the following tasks:

1. **Resource assessment and mapping** – what and where are the resources in your critical habitat 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;
3. **Status and long-term trends of user groups** – who are the major users and stakeholders of your critical habitat, 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, floods affect your critical habitat;
5. **Impacts of human activities** – how do the activities of people affect the critical habitat and its resources? This includes fishing, land use practices, coastal developments, and tourism;
6. **Performance evaluation & adaptive management** - how can monitoring be used to measure success of management goals and assist in adaptive management?
7. **Education and awareness raising** – how to provide support for critical habitat management through raising awareness and education of user communities, government, other stakeholders and management staff?
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, storms or tsunami or floods;
9. **Contributing to regional and global networks** – how to link up with and learn from other critical habitat managers around the world and assist others manage their critical habitats.

⁴ adapted from Wilkinson et. al., 2003



6.5 Before assessment and monitoring

6.5.1 Defining the objectives of research and monitoring⁵

Research is about understanding the functioning of a system and monitoring is the repeated observation of a phenomenon over time. The goal of research and monitoring is to enable management to meet the purposes set for the MPA.

Research and monitoring should provide answers to the following broad questions:

- What are, or have been, the pressures on the system (whether natural, e.g. severe storms, tectonic events or El Niño, or human-induced, such as pollution, habitat destruction or over-exploitation)?
- What is the state of the managed system, in particular of its:
 - Dominant biota,
 - Rare, endangered or threatened species,
 - Ecological processes (e.g. sedimentation, absorption of nutrients and toxic elements), and
 - Ecological states (e.g. water quality, temperature, suspended sediment levels, nutrient levels)?
- What is, or has been, the effect of the management response?
- Are the measures specified in the Management Plan or Zoning Plan being implemented?
- Are people complying with the conditions in the plan?
- Is the management meeting its objectives?

5 Source: Kelleher, 1999

6.5.2 Establish the ambit of research and monitoring (Source: Kelleher, 1999)

‘Ambit’ means the topics to be included in research and monitoring, such as testing whether water quality is improving, monitoring changes in fish stocks, and measuring the level of impact from tourists as visitor numbers grow. It also includes the geographic coverage, the time-scale to be covered, and related socio-economic factors.

In defining the ambit, it is advisable to focus on the ecosystem as the unit of study rather than be limited by the boundaries of the MPA itself. Because of the high connectivity in marine systems, there is little value in research and monitoring that is limited to small or medium-sized MPAs. Moreover, the research and monitoring should include those terrestrial and marine areas that significantly affect the MPA.

Socio-economic factors, such as the economic benefits brought by the MPA, can be just as important as biological ones. Indeed, it is often the combination of the two that provides the most valuable information to the manager. For example, if a no-fishing policy is to be reviewed, the manager would need to know the measured changes in fish stocks and the effect on the livelihoods of fishers. It is also important to appreciate the values and needs of the human societies involved, and the capabilities and interests of the institutions that work with the management team. Natural and social scientists should contribute at every stage: the approach should be inter-disciplinary.

The resulting analysis should consider all relevant practices in a given location – typically including fisheries, aquaculture, agriculture, forestry, industry, waste disposal and tourism – in the context of the conservation objectives of the MPA and the needs and aspirations of the communities affected. It should distinguish between issues that are important over the long term (e.g. climate change, population growth and the consumption habits of society) and more immediate concerns, such as those associated with conflicts among user groups.

Table 2 contains examples of research and monitoring relevant to particularly common issues – pollution, fishery management and the destruction and restoration of coastal habitats. The guidance in Table 2 is suitable for large MPAs covering marine ecosystems or to integrated coastal management.

6.5.3 Find out what is already known

Once the objectives and ambit of the research and monitoring are decided, the next stage is to plan the detailed programme. First, it is vital to find out what is already known. This may mean sifting through and assessing a large amount of information of variable quality on a wide range of topics, a process that requires skill and judgement.

Local scientists can help, especially in evaluating the source and quality of research results, as can other local people. The process should identify any obvious gaps in scientific knowledge, their likely implications for the MPA and the possibilities of filling them within a realistic time and cost.

Table 2. Examples of research and monitoring for MPAs (Source: Kelleher, 1999)

Topic	Examples of research	Examples of Monitoring
Pollution: Contaminant inputs (i.e. to control priorities)	Identifying major sources (industry, agriculture, fisheries, sewage, shipping, etc) and pathways (pipes/sewers, rivers, atmosphere, discards from ships, etc); developing suitable sampling and analytical methods.	Quantify loads of priority contaminants (e.g. heavy metals, nutrients, organochlorines, TBT, oil, faecal coliform bacteria).
Fishery management: Stock depletion. causes and solutions	Investigate life-cycles, reproductive features, feeding requirements and habitats of affected species; identify factors (climatic, trophic, human etc) controlling inter-annual variations in these characteristics; determine local factors limiting recruitment, such as fishing methods and intensity, predation, disease, poor water quality, reduced spawning habitat, etc.	Implement a schedule of measurements to obtain more reliable data on temporal variations in key parameters as identified from prior research (e.g. numbers and age-classes of fish or shellfish harvested by different methods, availability of prey species, variations in water and prey quality, rates
Conservation of habitats and biodiversity: Impacts of development/use of coastal areas and resources	Identify, classify and map remaining natural (undeveloped) habitats and compare with any historical records; characterize associated biotic communities and exploitable living resources; evaluate their inter-dependencies, ecological importance and sensitivities to human activities; identify factors that may determine habitat sustainability and appropriate measurable indicators of these factors; quantify relative extents of modified habitats and areas reclaimed for housing, industry, agriculture, aquaculture, forestry, tourism and recreation, transport, harbours and marinas; develop an interactive, computerized database to hold all such records.	Implement a long-term programme to quantify physical, biological and ecological changes in habitats with a particular focus on more sensitive species, communities and processes; develop indicators of long-term sustainability derived from prior research; maintain up-to-date records on rates of physical development and changes in patterns and intensities of human activities; record changes in demography, tourist numbers, aquaculture, fishery production, port traffic, offshore aggregate extraction, sewage and waste generation and other factors that may increase pressures on habitats and resources, or reduce biodiversity.

While each area presents its own challenge, there is a great deal of scientific knowledge relevant to MPAs to build on and borrow from. Often, special research is not necessary to answer management questions – they can be answered by looking at experience elsewhere.

6.5.4 Design and establish the research and monitoring programme

Without careful design and a systematic approach, volumes of information can be collected at great expense and effort, but these will not enable the critical questions to be answered. Simple and inexpensive technology is often all that is needed. Complex technology often absorbs much time and resources but confers only marginal benefits. Technology should never be applied for its own sake.

The precise design, scale and scope of a monitoring programme depend on the characteristics of the MPA. In many cases, the resources to establish and implement fully the level of research and monitoring identified are not available. The emphasis should then be on those elements that are most critical to assessing and achieving the objectives of the MPA. It is particularly important to measure changes in the ecology of the MPA, and resulting effects on the socio-economic condition of the human communities that depend on it.

All the science funded by the MPA programme should be subject to peer review. It is especially important for competitive proposals to be reviewed before funding decisions are made, so that scientific cooperation is not jeopardized by suspicions of unfairness.

Involving nearby scientific institutions is helpful. Their scientists are likely to be familiar with the historical and social roots of conflicts and may therefore be best able to deal with them. Physical proximity facilitates meetings and joint effort: modern electronic communication has many advantages, but nothing is as effective in solving complex problems as a group of people meeting and working together.

6.5.5 Getting Familiar with Critical Coastal & Marine Habitats: Overview

6.5.5.1 Mangrove Ecosystem:

India has only 2.66% of the world's mangroves, covering an estimated area of 4827 km². About 57% of this extent is found on the east coast, 23% on the west coast and the remaining 20% on the Bay Islands (Andaman and Nicobar). Insular mangroves are present in the Andaman and Nicobar Islands, where many tidal estuaries, small rivers, neritic islets and lagoons support a rich mangrove flora. The coastal zone, in general, and the mangroves in particular, are used for multiple purposes such as recreation, tourism, forestry, agriculture, aquaculture, housing and commercial fishing. Our knowledge about the occurrence and distribution of mangrove species is inadequate. The mangroves of India comprise 69 species excluding species found in salt marshes and other associated species, under 42 genera and 27 families. Mangroves serve as a wildlife sanctuary, especially in the Sunderbans in West Bengal, Orissa and Andaman and Nicobar Islands. Mangroves are also important nursery areas for the juveniles of many commercially important fish and shellfishes (Robertson & Duke 1987⁶) and play important roles in coastal protection and water quality (Saenger et al 1983⁷). Mangrove forests are one of the most productive and biodiverse wetlands on Earth. It is very important to develop standard methods for monitoring changes in mangrove habitats.



6 Robertson, A.I and Duke, N.C. (1987). Mangroves as nursery sites; comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in Tropical Australia. *Mar. Biol.* 96, 193-205.

7 Saenger P, Hegerl EJ, Davie JDS. 1983. Global status of mangrove ecosystems. *The Environmentalist* 3 (supplement 3).

6.5.5.2 Sea Grass Ecosystem:

Sea grasses are underwater flowering plants that often occur in vast meadows and provide nurseries, shelter, and food for a variety of commercially, recreationally, and ecologically important species (e.g., fishes, sea turtles, Dugong, sea horses, crustaceans). Additionally, sea grasses filter estuarine and coastal waters of nutrients, contaminants, and sediments and are closely linked to other community types: in the tropics to coral reef systems and mangrove forests, and in temperate waters to salt marshes, kelp forests, and oyster reefs. Existing at the interface of the land margin and the world's oceans, sea grasses are threatened by numerous anthropogenic impacts as well as global climate change. Humans, through commercial and subsistence fishing, and endangered fauna worldwide depend on sea grasses for a living.

Sea grasses are angiosperms (flowering plants) more closely related to terrestrial lilies and gingers than to true grasses. They grow in sediment on the sea floor with erect, elongate leaves and a buried root-like structure (rhizomes).

There are about 60 described species of sea grasses worldwide, within 12 genera, and 4 families. Sea grasses are unique amongst flowering plants, in that all but one genus can live entirely immersed in seawater. *Enhalus acoroides*, an Indo-Pacific species, is the exception, as it must emerge to the surface to reproduce; all others can flower and be pollinated under water. Adaptation to a marine environment imposes major constraints on morphology and structure. The restriction of sea grasses to seawater has obviously influenced their geographic distribution and speciation. Sea grasses are often closely linked to other community types. In the tropics, the associations are likely to be complex interactions with mangrove communities and coral reef systems.

Tropical sea grasses have important interactions with mangroves and coral reefs. All these systems exert a stabilizing effect on the environment, resulting in important physical and biological support for the other communities.

Barrier reefs protect coastlines, and the lagoon formed between the reef and the mainland is protected from waves, allowing mangrove and sea grass communities to develop. Sea grasses trap sediment and slow water movement, causing suspended sediment to fall out. Trapping of sediment benefits coral by reducing sediment loads in the water.

Mangroves trap sediment from the land, reducing the chance of sea grasses and corals being smothered. Sediment banks accumulated by sea grasses may eventually form substrate that can be colonized by mangroves. All three communities trap and hold nutrients, preventing them from being dispersed and lost into the surrounding oceanic waters.

A number of general parameters are critical in determining whether sea grass will grow and persist. These include physical parameters that regulate the physiological activity of sea grasses (temperature, salinity, waves, currents, depth, substrate and day length), natural phenomena that limit the photosynthetic activity of the plants (light, nutrients, epiphytes and diseases), and anthropogenic inputs that inhibit the access to available plant resources (nutrient and sediment loading). Various combinations of these parameters will permit, encourage or eliminate sea grass from a specific location.

Tropical sea grasses occupy a variety of coastal habitats. Tropical sea grass meadows typically occur in most shallow, sheltered soft-bottomed marine coastlines and estuaries. These meadows may be monospecific or may consist of multispecies communities, sometimes with up to 12 species present within one location. The stresses and limitations to sea grasses in the tropics are generally different from those in temperate or subarctic regions. Thermal impacts most often

result from high water temperatures or overexposure to warm air; osmotic impacts result from hypersalinity due to evaporation; radiation impacts result from high irradiance and UV exposure.

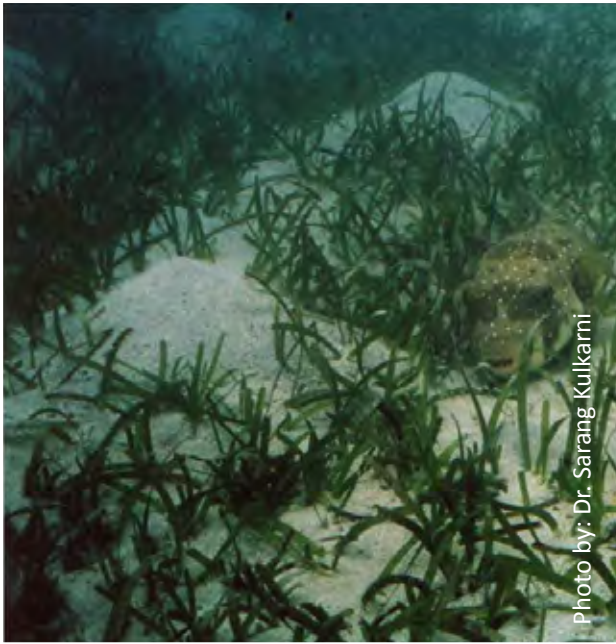
‘The greatest depth at which sea grasses are found is determined by the availability of light for photosynthesis. Exposure at low tide, wave action and associated turbidity and low salinity from fresh water inflow determine sea grass species survival at the shallow edge. Sea grasses survive in the intertidal zone especially in sites sheltered from wave action or where there is entrapment of water at low tide, (e.g., reef platforms and tide pools), protecting the sea grasses from exposure (to heat, drying) at low tide.

The habitat complexity within sea grass meadows enhances the diversity and abundance of animals. Sea grasses on reef flats and near estuaries are also nutrient sinks, buffering or filtering nutrient and chemical inputs to the marine environment. The high primary production rates of sea grasses are closely linked to the high production rates of associated fisheries. These plants support numerous herbivore- and detritivore-based food chains, and are considered as very productive pastures of the sea. The associated economic values of sea grass meadows are very large, although not always easy to quantify. Tropical sea grass meadows vary seasonally and between years. The potential for widespread sea grass loss has been well documented. The causes of loss can be natural such as cyclones and floods, or human influences such as dredging, agricultural runoff, industrial runoff or oil spills.

Loss of sea grasses has been reported from most parts of the world, sometimes from natural causes, e.g., high energy storms or “wasting disease”. More commonly, loss has resulted from human activities, e.g., as a consequence of eutrophication or land reclamation and changes in land use.

Anthropogenic impacts on sea grass meadows are continuing to destroy or degrade these coastal ecosystems and decrease their yield of natural resources. It is important to document sea grass species diversity and distribution, to be able to identify areas requiring conservation measures. Responsive management based on adequate information will help prevent any further significant areas and species being lost. In order to determine the importance of sea grass ecosystems and to detect changes that occur through perturbations (both man-made and natural), it is useful to map the distribution and density of existing sea grass meadows. Most importantly, sea grasses must be monitored in a statistically valid framework to determine natural variability in the extent of sea grasses (e.g., seasonal dieback) before estimates of loss or gain due to perturbation can be made. Coastal management agencies need to know what levels of change are likely to be ecologically or economically important, and sampling designs for baseline and monitoring surveys need to be sufficient to measure changes that are statistically significant. Spatial and temporal changes in sea grass abundance and species composition must be measured and interpreted with respect to prevailing environmental conditions. These may need to be measured seasonally, monthly, or weekly, depending on the nature of their variability, and the aims of the study. Physical parameters important to sea grass growth and survival include light (turbidity, depth), sediment type and chemistry, and nutrient levels. Detailed studies of changes in the structure of sea grass communities are essential to understand the role of these communities and the effects of disturbances on their composition, structure and rate of recovery.

Sea grass ecosystems in the tropics, particularly in India, have been given low priority by the scientific community and environmentalists. The expanse and density of sea grasses have significantly declined in most of these regions, including India. Although they extend over less than 1% of the ocean, they play an important role in the coast zone and provide ecosystem services and goods that have higher values compared with other marine habitats. Furthermore, recent studies have demonstrated that sea grasses can reduce the impacts of ocean acidification and act as an important carbon sink in the marine environment.



The global distribution and abundance of sea grasses have changed over evolutionary time in response to sea level changes, physical modification of coastlines and global climate change. Multiple stresses, including sediment and nutrient runoff, physical disturbances, invasive species, diseases, commercial fishing practices, aquaculture, overgrazing, algal blooms and global warming, cause sea grass declines at scales ranging from a few square metres to hundreds of square kilometres.

6.5.5.3 Seaweed ecosystem:

Seaweeds are a fascinating and diverse group of organisms living in the Earth's ocean. They can be found attached to rocks in the intertidal zones, washed up on the beaches, in giant underwater forests, and floating on the ocean's surface. They can be very tiny, or quite large, growing more than 20 meters.

Though they have many plant-like features, they are not true vascular plants. They are macro algae which come under the kingdom Protista that means they are neither plants nor animals. Seaweeds are not grouped with the true plants because they lack a specialized vascular system, roots, stem leaves and enclosed reproductive structure like flower and cones. However, like true plants, seaweeds are photosynthetic; they convert energy from sunlight into the materials needed for growth. Within their cells seaweeds have the green pigment chlorophyll, which absorbs the sunlight they need for photosynthesis. Chlorophyll is also responsible for the green colouration of many seaweeds. In addition to that some seaweeds contains other light absorbing pigments. These pigments can be red, blue, brown or golden and are responsible for beautiful colouration of red and brown algae.

Instead of roots seaweeds have holdfasts, which attach them to the sea floor. A holdfast is not necessary for water and nutrient uptake, but is needed as an anchor. Holdfasts are made up of many finger-like projections called haptera.

The thick masses of seaweeds provide an environment for a distinctive and specialized group of marine animals and plants, many of which are not found elsewhere. The beds of the different seaweeds provides feeding, breeding grounds and shelter for many micro and macro organisms including fishes and thus have a significant role in food chains.



Photo by: Dr. Sarang Kulkarni

Sargassum is a genus of brown (class Phaeophyceae) macroalgae (seaweed) in the order Fucales. It is one of the algin yielding seaweeds, growing abundantly in Indian waters. (Kaliaperumal and Kalimuthu 1997⁸). The thick masses of *Sargassum* provide an environment for a distinctive and specialised group of marine organisms, many of which are not found elsewhere.

Numerous species are distributed throughout the temperate and tropical oceans of the world, where they generally inhabit shallow water and coral reefs. However, the genus is best known for its free floating. While most species within the class Phaeophyceae are predominantly cold water organisms that benefit from nutrient upwelling, the genus *Sargassum* appears to be an exception to this general rule. Any number of the normally benthic species may take on a planktonic, often pelagic existence after being removed from reefs during rough weather. However, two species (*S. natans* and *S. fluitans*) have become holopelagic — reproducing vegetatively and never getting attached to the seafloor during their life-cycle.

The thick masses of *Sargassum* provide an environment for a distinctive and specialised group of marine animals and plants, many of which are not found elsewhere. Large beds of *Sargassum* are commonly found in shallow water (up to 6 metres) with a rocky substratum. These beds of *Sargassum* support rich marine life and also act as breeding areas for fish and nursery grounds for juvenile fish. These algae also grows in the subtidal region and attach themselves to moderately exposed or sheltered rocks. These tropical populations often undergo seasonal cycles of growth and decay in concert with seasonal changes in sea temperature.

6.5.5.4 Coral reefs:

Coral reefs are among the largest and most diverse ecosystems. They are held together by calcium carbonate structures secreted by polyps. Corals comes under the class Anthozoa of the phylum Cnidaria. Comprising over 6,000 known species, anthozoans also includes sea fans, sea pansies and anemones. Stony corals (scleractinians) make up the largest order of anthozo-

8 Kaliaperumal, N., and Kalimuthu, S. 1997. Seaweed potential and its exploitation in India. *Seaweed Research and Utilisation*, 19: 33–40

ans, and are the group primarily responsible for laying the foundations of, and building up, reef structures. For the most part, scleractinians are colonial organisms composed of hundreds to thousands of identical polyps.

Reef-building corals are restricted in their geographic distribution. This is because the algal-cnidarian symbiotic machinery needs a narrow and consistent band of environmental conditions to produce the copious quantities of limestone necessary for reef formation. The formation of highly consolidated reefs only occurs where the temperature does not fall below 18°C for extended periods of time. In Japan, where this has been studied in detail, and approximately half of all coral species occur where the sea temperature regularly falls to 14°C and approximately 25% occur where it falls to 11 °C. Many grow optimally in water temperatures between 23 °C and 29 °C, but some can tolerate temperatures as high as 40 °C for limited periods of time. Most require very salty (saline) water (32-42 parts per thousand (PPT)). The water must be clear to permit high light penetration. The corals' requirement of intense light also explains why most reef-building species are restricted to the euphotic (light penetration) zone, approximately 70 metres. Most corals, like other cnidarians, contain symbiotic algae called zooxanthellae. If these algal cells are expelled by the polyps, which can occur if the colony undergoes prolonged physiological stress, the host may die shortly afterwards. The symbiotic zooxanthellae also confers their colour to the polyp. If the zooxanthellae are expelled, the colony takes on a stark white appearance, which is commonly described as “coral bleaching”.

Coral reefs begin to form when free-swimming coral larvae (planulae) attach themselves to the submerged edges of islands or continents. As the corals grow and expand, the reefs take on one of three major characteristic structures—fringing, barrier or atoll. Fringing reefs, which are the most common, project seaward directly from the shore, forming borders along the shoreline and surrounding islands. Barrier reefs also border shorelines, but at a greater distance. They are separated from their adjacent landmass by a lagoon of open, often deep, water. If a fringing reef forms around a volcanic island that subsides completely below sea level while the coral continues to grow upward, an atoll forms. Atolls are usually circular or oval, with a central lagoon. Parts of the reef platform may emerge as one or more islands, and breaks in the reef provide access to the central lagoon.

The high productivity of coral reef ecosystems results principally from their flowing water, efficient biological recycling, and high retention of nutrients. The coral polyps have symbiotic



algae, zooxanthellae, within their tissues, which process the polyps waste products before they are excreted, thus retaining such vital nutrients as phosphates. Zooxanthellae utilise nitrates, phosphates and carbon dioxide produced in the polyps and, through photosynthesis, generate oxygen and organic compounds that the coral polyps can use. Living corals exist as a veneer over a porous limestone base that accumulates mainly through two mechanisms: the active growth of organisms (corals, molluscs and calcareous algae) and the cementation of calcareous debris (dead and broken corals and molluscs) by encrusting organisms (algae, bryozoans and sponges).

The great number of holes and crevices in a reef provide abundant shelters for fishes and invertebrates and are important fish nurseries. In addition, highly specialised creatures have become dependent for their survival on the reef environment. This environment provides a solid substrate for many bottom-living organisms (clams, sponges, tunicates, sea fans, anemones and algae) on which to settle and grow. For many other species, a coral reef is a critical habitat during a particularly vulnerable or critical stage of their life-cycles. The different parts of the reef are used for feeding, for spawning, as nursery grounds and for shelter.

An important function of fringing reefs along the wave-swept shores is preventing coastal erosion and storm damage. This is particularly important for regions with low-lying coastal plains, where fringing and barrier reefs protect the coast from the ravages of tropical storms and tidal waves. Fringing reefs are self-repairing breakwaters which permit the continued existence of hundreds of atolls and numerous other low tropical islands, as well as protect thousands of miles of continental coastline. Entire island archipelagos owe their existence to the reef building process of past millennia and the protective role of sea-level reefs. These islands are valuable to the communities inhabiting islands and coasts of tropical nations and recreation areas for their subsistence, security and cultural value. Protection from disturbance in such critical habitats is also essential for maintaining higher fisheries returns.

The physical structure of most ecological communities is formed by plants and in coral reefs it is formed mainly by corals. Variations in the abundance of these 'structural species' are critical to the dynamics of the whole community, including the associated 'interstitial species' such as mobile animals. Disturbances, which have been common events in the evolutionary history of both aquatic and terrestrial ecological assemblages are among the more important of the mechanisms that cause variations in structural species. This role has long been recognized in the study of recovery after disturbance.

Coral reefs are among the most valuable ecosystems on Earth, providing people with goods and services that include food, storm protection, and recreational opportunities. Despite their importance, coral reef ecosystems are in decline from a myriad of man-made and natural threats.

Degradation of coral reefs

Coral reefs are very sensitive to disturbances whether they are natural or anthropogenic. Mortality due to natural physical and biological disturbances is a routine process that is vital to the maintenance of diversity in coral reefs and many other systems. However, over the last few decades, coral reefs are being degraded on a global scale by a wide range of impacts, and their very existence is threatened by various causes such as global warming and sea level changes, storms, predation by the Crown-of-Thorns Starfish (COTS) and the gastropod genus *Drupella*, diseases, industrial pollution, overexploitation of reef resources, destructive fishing practices, tourism, and sedimentation.

As a result, descriptions about declining reef health are commonplace, and many reefs have recently experienced a drastic reduction in coral cover and richness, and a concomitant increase in algal cover. However, the causes and consequences of changing coral communities remain

contentious, particularly whether they are of natural or anthropogenic origin, and whether the persistence of scleractinian corals through geological time and historic disturbances should alleviate or accentuate concern. Coral community structure studies are valuable tools for assessing the severity of any given threat. Investigations of coral community structure at different spatial scales highlight the dependence of ecological dynamics on the spatial scale and those conducted at different temporal scales show that present trends are not predictable from history but may well be related to human-induced environmental modifications. Observation of the ecological dynamics of living reef communities over yearly to decadal time scales demonstrates that species compositions fluctuate greatly with changing environmental conditions. The temporal and spatial scales of observation have been central to arguments about the significance of recent changes in the structures of coral reef communities. While reefs appear to be highly susceptible to disturbances and unpredictable on a time scale of years to decades, some are known to persist.'

Bio-monitoring of the coral reef communities and their condition has often been a purpose of surveys. A major consideration in coral reef survey studies for bio-monitoring purposes is how to measure coral stress responses and how to relate them to the relevant environmental variables.

Throughout the world, integrated coastal zone planning and management have been recognised as necessary steps on the way to sustainable development. The establishment of marine protected areas is one aspect of coastal zone planning and management that was rapidly adopted in many tropical countries, particularly with respect to tourism and fisheries development in coral reef areas.

Unfortunately, in an effort to rapidly protect these precious resources, some developing nations established marine reserves and parks before management plans had been completed. For coral reef protected areas, no matter how well the ecosystem within the protected area boundary is protected, the system will be influenced by factors outside the park and truly effective coral reef conservation needs must extend onto land where the major disturbing influences originate. Though land management and sustainable rural development seem far removed from reef conservation, they will probably for longer way towards protecting the reef decline. To control excessive sedimentation and nutrient input is of great benefit to the habitats and commercial enterprises, both at the source and at the destination, both on the land and on the coral reef. Soil and nutrients are valuable to the farms and other terrestrial enterprises, and sediment and nutrients are damaging to fisheries, tourism, and other coral reef enterprises. Sedimentation from improper land management is the form of pollution most harmful to coral reefs. A major block to development of an operative integrated coastal area management programme is the fact that is that the administrative law often demands precisely defined boundaries usually near the shoreline, but the natural law and ecological processes operate through distances that vary in space and time.

Coral reefs in India

In India, major coral reef formations occur in the Lakshadweep, Andaman and Nicobar Islands, Gulf of Mannar and Gulf of Kachch. The recently explored Angria Bank (65 nautical miles off Sindhudurg coast, Maharashtra), also has over 400 square kilometres of coral reef. Various areas such as Malvan, Vijaydurg, Ratnagiri (Maharashtra), Netrani Island (Karnataka) and Goa have patchy coral areas.



6.5.5.5 Rocky shores

A rocky shore consists of rocky ledges with tide pools, boulders and pebbles. A rocky shore biodiversity hotspots area which has a hard rocky substratum which form diverse habitats in the form of crevices, wall and caves which support diverse and abundant fish population. Community of hardy plants and animals and each species is specially adapted for coping with the harsh environment around it. The plants and animals interact with each other and with their habitat to form the rocky shore ecosystem.

There are a wide range of intertidal habitats, each of which is divided into separate zones based on the influence of the tide. Spring tides occur every two weeks at times of the full and new moon. The best time to study the shore is during these tides as they rise further up and drop lower down the shore than neap tides, which happen between spring tides.

Seashore life occurs in zones on the shore, according to how tolerant different species are of exposure to air and sunlight. Above the level of the highest tides is the splash zone, strongly affected by salt spray. The upper shore is not covered by every high tide, usually only those of spring tides. Very few species can tolerate the relatively dry conditions of the upper shore. Most seashore animals and plants live in the middle shore, the main area of the shore which is covered and uncovered by every tide. The lower shore is only exposed during the low tides of spring tides, and this is where many delicate species may be found – those that cannot withstand much exposure.

Herbivores organisms including limpet, abalone and periwinkles, graze on young seaweeds and other plants growing on rocks. Carnivores, such as larger molluscs and crabs, hunt and scavenge for food. Others, for example zooplankton (microscopic animal life), feed on phytoplankton (microscopic plant life in the sea). Intertidal organisms are also dependant on the sea for their reproduction. Many of these organisms must shed their eggs or larvae into the sea to survive

6.5.5.6 Estuaries

An estuary is a body of water formed where freshwater from rivers and streams flows into the ocean, mixing with the seawater. Estuaries and the lands surrounding them are places of transition from land to sea, and from freshwater to saltwater. Although influenced by the tides, estuaries are protected from the full force of ocean waves, winds, and storms by the reefs, barrier islands, or fingers of land, mud, or sand that surround them. The complete salinity range from 0 to 35 ppt is seen from the head (river end) to the mouth (sea end) of an estuary. About 100 such channels of varying sizes and shapes occur along the coast of India. Each estuary receives its freshwater from drainage channels of a river basin. The banks of estuarine channels form a favoured location for human settlements, which use the estuaries for fishing and commerce, but nowadays also for dumping civic and industrial waste.



Photo by: Dr. Sarang Kulkarni

Estuaries are usually biologically highly productive zones. They also act as a filter for some dissolved constituents in river water; these precipitate in the zone where river water meets seawater. More important is the trapping of suspended mud and sand carried by rivers which leads to delta formations around estuaries. Major estuaries occur in the Bay of Bengal. Many estuaries are locations of some of the major seaports. Most of the India's major estuaries occur on the east coast. In contrast, the estuaries on the west coast are smaller. Two typical examples of estuaries on the west coast are the Mandovi and Zuari estuaries located to the north and south of the main campus of the National Institute of Oceanography at Dona Paula, Goa.

6.5.5.7 Coastal Wetlands

Wetlands are areas where dry land meets or is saturated by water and are characterised by the presence of water-dependent species of plants and animals. As an integral part of the water cycle, wetlands are amongst the most productive ecosystems on earth and are of great economic and cultural importance to mankind.

The term "wetland" is a relatively new coinage (Smart, 1997) that covers a broad range of distinctive habitat types which do not fit neatly into aquatic/terrestrial classification systems. Wetlands commonly occupy a transitional zone between wet and generally dry environments and share characteristics of both. Collectively, they range from permanently or intermittently wet land to shallow water and land-water margins (Rubec et al, 1999⁹).

Whilst they have traditionally been associated with areas of shallow water, such as marshes, swamps and peatbogs, there is no scientific reason to restrict their definition to freshwater habitat types. On the other hand, a line must be drawn when delimiting coastal and marine wetlands to avoid extending such a definition to all water surfaces of the world, including oceans and seas

A common frame of reference is now provided by the Convention on Wetlands of International Importance Especially as Waterfowl Habitat, concluded in Ramsar, Iran on 2 February 1971.

The internationally agreed definition describes wetlands very broadly as areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

⁹ Rubec, P.J., J.C.W. Bexley, H. Norris, M.S. Coyne, M.E. Monaco, S.G. Smith, and J.S. Ault. 1999. Suitability modeling to delineate habitat essential to sustainable fisheries. In: L.R. Benaka (ed.), Fish habitat: Essential fish habitat and rehabilitation, Am. Fish. Soc. Symp. 22:108-133.



This represents the first attempt by the international community to develop a coordinating concept for a specific group of ecosystems and provides a useful starting point for wetland identification and management. However, the definition is not free of difficulty: some have considered that it makes the description of wetlands and their uses and threats more complex (OECD, 1996).

6.5.6 Functioning of critical habitats

Critical processes at the ecosystem level influence plant productivity, soil fertility, water quality, atmospheric chemistry, and many other local and global environmental conditions that ultimately affect human welfare. These ecosystem processes are controlled by both the diversity and identity of the plant, animal, and microbial species living within a community. Human modifications to the living community in an ecosystem as well as to the collective biodiversity of the earth can therefore alter ecological functions and life support services that are vital to the well-being of human societies. Substantial changes have already occurred, especially local and global losses of biodiversity. The primary cause has been widespread human transformation of once highly diverse natural ecosystems into relatively species-poor managed ecosystems. Recent studies suggest that such reductions in biodiversity can alter both the magnitude and the stability of ecosystem processes, especially when biodiversity is reduced to the low levels typical of many managed systems.

Available evidence has identified the following certainties concerning biodiversity and ecosystem functioning:

- Human impacts on global biodiversity have been dramatic, resulting in unprecedented losses in global biodiversity at all levels, from genes and species to entire ecosystems.
- Local declines in biodiversity are even more dramatic than global declines, and the beneficial effects of many organisms on local processes are lost long before the species become globally extinct.
- Many ecosystem processes are sensitive to declines in biodiversity.
- Changes in the identity and abundance of species in an ecosystem can be as important as changes in biodiversity in influencing ecosystem processes.

The functioning of an ecosystem reflects the collective life activities (feeding, growing, moving, excreting waste, etc.) of plants, animals, and microbes and the effects these activities have on the physical and chemical conditions of their environment. (Note that functioning means showing ac-

tivity and does not imply that organisms perform purposeful roles in ecosystem-level processes.) A functioning ecosystem is one that exhibits biological and chemical activities characteristic of its type.

A marine ecosystem contains detritus and hundreds of kinds of organisms including bacteria, phytoplankton, zooplankton, fishes, mammals, and birds. All these components are connected in a complex food web by evolving interactions. Ecosystems carry out a diverse array of processes that provide both goods and services to humans. It also becomes important to understand what impacts an ecosystem can tolerate before major structural changes occur, and how reversible these changes are. In this respect, improved understanding of ecosystem dynamics is critical to predict and manage the consequences of environmental variability and human impacts, such as those induced by marine fisheries, an activity targeting specific species and size-classes.

Coral reef and mangrove ecosystems function in a symbiotic relationship, which enhances tropical and subtropical coastal environments. The health and extent of coral reefs are largely dependent on coastal mangrove forests, which stabilize shorelines, remove pollutants, improve water quality, and provide nursery habitats that maintain fisheries. If fisheries are degraded due to the destruction or loss of mangrove habitats, then coral reefs will be adversely affected. Corals are correlated with the strength of fisheries and without viable fisheries, coral reefs cannot survive.

Given the connectivity among tropical marine habitats, their great ecological and economic importance and the suite of threats to their health, it is important to understand how ecosystem processes function across whole seascapes. A better understanding of processes will illuminate the ecological and societal consequences of both natural and anthropogenic disturbances to the ecosystem. Furthermore, a better understanding of processes will enable the effects of potential management options, perhaps aimed at enhancing coral reef resilience, to be mapped, modelled and compared.

Functional value indicates the importance of a particular habitat to a particular process. For example, we document that a sea grass bed has a higher (more important) functional contribution to primary production than, say, a mud flat. Wherever possible, we use direct measures of a process, but proxies were used where necessary. For example, the density of herbivores and piscivores was used as a proxy for secondary and tertiary production because few data are available to convert biomass to rates of production. This need to integrate static data on states with data on rates reflects the lack of empirical observations for many processes in many habitats. In addition to assigning functional values, we also assess the susceptibility of habitats to impacts from hurricanes, coral bleaching and disease. Because each of these disturbances is habitat specific, this analysis aims to indicate possible changes to the functional value of marine habitats. Habitats represent an appropriate scale for reviewing functional values and susceptibility because, by definition, they are relatively homogeneous areas that might be expected to have a consistent contribution to a given process or response to a particular impact.

6.5.7 Importance of critical habitat

Critical habitats can be defined as ‘habitats that are critical to the survival of the species or community concerned and the actions needed to protect those habitats’ where survival means the long term security or persistence of the species, that is, that it recovers to the point it is no longer endangered or threatened with extinction.

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Specifically, critical habitat areas include:

- Areas where the species is currently known to breed, feed, rest and raise young;
- Areas where the species may not presently occur which are critical if the species is to recover from its presently endangered state and to persist in the long term despite environmental change;
- Areas of migration, such as movement or migratory corridors which may be critical to long-term population viability.

Scientists will typically assess both the physical and biological habitat features needed for the life and successful reproduction of the threatened species. It is when these geographic area(s) are considered essential for the conservation of a threatened or endangered species that it is defined as ‘critical habitat’ and provisions for special management and protection are made.

Critical habitats are a broad conservation tool that has been implemented in diverse ways. In the past, it has been most successful as a regulatory power to impose specific management regimes in both the terrestrial and marine environments.

Coral reef habitats, sea grass beds and mangrove stands provide many important ecosystem goods and services such as coastal defence, sediment production, primary production, fisheries and the maintenance of high diversity of species. Furthermore, all three systems often occur in close proximity, and many physical and ecological processes transcend individual habitats. For example, estuarine mangroves trap riverine sediments that might otherwise discharge onto reefs and cause mortality through sedimentation. Ecological linkages among habitats include the migration of organisms on an ontogenetic or diurnal basis. Many snapper, grunt and parrotfish species, for example, undertake ontogenetic shifts in habitat use from seagrass beds or mangroves to their adult coral reef habitats. Abiotic and ecological links frequently underpin key economic resources such as the valuable fishery sector. The coastal zone also generates significant revenue from tourism including through the snorkelling and scuba diving industry in Malvan, Maharashtra, as with the Andaman and Lakshadweep islands), much of which is focused on shallow marine habitats. The economic and ecological importance of tropical marine habitats is threatened by fundamental changes to their ecology, including increases in macroalgal cover and concomitant decreases in coral cover on reefs, reductions in the biomass of fish assemblages and species extinctions. Changes to marine ecosystems globally have been attributed to a suite of anthropogenic factors, including pollution, coastal development, overfishing, the El Nino and introduced pathogens.

6.5.8 Getting familiar with critical coastal and marine species

Understanding the key indicator species helps understand the status of any ecosystem in a short time. Though marine ecosystems or their critical habitats are complex ecosystems, it is relatively easy to identify the key indicator species for assessment and monitoring.





6.6. Conducting the assessment

6.6.1 Basic steps

Conducting assessment of critical habitats and species included the following steps:

Step 1- Collecting data in field

Step 2 - Manage and compile the data

Step 3 -Analyse the data

Step 4- Interpretation and peer-review of data

Step 5 -Communicating the results and adapting the management planning based on the evaluation

Step 6- continuously monitor the indicators at a regular frequency



6.6.2 Assessment of Mangrove Habitats

Source : Prakash, S., Chinnasamy, R., and Sivakumar, K. (2013)

Schwarz et al (2004) developed the method described in the following section. It can be used to understand the distribution, habitat and character of mangroves and their changes over time.

6.6.2.1 Choosing sites

Study sites should be selected so as to be representative of the type of habitat so that the results will also be relevant to other parts of the mangrove habitat. A predetermined number of sites should be delineated within the area of interest. Monitoring multiple sites (replicates) will help account for natural variability. Monitoring transects over time is the recommended approach. This means that one or more sites need to be chosen where transects can be established that can be easily located at a later date. For a statistically rigorous monitoring programme, it is essential to have more than one transect at each site. The choice of the number of replicate transects will depend on the size of a given estuary or the size of the area of interest in an estuary, as well as the specific question of interest regarding a particular community group. It is suggested that carrying out the following method be used on at least two transects across similar boundaries of interest at each site (Figure 3).

6.6.2.2 Frequency of sampling

The methods outlined in the following should be used on an annual basis and all the parameters should be sampled at the same time of the year, as much as possible. The reason for this is that the production, survival and growth of mangrove seedlings have a seasonal component. With sampling at the same time of the year, differences in seedling numbers between annual monitoring events will reflect year-to-year changes rather than seasonal fluctuations. Additional sampling using the same methods outlined below can be carried out at 6-month intervals to obtain a seasonal component if that is of interest.

Physical characteristics may be sampled more frequently, at least initially, to build an understanding of how quickly things change at the study site.

6.6.2.3 Methods of sampling

Each transects needs to be permanently marked so that it can be returned to on different occasions and in successive years. Wooden stakes (approximately 100 cm × 5 cm × 5 cm) hammered into the ground will fulfil this purpose. Ideally these stakes will also be located with a GPS position and a simple sketch map made of the relevant features so that transects can be relocated if the markers are lost. Making measurements on transects running perpendicular to channels and/or the shoreline is recommended; however, the exact location will depend on the selected location or interest.

6.6.2.4 Placing transect

The selected site needs to be marked at each end of the two replicate transects by hammering a tantalized wooden stake (approximately 100 cm × 5 cm × 5 cm) into the ground. The length of transect, and the location relative to the mangrove boundary, will depend on the characteristics of the selected site. The important thing is to ensure that the transect is long enough to cover the habitats of interest (e.g., edge of mangrove forest and mudflat or edge of mangrove forest and salt marsh—as an indication, it is likely to be 20–50 m long). It is important to place permanent markers so that transects can be relocated. The GPS location also needs to be noted where the stakes are placed in case they are removed or lost at any time.

6.6.2.5 Habitat boundaries on mangrove transects

Transect is delimited using marked rope or measuring tape laid between the stakes. Record which stake is equivalent to zero, and this should be the same on subsequent visits. Walk along one side of the transect line only (to avoid trampling) and note the distance on the transect line where there are changes in plant communities (e.g., sea grasses, mangrove seedlings, saplings, pneumatophores and mangrove trees) or surface features, including different types of sediment.

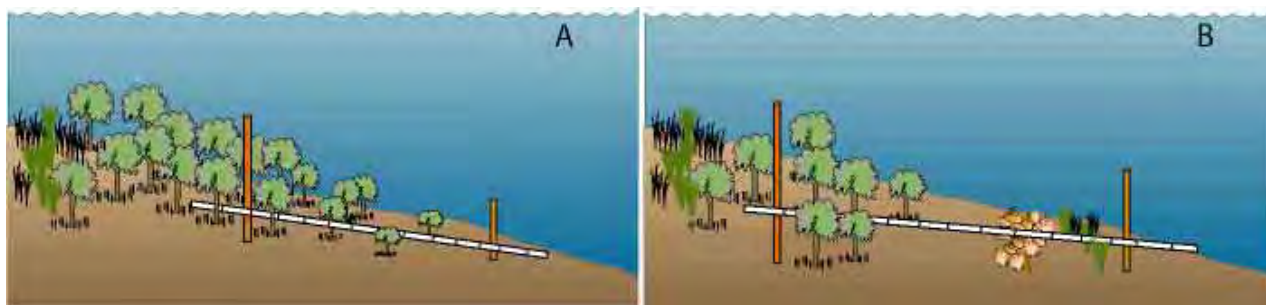


Figure 3: Permanent markers with a temporary measuring tape laid between them across (A) a mangrove mudflat/sand flat boundary and (B) mangrove/shell bank/salt marsh/mudflat boundaries (Source: Schwarz et al (2004))

6.6.2.6 Mangrove community characteristics across boundaries

This method enables you to follow changes in relative numbers of seedlings, saplings and trees between years and so better understand how a forest develops with time. The seaward boundary between the mangroves and tidal flats is likely to be selected as the main boundary of the area. However, the same methods can be used across other boundaries if doing this is relevant to the selected site.

A plot that crosses a mangrove forest boundary should be marked. See Figure 4 for an example. The plot size will depend on the characteristics of the selected site (e.g. 5 m × 10 m was appropriate for sparse shrub and seedling cover on a sand flat, while 5 m × 1 m or 2 m × 1 m was appropriate for dense areas of seedlings in very muddy habitats). It is important that one edge of the plot run along the transect and that an accurate record of the location of the plot relative to the transect be maintained for future reference. A sketch can help. Ensure that the plot overlaps the existing boundary of mangrove trees and a mostly clear area where mangroves might be expected to expand into overtime. Within the plot, measurements should be taken of the following variables, related to the characteristics of mangroves: (a) total number of trees, (b) total number of saplings and (c) total number of seedlings.

If the number of seedlings in the plot is too large to count, counting can be done of all individuals in smaller subplots and the number multiplied up to the area of interest. It is important to keep a record of exactly which methods were used. On subsequent visits, carry out mangroves counts in exactly the same plots using the same methods.

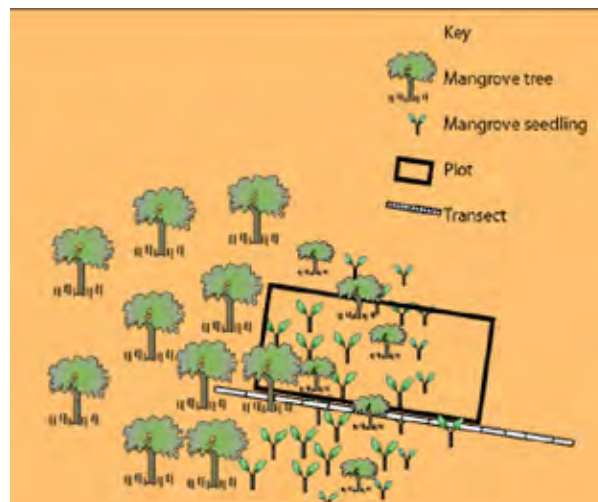


Figure 4: Plan view of the boundary of a mangrove forest showing a transect line crossing a boundary of trees into seedlings and the positioning of a 5 m x 1 m plot (black rectangle). If the number of seedlings in the plot is too large to count, three 1 m x 1 m subplots could be laid and the numbers of seedlings in each of these counted. (Adopted from Schwarz et al (2004))

Mangrove monitoring data sheet is given on next page

6.6.2.7 Mapping of mangroves at community level using satellite imagery

The SAC study (2012) envisages mapping mangroves at the community level (1:25,000 scale) for all maritime states/union territories with mangroves. These are Andhra Pradesh, Goa, Maharashtra, Orissa, Karnataka, Kerala, Puducherry, Tamil Nadu, Gujarat, West Bengal and the Andaman and Nicobar Islands. IRS P6 LISS-III and LISS-IV data of 2005–2007 (for October–March) have been utilized for discerning mangrove communities of the coasts of Andhra Pradesh, Goa, Maharashtra, Orissa, Karnataka, Kerala and Puducherry (Figure 5). As mangrove forests are tide inundated, care was taken to utilize data sets of coastal regions relating to low tides. For delineating fringe mangroves along narrow creeks and new plantation areas, QuickBird data available from Google Earth services were also utilized.

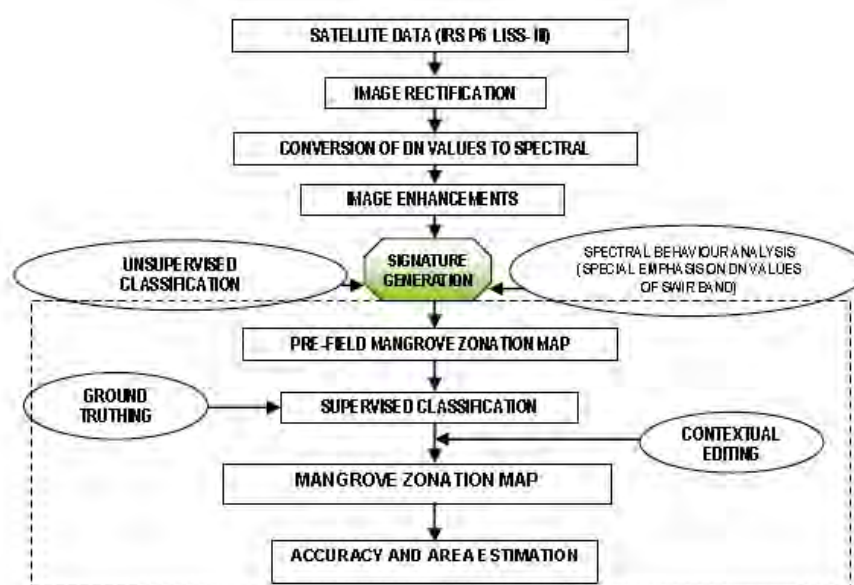


Figure 5. Methodology for mapping mangrove communities (Source: SAC (2012))

IRS P6 LISS-III data are considered to be the primary data source for digital data analysis. Digital values are converted to spectral radiance values using equations and calibration coefficients obtained from the sensor calibration details available in the metadata.

$$L_{rad} = \{[DN / \text{max grey}] \times [L_{max} - L_{min}]\} + L_{min}$$

where DN = digital number of each pixel and max grey = 255 for LISS-III.

As the information available regarding community zonation was scanty, geo-referenced spectral radiance images were subjected to unsupervised classification using the commonly used Iterative Self-Organizing Data Analysis (ISODATA) classifier to start the work. The ISODATA method uses the minimum spectral distance to assign a cluster for each candidate pixel. Depending upon the scene characteristics, arbitrary clusters are specified with a convergence threshold of 0.99. The clusters thus obtained were colour coded for better visual discrimination, and pre-field classification maps were prepared. From the field observations, the elevation of land, level of salinity and duration of tidal inundation were found to be the predominant factors influencing the species composition. The false colour composite developed from the digital data is able to discern the major communities to a considerable extent. To identify the subtle differences in species composition, classified outputs developed from the ISODATA classifier are used in ground truthing. Ground truth points are selected in such a way to sufficiently represent all the digitally discernible communities. Geographical coordinate information, species composition and dominance, influence of tidal inundation and digital view of each selected reference point are also collected. Based on the ground truth information, supervised classification is performed using a sufficient number of training sets for each community. The mangrove community classes thus obtained is evaluated critically against the ground information and expert knowledge. The shortwave infrared band of IRS LISS-III, with a spatial resolution of 23.5 m, has been effectively used for differentiating mangroves from other vegetative cover. Contextual editing is performed wherever necessary to improve the classification accuracy. Further details are available in SAC (2012).

6.6.2.8 Mangrove Monitoring sheet

(10 x 10 m Plot, 5 plots in a line with 100 m interval)

Name of Observer:

Date:

Time:

Tide: Low/High **Type:** Natural/ Plantation

Weather:

GPS Location:

Grid No.:

Plot No.:

Sl.No.	Species	Tree/ Shrub	GBH (cm) Tree	Alive/ Dead	Phenology Status	Height	No. of seed lings	Canopy Cover	Compaction of ground (cm)	Salinity

Phenology Status: (Inflorescence/ Flowering/development of fruit/ ripened fruit)

Total number of saplings/seedlings inside the plot

Compaction - Sediment availability check using penetrometer (50 m long 0.5 cm dia iron rod, drop from 1 m height, 5 readings in each plot:

Height - Tree height:

Salinity – Salinity of water found in a pit inside or near to plot

6.6.2.9 Monitoring of gastropods and crabs in mangroves

(Each monitoring should come on separate page)

(2 m radius circular plot inside the Mangrove plot, each individual in a separate row)

Name of Observer:

Date:

Time:

Tide: Low/High Type: Natural/ Plantation

Weather:

GPS Location:

Grid No.:

Plot No.:

Sl.No.	Gastropods/ crabs	Species	Size (length/ diameter/width) (cm)	Weight (gm)	Remarks



6.6.3 Estuarine Ecosystems

Source : Prakash, S., Chinnasamy, R., and Sivakumar, K. (2013)

An estuary can be defined as a partially enclosed body of water that is open to the sea (permanently or periodically) and within which there are variations in salinity due to dilution of seawater with freshwater from land drainage.

Although estuaries are considered short-term features of the landscape on a geological timescale, they are often highly productive areas that play important roles at the boundary between land and sea. They also play a vital role in global ocean processes due to their intricate habitat structure. Estuarine systems are considered to be highly exploited due to continuous human disturbances as a result of the availability of natural resources. These water bodies are ill-treated through domestic, agricultural and industrial wastes. They have the capacity of self-purification due to the diurnal tidal cycle and other ecological interactions. However, the exponential growth of urbanization and industrialization together is of major concern because of the degradation of habitats and loss of ecosystem services and socio-economic values caused. Tropical estuaries are influenced by the monsoon, which produces significant changes in the physio-chemical and biological characteristics of the system.

Successful management of estuaries and their catchments for sustainable use in the future requires us to focus our knowledge and efforts on developing simple, defensible and cost-effective strategies to assess and monitor estuary conditions and predict the results of management actions. However, despite the great amount of research on estuaries, our ability to predict the consequences of change or even develop a set of cost-effective monitoring indicators of estuary conditions is limited. The reasons for this include a lack of funding to determine the monitoring indicators, the complexity of estuaries and the fact that most research has focused on local estuary problems and cannot be applied easily to other sites. Thus the development of management techniques to assess estuarine habitat status and change is currently a major resource management priority within India.

Estuarine habitat assessment:

Three potential assessment tools were developed by Robertson et al (2002¹⁰) to represent different scales of investigation in an estuarine monitoring protocol:

(1) Preliminary assessment includes development of a decision matrix that allows managers to prioritize estuaries for monitoring and provide a defensible basis for their long-term planning.

10 Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson, S.J., Tuckey, B.J. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

(2) Broad-scale habitat mapping includes the development of robust GIS-based methodology for mapping the spatial distribution of intertidal estuarine habitats.

(3) Fine-scale environmental monitoring includes development of methodology to measure the spatial variations and inter-relationships of a suite of commonly measured indicators.

6.6.4 Beach Ecosystems

Tremendous population and developmental pressures have been building up in coastal areas for the last four decades. The urbanization and the rapid growth of coastal cities have been dominant population trends over the last few decades, leading to the development of numerous mega cities in all coastal regions around the world. Furthermore, global climate change and the threat of an accelerated sea level rise exacerbate the high risks of storm surges, severe waves and tsunamis.

Over the last 100 years, the global sea level rose by 1.0–2.5 mm per year. Present estimates of the future sea-level rise induced by climate change range from 20 to 86 cm for the year 2100, with a best estimate of 49 cm. It has been estimated that a 1-m rise in sea-level could displace nearly 7 million people from their homes in India (IPCC 2001). Study the natural hazards and coastal processes of the Indian coast scientifically has assumed greater significance after the December 2004 tsunami because the country learned lessons about the impacts of natural hazards in terms of high potential for damage to life, property and the environment.

Several recent studies indicate that beach protection strategies and changes in the behaviour or frequency of storms can be more important than the projected acceleration of the sea level rise in determining future beach erosion rates. Thus there is no simple relationship between the rising sea level and the horizontal movement of the shoreline, and sediment budget approaches are most useful in assessing beach response to climate change. The combined effects of beach erosion and storms can lead to erosion or inundation of other coastal systems. The impacts of an accelerated sea level rise on gravel beaches have received less attention compared with sandy beaches. These sandy beach systems are threatened by the rising sea level.

Beach assessment¹¹

Beaches that are used by the turtles nesting need to be monitored regularly, which is crucial in the conservation of marine turtles. Beaches and dunes are in constant motion, continually changing shape and shifting position in response to winds, waves, tides, the relative sea level and human activities. The most significant changes occur seasonally and after storms. During summer, beaches are generally higher and sandier than they are in winter. During the winter, the 'missing' sand moves from the beach to near-shore areas to form sandbars. This happens as a result of changing wave shape due to more intense storm activity. Comparing season-to-season profiles and profiles taken before and after a significant storm clearly illustrates the important changes taking place along the shoreline and how quickly coastal landforms change.

11 Source : Prakash, S., Chinnasamy, R., and Sivakumar, K. (2013)

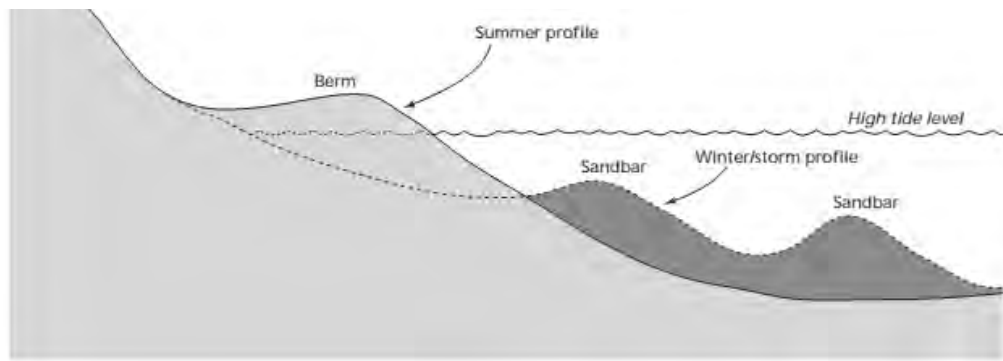


Figure 6. Typical summer and winter beach profiles (WHOI 2000)

Two-dimensional on-shore models are ideal for management applications as they are simpler and have fewer inputs compared with three-dimensional models or models that include long shore interactions. By definition, stable dynamic beaches do not experience a significant net long shore transport and as such lend themselves to a two-dimensional on-offshore model approach. The impact of concern is the potential increase in offshore sediment transport due to higher water levels. Currently available models for determining impacts of different water level scenarios have been provided by Geomorphic Solutions (2009). These models are used for estimating short-term shoreline evolution, such as changes during individual storm events, making them ideal for a ‘worst case scenario’ approach. The models vary in complexity and approach; however, they are limited by the current understanding of the physics of near-shore sediment transport.

Further, the use of a two-dimensional model such as SBEACH (Storm-Induced BEACH CHange model), which was developed by USACE for simulating cross-shore beach, berm and dune erosion produced by storm waves and changes in water levels, can be validated with field data. Physical processes represented in the model include varying wave conditions and water levels, irregular initial profile shapes, bar formation and movement and setup and run up. The model has been refined over time to include irregular waves and dune over-wash. In fact, it is continuously being updated and extensively evaluated and widely used.



6.6.5 Assessment methods for sea turtles

Five species of sea turtle including the Olive Ridely (*Lepidochelys olivacea*), Green Sea Turtle (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Leatherback (*Dermochelys coriacea*) and Loggerhead turtle (*Caretta caretta*) are reported to occur in Indian waters.

6.6.5.1 Conservation concerns

All the species except the Loggerhead nest along the Indian coast line. All the five species are protected under the Wildlife Protection Act 1972 and are listed in Appendix I of Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2008). They are a priority for conservation under the Convention on the Conservation of Migratory Species of Wild Animals (CMS); however, fisheries bycatches, hunting, habitat destruction, and other environmental factors have severely reduced the marine turtle populations (WWF 2003).

Globally, conservation efforts are trying to secure stable populations by raising awareness, influencing international treaties and policies, reducing bycatch and actively protecting nesting beaches. It is vital for turtle conservation to work with local communities and develop an understanding of the risks of poaching turtles for meat, eggs or trade. Non-consumptive uses such as ecotourism and employment in turtle conservation can help local communities and promote conservation at the same time (WWF 2003).

Sea turtle monitoring programmes are an important component as they eventually provide information on habitats, diversity, distribution and other natural and anthropogenic pressures. However, a reduction in the mortality will increase the current survival rate of marine turtles across their range. Such programmes, established in each jurisdiction, will be able to identify any reductions in mortality, the effectiveness of management measures in reducing mortality and subsequent increases in populations over the medium to long term.

6.6.5.2 Aims of turtle monitoring programmes:

The aim of sea turtle monitoring programmes is to determine increases or decreases in sea turtle populations of nesting species, increasing at the same time the hatchling success through beach controlling and hatchery management. By collecting data through continuous nesting seasons, these programmes allow us to make reliable comparisons.

6.6.5.3 Key information to be gathered

Monitoring programmes should gather and collate information through

- Assessment of marine turtle mortality related to fisheries
- Assessment of marine turtle distribution at sea from information provided by fishers and
- Assessment of the feasibility of tracking entangled turtles after release to determine survivorship and migratory paths.

6.6.5.4 Equipment required for turtle monitoring

- Torch with red filter
- Dark clothing
- Notebooks with data sheets
- Closed-toed shoes
- 2 pencils
- Tagging pliers
- Tags
- Alcohol
- Measuring tape (50/100 m and 5 m)
- Gloves
- Untreated plastic bags
- GPS (not essential)

6.6.5.5 Conducting the assessment¹²

Dividing the beach into sectors

Setting out beach transects is a good way to determine which area has the highest density of nests. This can decide the place of the hatchery as well as areas in need of higher vigilance. Every 100 metres a marker post is to be placed to facilitate quick recording of location when gathering data. Starting at 0.1 kilometres on the stretch of beach, marker posts from 1 to 10 indicate the distance or as far as monitoring is manageable.

Beach patrolling

Patrol groups should never be larger than four to six people. Larger groups are harder to control when working with a turtle, and there is a much higher risk of disturbing the animal. Make sure the group is aware of the etiquette when working with a turtle along with the health and safety regulations, such as wearing closed toe shoes. The pace on the beach is slow to avoid accidents. It is vital that the lead researcher be at the front to spot signs of turtle activity. When a track is spotted, the researcher will leave the group at the high tide line and investigate the situation, returning to the team with the plan of action. If the turtle is found choosing her nesting spot the team must stay at least 5 metres away so that the animal is not scared. This is when the turtle is most sensitive to disruptions. When the researcher believes the turtle has nearly completed digging her nest the group can join in from behind the turtle, never walking directly in front of her.

The use of light during the patrol has to be minimized as too much light will deter turtles from nesting. The use of video-equipment and cameras is strongly discouraged as the flash of the camera or the white light on the video-camera may disturb the turtle and could scare her back to the sea.

Approaching a turtle

Sea turtles are sensitive animals. When choosing a nesting site they can easily get scared. Delaying the nesting process may lead to dangerous consequences for the turtle including death. Their sight and hearing are very primitive but they can easily detect vibrations while on the beach, making it important to keep patrol groups small. Furthermore, their sense of smell is very well developed and therefore the use of insect repellents or strong odours while working around a turtle will not only disturb the nesting process but may also pose a health risk to the animals due to chemicals contained in products.

¹² Source : Frontier Nicaragua (2009)

Always approach a turtle from behind to minimize disturbance. Never stand in front of her unless checking her tags as she returns to sea on a false crawl (i.e. without nesting). The tails and cloacae of turtles are very sensitive and therefore must never be touched. Whilst waiting for the turtle to lay it is advised to kneel down behind her. During this period keep activity to a minimum, as the priority is for her to lay her eggs successfully. Measuring and tagging should be done after the turtle has laid.

Location of nest

The sea turtle species nest at different levels of the beach. To record the location, it is advised to use the sector markers as well as a zone description. The recorded locations are wherever the turtle lays her eggs, not where she enters the beach.

Zone descriptions are shown below:

Low Tide (L)

Nest placed on the low tide zone on the beach

High Tide (H)

Nest placed on the high tide zone on the beach

Vegetation (V)

Nest placed in vegetation or dunes on the beach

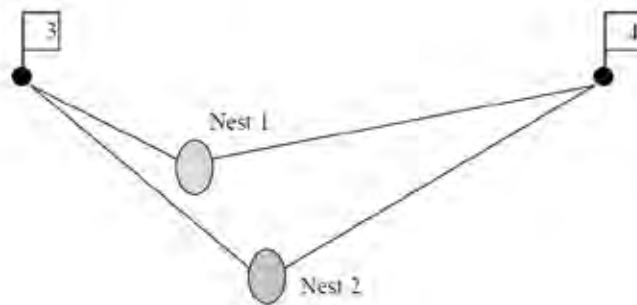


Illustration of nest location recording

With sector markers you can either record distance to nearest northern marker or, if you are working on a beach extending far inland, record the distance to the two nearest sector markers which provides you with a more precise recording of the nest's location within the zones. If available, GPS can be used for nest recordings but the accuracy must be noted and the reliability of the technique evaluated.

Nest information

Relocated (R) or in situ (IS) need to be recorded under NEST on the data sheet. In situ means you either are not able to find the eggs due to the turtle camouflaging the nest or the nest is located close to the hatchery and is thus provided with sufficient protection and is not in need of relocation. Preferably the position of the in situ nest needs to be measured in order to excavate the nest at a later stage. When the turtle does not nest, FC (False Crawl) is noted.

Nesting process

The nesting process of every species of sea turtle can be divided into seven activities. The activity of the turtle needs to be recorded when the patrol team discovers the turtle.

1. Beaching (B)

When the turtle comes out of the sea looking for a place to nest.

2. Making bed (MB)

Digging a body pit. Using both front and hind flippers to dig herself in before creating her nest cavity. The length of time differs between species, with a Leatherback taking up to 45 minutes.

3. Digging nest (D)

Digging the nest carefully with hind flippers. Nest depths and widths differ again between different species.

4. Laying eggs (L)

Laying fertile and infertile eggs. The number of eggs varies between species, with the Leatherback laying an average of 70-80 fertile eggs and 20-30 infertile eggs and the Olive Ridley laying between 80-100 fertile eggs and no infertile eggs.

5. Covering up (CU)

After the turtle has finished laying she will use her hind flippers to start pressing down sand on the eggs. This activity needs to be imitated in a relocated nest after putting the eggs in. The activity will compact the sand and therefore prevent rain entering the nest.

6. Camouflaging (C)

Camouflaging nest area with front and hind flippers. Sand is thrown over the whole area as the turtle turns. The length of time differs again between species and individual turtles. Green turtles can camouflage for up to 2 hours! This is also dependent on the level of human interference. When a turtle is disturbed, she will hurry to the sea.

7. Returning to sea (R)

After finishing the camouflaging process the turtle returns to the sea.

Counting / collecting eggs

This section focuses on egg collection for the purpose of relocation to a hatchery, but the precautions during egg handling are just as relevant if the aim is to simply count the eggs. Egg relocation can be a valuable conservation tool in areas of high poaching or erosion but should always be used as a last option after exhausting other conservation methods. Inevitably there are risks associated with moving eggs from their natural conditions.

By bag

Collecting eggs by bag has several advantages; the eggs are being handled less, which decreases the risk of cross-contamination and it keeps the turtle's fluids with the eggs, maintaining a more natural process which could influence the hatching success. The moment oviposition begins is often hard to judge. Therefore, make sure your team is prepared. While the turtle is digging her nest, the egg counter/collector sits ready behind the turtle with the re-location bags (non-chemical, doubled up to prevent breaking of bag) and wearing gloves. Nest depth should be recorded at the start of the laying process. The turtle gives a single sign as she is about to lay; she moves one or both of her hind flippers to gently cover the nest. At this moment the plastic bag needs to

be slid in below (not touching tail and cloaca). A hand can be used to lead the eggs from the cloaca into the bag. If any eggs fall outside the bag, they can be carefully fished out while the turtle is laying, but this should be avoided whenever possible. The bag needs to be pulled out when the last egg has been laid. You will know when she has finished as she will start to move. During oviposition the turtle is completely still.

Some turtle species lay infertile eggs (smaller and yolkless) together with the fertile ones. It is important to collect these infertile eggs as well as they have an important role in the survival of the fertile eggs in providing space for gas exchange and protection against predators.

By hand

When a turtle is found during or after laying her eggs, the eggs can be collected by hand. Using gloves the eggs are carefully placed in a plastic bag. The depth of the nest can be measured even after the turtle has finished laying eggs, but it should be measured without any delay.

6.6.5.6 Tagging sea turtles

Tagging should be done only when the egg laying is complete. A metal tagging scheme is a relatively cheap option compared with expensive micro-chipping techniques or the use of satellite transmitters, and standard tags can be obtained from various suppliers. There are two different sized tags; the large tag is designed for the Leatherbacks only, due to their size, while the second, smaller tag is for the smaller species including the Hawksbill, Olive Ridley, Green Turtle and Loggerhead. The turtle should be tagged on the left and the right flipper, starting with the lowest number tag on the left flipper. Before putting in a tag, clean the area of the flipper with alcohol or benadine. The tags should be cleaned with alcohol before leaving for patrol. The tag should be placed far enough into the flipper to reduce the chance of it falling out but with enough space for movement and growth (1 centimetre gap will be sufficient). Leatherbacks are tagged on their hind flippers while the other species are tagged on their front flippers next to the primary scale. It is advisable to give training in tagging to those responsible.

When a new tag is used, the tag number will not be boxed on the data sheet. Any tags read on a re-emerging turtle should have a box drawn around the tag number on the data sheet. This way information on the number of new nesting females and returning nesting females can be recorded.

Tags provide us with information not only on the individual turtles but also on the species and their migration routes. The tag carries a message that requests tags to be returned if found (dead turtles in fishing nets or washed up). A small reward may be given to the person who sends the tag back. This allows us to understand the risks turtles face.

6.6.5.7 Measuring the carapace

As with tagging, measurements take place after egg laying to avoid causing any distress during laying. Using a tape measure (preferably not a role-tape measure), the length and width of the turtle are measured. Before measuring, the sand is cleaned off the turtle's carapace to get an accurate reading. Measurements are taken twice. If there is a difference of more than 5 centimetres, a third measurement can be taken.

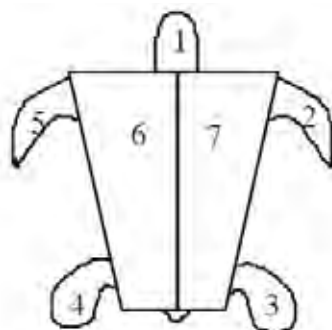
The width is always measured from the widest part of the carapace. The length measurement is taken along the centre of the carapace starting where the carapace meets the skin behind the turtle's head all the way to the notch of the carapace. When dealing with Leatherbacks you must measure to the end of the caudal projection.

The width is filled in under WCC (Width Curved Carapace) and length under LCC (Length Curved Carapace). Keep in mind that the WCC of the Olive Ridley is normally wider than the LCC.

6.6.5.8 Recording turtle injuries

Injury data provide us with information on the threats sea turtles face in the ocean. On the data sheet under comments is an outline of a turtle with numbers that correspond to parts of the turtle. For example, if an injury is identified on the front right flipper the researcher will try and detect a reason, and it will be recorded as:

Injury #2 (shark attack).



Turtle structure to reference injuries

Old tag holes (OTH) / old tag notches (OTN)

Frequently, you will come across turtles with holes in their flippers or scarred flippers due to lost tags. Such holes and scars are known as rips. An OTH is a puncture left behind after a tag has opened up, and an OTN is a notch.

Comments

Any other distinctive features of the turtle will be recorded under comments, such as injuries, fibropapillomas or fishing hooks (Couchman et. al., 2009).

6.6.5.9 Data recording sheet

Turtle assessment and monitoring data sheet

Parameters	Recorders		
	Recorder 1 name	Recorder 2 name	Recorder 3 name
Time	21.30	1.30	2.45
Date	13/01/2002	13/01/2002	13/01/2002
Distance to Sector marker	50 m to sector 3 68 m to sector 4	51 m to sector 1 47 m to sector 2	80 m to sector 9 85 m to sector 10
Zone	H	B	H
Species	Leatherback	Green	Olive Ridley
Left Tag	VA3404	796753	VA3408
Right Tag	VA3407	796754	VA3409
Carapace Length	156	162	70
Carapace Width	111	115	75
Activity	MB	R	B
Nest	R	IS	FC
Nest Depth	76	68	-
Old Tag Hole	# 3	-	-
Old Tag Notch	-	-	-
Eggs	83	76	
Infertile eggs	21	18	
Comments	Injury #2 (shark)		
	Half missing #4		

6.6.6 Assessment methods for coastal birds¹³

6.6.6.1 Assessment and monitoring methods for coastal birds

A coherent monitoring system of birds along the coastal area is important, in order to detect bird population changes, understand their causes and predict future changes. The measurement of regional population of bird dynamics should be as thorough as possible, and the aim should be to identify the population processes that are affected by environmental changes. Birds are usually monitored by counting pair numbers and densities of breeding populations (O'Connor 1985¹⁴).

However, data on population sizes and densities do not reveal the causes of population trends, neither help to predict future population changes (Elmberg et al. 2006¹⁵). Moreover, the effect of environmental changes may not reflect immediately on a breeding population. This applies in particular to those seabirds that are long-lived, do not easily change their breeding sites (Grenquist 1965;¹⁶) or may have delayed recruitment. Breeding success is a more rapid and direct indicator of environmental impact than pair numbers. Changes in breeding success may also provide clues to the factors affecting bird populations. Breeding success should therefore be included in seabird and coastal bird monitoring schemes and used in the assessment of environmental changes.

The assessment method for coast line birds will be a combination of point and round counts (Koskimies and Väisänen 1991¹⁷).

The coastal areas would be censused by walking standard routes along the shore and stopping at standard sites like feeding and wading grounds. The census route should be chosen so that all breeding birds in the area could be counted.

However, searching nests of many birds is impractical due to habitat structure, the nesting may be counted according to the pair numbers of the birds during the nesting seasons. The numbers of individuals can be converted into pair numbers according to the recommendations by Linkola (1959¹⁸) either by dividing the individual number by two or by using the number of males or females as the pair number.

13 Source: Rönkä, M., Saari, L., Hario, M., Hänninen, J. & Lehtikoinen, E. 2011: Breeding success and breeding population trends of waterfowl: implications for monitoring. - *Wildlife Biology* 17(3): 225–239.

14 O'Connor, R.J. 1985: Long-term monitoring of British bird populations. - *Ornis Fennica* 62: 73–79.

15 Elmberg, J., Nummi, P., Poysa, H., Sjöberg, K., Gunnarsson, G., Clausen, P., Guillemain, M., Rodrigues, D. & Vaananen, V.-M. 2006: The scientific basis for new and sustainable management of migratory European ducks. - *Wildlife Biology* 12(2): 121–127.

16 Grenquist, P. 1965: Changes in abundance of some duck and sea-bird populations off the coast of Finland 1949–1963. - *Finnish Game Research* 27: 1–114.

17 Koskimies, P. and R. A. Väisänen. 1991. Monitoring bird populations. Zoological Museum, Finnish Museum of Natural History. Helsinki, Finland. 144 pp.

18 Linkola, P. 1959. Zur Methodik der quantitativen Vogelforschung in den Binnengewässern. *Ornis Fennica* 36:66–78. (In German).



6.6.6.2 Case: Bird census at Gosabara wetland in Porbandar

Gujarat Council on Science and Technology (GUJCOST) sponsored

ASIAN WATERBIRD CENSUS (AWC) 2015 PORBANDAR

Objectives and Rational:

- The number of birds visiting any wetland is very important. It indicates the health of a wetland and highlights seasonal change in the bird count.
- International recognition of any wetland requires bird count.
- To be listed as Wetlands of International Importance or “Ramsar site”, a wetland must meet one or more internationally accepted criteria in relation to their zoology, botany, ecology, hydrology or limnology and importance to waterbirds.

Census is required to report data on certain criteria.

METHODOLOGY OF AWC (PORBANDAR):

17 birdwatchers from Jamnagar and Porbandar have participated in AWC. These birdwatchers were grouped in four different teams and were allotted four separate routes and covered 21 sites. AWC was conducted by birdwatchers on above mentioned sites and routes on 1st February- 2015. 2nd February-2015 is known as World Wetland Day. Mr. Dhaval Vargiya, Science Co-ordinator and Mr. Viek Bhatt, Science Communicator, Shree Sahajanand Swami District Community Science Centre, visited Shree Madressa Boys School and explained importance of wetland and threats to wetland with PowerPoint presentation on world wetland day i.e. 2nd February-2015. Team on a particular route was selected on the basis of the talent and expertise of birdwatchers. Due care was taken that each team receives at least one photographer, one expert and one or two assistants. During a day, birds migrate from one wetland to another. So there are chances that a flock of a bird may be counted twice which generates non-reliable data. So, to avoid such problems, all the sites were studied on a single day and all together.

[Source: Vargiya D. V. et al. 2015. Asian Waterbird Census (AWC) 2015 Porbandar, Shree Sahajanand Swami District Community Science Centre, Gujarat, India. Available from http://www.mokarsagar.org/get_download.php?aid=3]

6.6.6.3 Bird count using variable radius point count method

Date: **Time:** **Place:** **Location:**
Climate: **Transect Name:** **Starting time:** **End time:**
Length of Transect: **Altitude:** **Habitat: Natural / plantation**

Plot No.	Species	Numbers	Per. Dist	Activity	Remarks

6.6.6.4 Bird count using boat along estuarine canals

Date: **Time:** **Place:** **Location:**
Weather: **Canal Name:** **Starting time:** **End time:**
Starting GPS: **End GPS:**

Plot No.	Species	Numbers	Per. Dist	Activity	Remarks

6.6.7 Preparing for underwater assessment: SCUBA diving

Since the anthropogenic impact (climate change, sedimentation, over exploitation, tourism, over and destructive fishing practices etc.), scientists have felt the necessity to measure ecological processes on spatial and temporal scales. While the focus on global and ecosystem processes is indeed imperative, controlled field experiments and carefully designed surveys and monitoring programmes could be completely misinterpreted if analysis of data obtained via scuba is not also incorporated.

Scuba diving created a scientific revolution by providing direct access to underwater habitats composing a large part of the biosphere. While there have been many important specific advances, we believe that the overarching benefit of scuba for marine population, community, and ecosystem ecology has been to facilitate the direct observation and manipulations of individual organisms and their surrounding conditions.

Prior to scuba, subtidal organisms were studied primarily by peering into the water on calm and by analysing specimens collected by fishing, dredging, or plankton nets. The invention of scuba enabled scientists to observe the behavior and ecology of organisms in their natural habitats, quantify patterns, study interactions, and conduct experiments to test hypotheses about ecological processes. Scuba has been associated with an increasing number of scientific publications and the rapid increase in our knowledge of marine biodiversity.

6.6.7.1 The diving certification

This handbook strongly recommend proper certification in scuba diving preferably PADI (Professional Association of Diving Instructor) or equivalent and by qualified and experienced Scuba Diving instructor.

- Open Water Diver Certification is a full entry level certification earned by successfully completing the entire Open Water Diver Course. The PADI Open Water Diver certification qualifies you to: Dive independently while applying the knowledge and skills you learn in this course, within the limits of your training and experience
- Procure air fills, scuba equipment and other services
- Plan and conduct and log open water no stop (no decompression) dives when equipped properly and accompanied by a buddy in conditions with which you have training and/or experience
- Continue your diving training with a speciality dives in a diving programme.

6.6.7.2 Course prerequisites:

To become qualified scuba diver, you need to be comfortable in water and have basic swimming skills, so your instructor will have you do some swimming and floating - nothing extreme (200 meters and ten minute float or 300 meters mask, fin and snorkel swim and float), just to determine you have basic swimming abilities. You don't need to be an athlete, but you should be in good overall health, particularly your respiratory and circulatory systems. Mentally, you need a mature attitude, good judgement and the self-discipline to follow the guidelines and principles required for safe diving.

Before any confined water dives or water skills, your instructor will have you complete a medical statement. The information you on it will remain confidential. Because the statement identifies medical conditions that may be affected by diving, for your safety and health it's important that you complete it completely and accurately. If any of the conditions listed apply to you, as a prudent precaution, your instructor will ask you to consult a physician before participating in any water activities.

6.6.7.3 Open Water Diver course structure

Open Water Diver course consists of three segments: Confined water dives, knowledge development and open water dives. Each plays an important role in learning to dive in meeting the performance objectives you need to qualify as a diver.

The training begin in the confined water (preferably in swimming pool), during which you apply dive principles, and learn and practice dive procedures and skills. You will do this in either a swimming pool, or a body of water with pool like conditions, under your instructor's guidance and supervision. There are five confined water dives that correspond with five knowledge development sections.

Knowledge development establishes the principles and basic information all divers need to have diving safety. It's divided into five segments that you will complete primarily on your own time at your convenience using the manual and the PADI Open Water Diver video. For each segment, your instructor reviews and elaborates on the material, applying what you are learning to your specific needs, interests and the local dive environment. A short quiz confirms that you have picked up the information you need from that section.

The open water dives complete your training as an entry level diver by applying and further developing your knowledge and dive skills in a dive environment under your instructor's supervision and guidance. You will make at least four scuba diving and perhaps an optional skin dive, during this part of the Open Water Dive course.

You will be learning in a sequence that establishes skills and knowledge from the simple to the complex, with later skills and knowledge building on what you learn first. For this reason it's important to successfully complete each section before moving on to the next.

6.6.7.4 Equipment required for SCUBA diving:

SCUBA (Self Contained Underwater Breathing Apparatus) diving is highly technical but easy to use instrument oriented

Mask: Light behaves differently in water than in air and your eyes focus accordingly to how light behaves in air. That's why water makes everything blurry. The mask creates an air space so your eyes can focus.

Snorkel: Since scuba divers have a tank and regulator, you may wonder why a snorkel is a standard piece scuba gear. Snorkel is important for a few reasons when scuba diving. First, it lets you rest or swim with your face in the water, like when you are looking for something below, without wasting tank air.

Particulars



Cylinder



BCD



Wet suit (3 mm)



Gloves



Regulator



Weights



Weight Belt



Fins

Boaties



Mask and Snorkel



Underwater Knife



Compass



Dive computer



Depth finder



Underwater torch



Underwater still camera



Portable Scuba diving compressor



Lift Bag (100 kg, 200 kg, 500 kg, 1000 kg)



Inflatable boat (10 person capacity)



Out Board Motor (OBM - 25 HP)



6.6.8 Sea grass habitat assessment

The habitat complexity within sea grass meadows enhances the diversity and abundance of animals. Sea grasses on reef flats and near estuaries are also nutrient sinks, buffering or filtering nutrient and chemical inputs to the marine environment.

6.6.8.1 Why assess and monitor sea grasses?

Environment monitoring programmes provide coastal management agencies with information and assist them to make decisions with greater confidence. Sea grasses are often at the downstream end of watershed, receiving runoff from a range of agricultural, urban and industrial land-uses. Their ecological values and location in areas likely to be developed for harbors and ports have made sea grasses a useful monitoring target for assessing environmental health and impacts on coastal systems.

The ideal “bio-indicator” must show measurable and timely responses to environmental impacts. Sea grass habitats provide sessile plants - individuals, populations and communities – which can all be easily measured. Sea grass plants generally remain in place so that the prevailing anthropogenic impacts can be monitored. Improved knowledge of the relationships between various sea grass growth characteristics and environmental parameters such as light and nutrients provide very useful tools for monitoring environmental impacts on coastal sea grass systems.

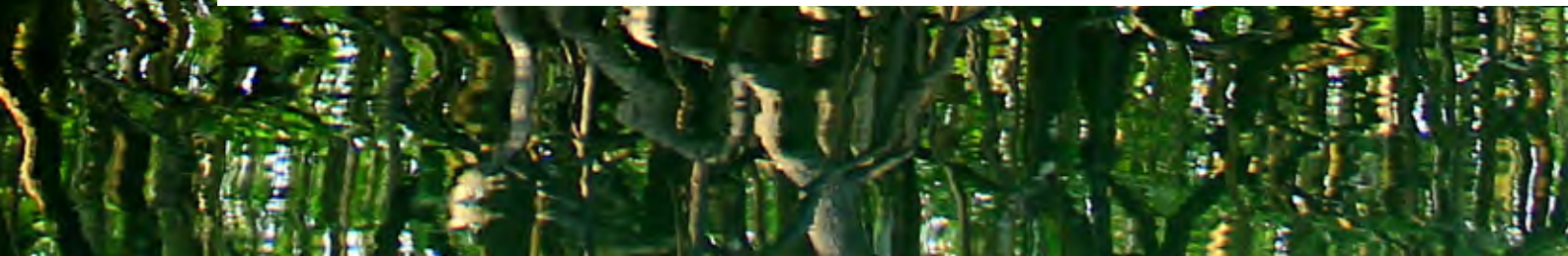
Coastal zone managers increasingly recognize the importance of sea grasses in coastal marine communities for supporting diverse flora and fauna, in supporting coastal fisheries productivity, and in stabilizing sediments and maintaining coastal water quality and clarity. In Indian waters, sea turtles and dugongs are direct grazers of sea grasses areas especially in Andaman & Nicobar Islands, Gulf of Mannar and Gulf of Kutch.

6.6.8.2 Measuring changes in sea grass habitats

Sea grass meadows can change in several ways. There can be a change in biomass without a change in area; a change in area, or shape, depth or location of a meadow; a change in species composition, plant growth and productivity; the fauna and flora associated with the meadow; or a combination of some or all of these.

Some changes will also occur naturally and on a regular seasonal basis. Environment monitoring programmes require knowledge of these patterns of natural change. They also require cost-effective data collection, selection of appropriate parameters and scales, and measures of change which are statistically appropriate for determining if management action is required.

Mapping the extent of sea grass distribution in a given area of coastline can provide a basis from which loss or gains in sea grass habitat is quantified. Such maps can be created from ground surveys using GPS or from aerial photography combined with ground truthing when available. Comparison of maps from two or more dates can quickly document the change in sea grass distribution and provide notice of a local impact.



Choosing the most efficient and appropriate parameter(s) to monitor is equally important. Sea grass species composition and its abundance, e.g., biomass (above-ground and below-ground), total area, or percent ground cover, can be measured quickly, and these have been the most commonly chosen parameters. Sea grass growth parameters (e.g., plant growth rates, plant tissue C:N:P, carbohydrate composition) are proving useful for obtaining insight into the causes and mechanisms of change in sea grass abundance. At the “meadow level”, measures of species composition, and estimates of means and variances for parameters such as biomass or percent cover, can be easily obtained.

Physical parameters measured usually include depth (below mean sea level, MSL) and sediment composition. Turbidity, light, salinity and temperature should ideally be included in monitoring, but require more frequent measurements according to the time periods over which they vary and affect sea grass growth and survival. Depth at which sea grasses occur can be a useful indicator of impact and may change according to light attenuation in the water column.

The next step is to choose biological and physical parameters that are relevant and logistically possible and to design of sampling programmes which enable the minimum monitoring effort required to detect changes which are statistically and biologically meaningful. The expected use of the data, the questions likely to be asked of the data, and the accuracy and precision of the answers required determine the type of information we collect from coastal sea grass habitats. Increased requirements for accountability in coastal management decisions has caused greater need for statistical rigor in design of sampling programmes for monitoring environmental impacts. Government agencies and coastal zone managers need to know the extent of natural change in sea grasses. The impacts - particularly habitat losses - from watershed and human activities can then be separated from normal background variation.

Monitoring programmes aim to detect change. Environment monitoring programmes which are designed to detect realistic levels of change, enable coastal management agencies to make decisions with greater confidence. Below the actual monitoring methods are described in detail.

6.6.8.3 Mapping the habitat using satellite imagery and aerial photography

In order to visualize data relating to sustainable management and conservation of sea grass ecosystems, systematic mapping and continuous monitoring are needed at different intervals (Wabnitz et al 2008¹⁹). Studies on temporal and spatial changes in the distribution of sea grasses have still not been conducted, particularly around remote islands. Currently, satellite imagery, coupled with GIS techniques, is considered to be one of the best tools for understanding changes in sea grass coverage (Wabnitz et al 2008; Nobi 2010²⁰). It is cost-effective and reliable.

Recently, studies were conducted using aerial photos and IRS-P6 LISS-III sensor imagery to gain an understanding of the geomorphology and coastal resources of the Rameswaram group of islands. Visual interpretation techniques were employed, and the satellite data were geocoded. These data were again used in the field for collecting ground control points (using handheld GPS). The satellite imagery were geo-corrected using these ground control points. Based on the image characteristics, tone, texture, pattern and association, various coastal geomorphic categories and resources were identified and mapped (Nobi et al 2010²¹).

19 WABNITZ, C.C., ANDREFOUET, S., PULLIZA, D.T., MULLERKARGER, F.E. & KRAMER, P.A. 2008. Regional scale sea grass habitat mapping in the wider Caribbean region using Landsat sensors: Applications to conservation and ecology. *Remote Sensing and Environment* 112(8): 3455-3467.

20 NOBI, E.P. 2010. Assessment and evaluation of the seagrass resources of Lakshadweep Islands (India): A remote sensing and GIS approach. Ph.D. thesis. Annamalai University

21 NOBI, E.P., SHIVAPRASAD, A., KARIKALAN, R., DILIPAN, E., THANGARADJOU, T. & SIVAKUMAR, K. 2010. Microlevel mapping of coastal geomorphology and coastal resources of Rameswaram Island, India: A remote sensing and GIS perspective. *Journal of Coastal Research* 26(3): 424-428.

Another study was conducted by Fletcher et al (2009²²) in Texas, USA to evaluate and monitor the landscape changes in the sea grass beds related to human and natural disturbances using aerial photography. High-resolution aerial colour film photography, colour space transformation, pixel threshold models and GIS technology were integrated to detect, assess and monitor 1-m ground feature changes and disturbed areas of shallow sea grass beds. The procedure entailed transforming digitized aerial colour film transparencies from the red, green and blue colour space to the intensity, hue and saturation colour space; analysing the saturation and/or intensity of the imagery and their histograms to identify bare areas; and developing threshold models to separate bare areas from vegetated area.

Maps created using this semi-automated approach had classification accuracies ranging from 75% to 100%. In a recent study, Nobi et al (2013²³) estimated the extent of restored sea grass habitats at selected islands of Lakshadweep using satellite maps, GIS and field observations. Sea grass maps were integrated for the year 2000-2008 specific areas and buffer zones were generated to delineate the restoration sites.

Attempts have been made to use different site selection models around the world (Kopp et al 1994²⁴; Short et al 2002²⁵) as mitigation projects for sea grass losses. Of the possible factors that can directly influence the survival of transplanted sea grasses, poor site selection has been identified as the major cause (Harrison 1990²⁶; Fonseca 1992²⁷).

Thus, it is better to select areas where sea grasses were present in the past for restoration as conflicts over site selection, habitat requirements and invasion of other habitats will be avoided (Calumpong & Fonseca 2001²⁸; Campbell 2002²⁹; Katwijk et al 2009³⁰).

6.6.8.4 Selection of site

The site is selected to be representative of the sea grass communities in that location. It is useful to review any available information on the distribution and status of sea grass meadows in the area, region, or country before you start. Good sources of baseline information include aerial photographs or earlier maps of sea grass habitat. It is important to use care in choosing a place to establish a site for monitoring.

A good monitoring site is

- a sea grass meadow which is typical/ representative of the location
- a sea grass meadow that is relatively homogeneous

-
- 22 FLETCHER, R.S., PULICH, W. Jr HARDEGREE, B. 2009. A semiautomated approach for monitoring landscape changes in Texas seagrass beds from aerial photography. *Journal of Coastal Research* 252: 500-506
 - 23 NOBI, E.P., DILIPAN, E., THANGARADJOU, T. & DINESH KUMAR, P.K. 2013. Restoration scaling of sea grass habitats in the oceanic islands of Lakshadweep, India using geospatial technology. *Applied Geomatics* 5(2): 167-175.
 - 24 KOPP, B.S., DOHERTY, A.M. & NIXON, S.W. 1994. A Guide to Site Selection for Eelgrass Restoration Projects in Narragansett Bay, Rhode Island. Technical Report. University of Rhode Island.
 - 25 SHORT, F.T., DAVIS, R.C., KOPP, B.S., SHORT, C.A. & BURDICK, D.M. 2002. Site selection model for optimal restoration of eelgrass, *Zostera marina* L. *Marine Ecology Progress Series* 227: 263-267.
 - 26 HARRISON, P.G. 1990. Variations in success of eelgrass transplants over a five-year period. *Environmental Conservation* 17: 157-163.
 - 27 FONSECA, M.S. 1992. Restoring seagrass systems in the United States. In: Thayer G.W. (Ed.) *Restoring the Nation's Marine Environment*, UM-SG-TS-92-06, Maryland Sea Grant Publication. Maryland: College Park. Pp. 79-110.
 - 28 CALUMPONG, H.P. & FONSECA, M.S. 2001. Seagrass transplantation and other seagrass restoration methods. In: Short, F.T. & Coles, R.G. (Eds.) *Global Seagrass Research Methods* Elsevier Science. Pp. 425-442.
 - 29 CAMPBELL, M.L. 2002. Getting the foundation right: A scientifically based management framework to aid in the planning and implementation of seagrass transplant efforts. *Bulletin of Marine Science* 71: 1405-1414.
 - 30 KATWIJK, M.M.V., BOS, A.R., DE JONGE, V.N., HANSSSEN, L.S.A.M., HERMUS, D.C.R. & DE JONG, D.J. 2009. Guidelines for seagrass restoration: Importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. *Marine Pollution Bulletin* 58(2): 179-188.

- a sea grass meadow in a place which you can come back to and monitor again at regular intervals
- a sea grass meadow that is removed from any large obvious impact such as a dredge channel, or a sewage outfall

Selecting a good monitoring site is the first critical step in any monitoring effort. For a site to be typical or representative, it should contain the same assemblage of sea grass species found throughout the area, reflect the depth range where sea grasses are typically found, and in general not be exceptional in any characteristic.

A homogeneous sea grass site has a fairly even sea grass distribution without large empty patches or physical disruptions such as reefs or tidal channels. The need for a homogeneous sea grass meadow is to enable the collection of replicate samples reflecting the natural conditions but not incorporating a high degree of variability. In this way, long term change can more easily be detected.

Clearly, a site which can be visited without difficulty is preferred since repeat access over the long term will be required. Choosing a site away from any large human or natural impact is important to insure long-term repeated monitoring without total loss of the sea grass habitat in that location.

Also, for the monitoring of representative conditions in an area, it is important to avoid an immediate or point source of impact. The aim of the monitoring is to pick up any broad changes in a sea grass community, not necessarily changes between stations within the sea grass community.

6.6.8.5 Laying transect

Transect establishment is important to ensure consistency of the monitoring programme, and is done once you have identified the most appropriate monitoring site.

Transect establishment should be achieved with minimum disturbance of the surrounding sea grass meadow.

The transect will be marked with three permanent station markers at stations A, B and C. These permanent station markers will be kept throughout the monitoring programme regardless of changes in the sea grass community.

Relocating the transect will be made easier by ensuring that the permanent markers are secure, and preparing a good sketch map and description of the site, ideally using GPS to identify the exact coordinates. When you prepare the map and description, write it in a way that someone who has never been to the site could still find it.

6.6.8.6 Monitoring sea grass beds

Sea grass beds are highly productive for fisheries by providing food and shelter for grazing fish and a place to grow for algae and invertebrates that the fish feed on. Sea grasses are nursery grounds for juveniles of commercial prawns and fishes.

Monitoring the amount of the sea grasses gives important information for fisheries but sea grass beds are naturally variable and some have annual periods of dieback. This should be considered and monitoring should be repeated at different times of the year.

Manta towing is rarely possible in sea grass beds as the visibility is too low. Three methods can be used:

- A. first is measuring the weight of living material or biomass by removing samples of it. As this is destructive, it should only be done in large sea grass beds. Second is a method to visually estimate the weight of the sea grass (biomass) by trained divers. Both methods need training and laboratory work.
- B. A simpler method is to monitor the sea grass area from year to year to see whether they are declining or enlarging. This can be done using natural landmarks and marking the outlines of the sea grass beds on a map at a very low tide.
- C. Even better is using aerial photography on a sunny day at low tide, when shallow water sea grass beds are obvious. Doing this annually at the same time of year will give a good idea of change in sea grass beds. Aerial photography will give a good indication of what is happening and what are the causes.

6.6.8.7 Sea grass monitoring sheet

Date: _____ **Time:** _____ **Place:** _____ **Location:** _____

Weather: _____ **Starting time:** _____ **End time:** _____

Transect Starting GPS: _____ **Transect End GPS:** _____

Quadrant (meter from transect origin)	Sediment (mud/ sand/shell)	% of sea grass species composition					Comments (presence of other animals/ distur- bance)
		Sea grass (Y/N)	% of sea grass Coverage	Canopy- BLade height? height	% Algae cover	% Epi- cover	
0 m							
5m							
10m							
15m							
20m							
25m							
30m							
35m							
40m							
45m							
50m							

6.6.9 Seaweeds

Seaweeds are a fascinating and diverse group of organisms living in the earth's ocean. They can be found attached to rocks in the intertidal zones, washed up on the beaches, in giant underwater forests, and floating on the ocean's surface. They can be very tiny, or quite large, growing to more than 20 metres in length.

Though they have many plant-like features, they are not true vascular plants. They are macro algae which comes under the kingdom Protista that means they are neither plants nor animals. Seaweeds are not grouped with the true plants because they lack a specialized vascular system, roots, stems, leaves and enclosed reproductive structures such as flowers and cones. However, like true plants, seaweeds are photosynthetic; they convert energy from sunlight into the materials needed for growth. Within their cells seaweeds have the green pigment chlorophyll, which absorbs the sunlight they need for photosynthesis. Chlorophyll is also responsible for the green colouration of many seaweeds. In addition to that some seaweeds contains other light absorbing pigments. These pigments can be red, blue, brown or golden and are responsible for the beautiful colouration of red and brown algae.

Instead of roots seaweeds have holdfasts, which attach them to the seafloor. A hold fast is not necessary for water and nutrient uptake, but is needed as an anchor. Holdfast are made up of many fingerlike projection called haptera.

The stalk or stem of a seaweed is called a stipe. The function of the stipe is to support the rest of the plant. The structure of the stipe varies among seaweeds; they can be flexible, stiff, gas filled, very long, short or completely absent.

The leaves of seaweeds are called blades. The main function of the blades is to provide a large surface for the absorption of sunlight. In some species the blades also support the reproductive structure of the seaweed. Some seaweeds have only blade, which may be divided, while other species have numerous blades. Many seaweeds have hollow, gas-filled structures called floats or pneumatocysts. These help to keep the photosynthetic structure of the seaweeds buoyant so they are able to absorb energy from the sun. The term thallus refers to the entire part of the seaweed.

The thick masses of seaweeds provide an environment for a distinctive and specialized group of marine animals and plants, many of which are not found elsewhere. The beds of the different seaweeds provide feeding, breeding grounds and shelter for many micro and macro organisms including fishes and thus have a significant role in the food chain.

Sargassum is the genus of numerous species of brown algae found throughout the world's tropical and temperate oceans. It is commonly found along the Indian coast wherever there are sheltered habitats. It is commonly known as seaweed. Sargassum is unique in that it is actually two things at once, a species of alga individually, and collectively a habitat for a large and diverse community of marine life.

Most people who have ever visited, either Sindhudurg or Ratnagiri coast in Maharashtra or Goa or spent any time strolling the beaches have seen *Sargassum* washed ashore. It is a common sight for snorkelers or scuba divers in Sindhudurg. It is characterised by berry-like pneumatocysts (floats) and thick leaf-like blades that almost resemble a bunch of leafy grapes with its highly branched stems. It is attached to the hard substratum with the help of holdfasts. The floats on *Sargassum* are filled mostly with oxygen with some nitrogen and



carbon dioxide present and are what give the plant its buoyancy and this fragile plant stands tall in water forming forest-like structures in the water. This provides food and cover for a large and diverse assembly of juvenile fishes and endangered invertebrates such as sea horses.

Assessment and monitoring

The occurrence of *Sargassum* in Indian waters is from the intertidal region to a depth of 10 metres, depending on the penetration of light. In Maharashtra (Ratnagiri and Sindhudurg) and Goa, *Sargassum* occurs at depths up to 5 metres.

In order to collect representative data of each *Sargassum* bed, multiple transects should be laid which are parallel to each other, perpendicular to the shore and separated from each other by a reasonable distance. The length of a transect depends upon the width of the *Sargassum* bed and extends to the outer limits of the beds where the *Sargassum* disappears. All transect points should be established with their coordinates recorded using a GPS. At each station the presence or absence of *Sargassum* should be recorded. GPS can be used to record polypoint data in the field by walking/snorkelling or by boat. These data are inputted into a GIS software to calculate the total area and polygon of each species of *Sargassum* beds. The coverage of *Sargassum* is estimated at 5 metre intervals along the transect.

A quadrat (50×50 cm²) divided into 25 squares (10×10 cm²) is placed on the substratum, and the coverage of *Sargassum* in each of the 25 squares is scored. The percentage cover of *Sargassum* in each quadrat is estimated according to the weighted average of the scores of the 25 squares. The Production of *Sargassum* is calculated by the equation: $P = B \times A \times C$ [where P (kg): production; B (kg/ m²): fresh biomass; A: total area (m²); C (%): coverage] Samples for biomass determinations are also collected at each sampling date, weighted and transported to the laboratory. In the laboratory, these biomass samples are rinsed with fresh water, and the length of branches is measured before drying. *Sargassum* samples are then dried at 60 for 24 hours to constant dry weight.

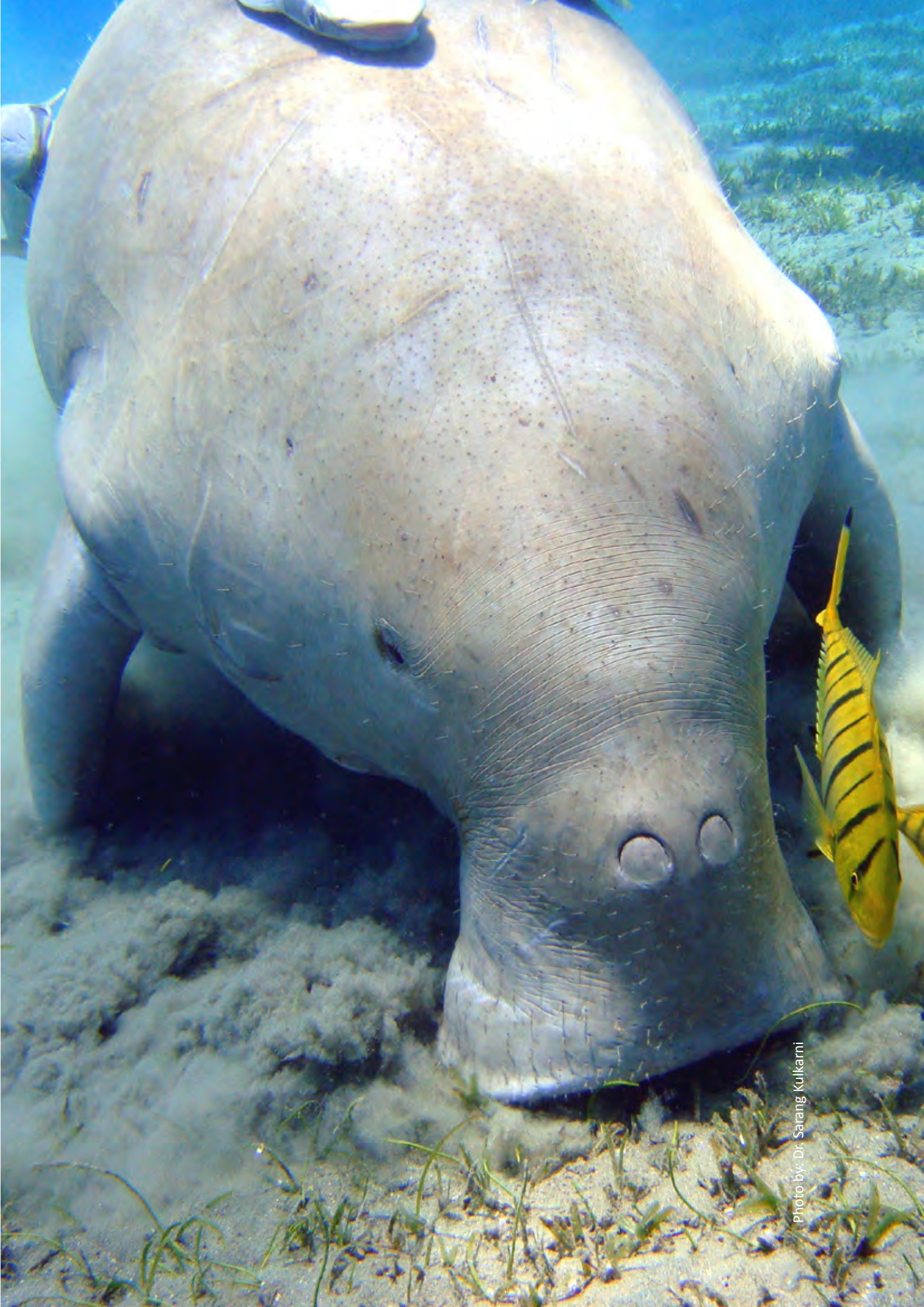


Photo by: Dr. Sarang Kulkarni

6.6.10 Methods of assessing sea mammals

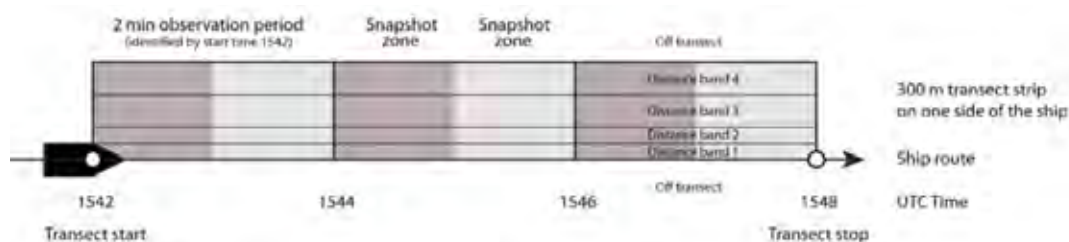
Common objectives of marine mammal monitoring programmes are to characterise species distribution and density in a given area, monitor the status of the population, monitor the impact of anthropogenic activities or biological events, or to examine the spatial and temporal habitat use to identify important areas for marine mammals, such as for feeding or breeding grounds.

Marine mammals in Indian waters includes Cetaceans (Whales, Dolphins and Porpoise) and Dugong.

6.6.10.1 Basics of mammal assessment and monitoring

As sightings of marine mammals are comparatively rare, they are treated a little differently and shall collect data through systematic line transect survey following distance sampling procedure to estimate the absolute abundances of cetaceans population from visual sighting data (Johansen et. al., 2012³¹; Hiby and Hammond 1989³²) in addition to that, Genetic, photographic, acoustic, and behavioral information of cetaceans can also be collected from the vessel.

The method involves 300 m (or 500 m) wide strip transects operated only on one side the ship (fig). Longitudinally, the transects are subdivided into so-called observation periods (e.g. 2, 5 or 10 minute intervals) and the sightings (marine mammals) are grouped under these periods. No matter where marine mammals are sighted (inside or outside the transect strip), they are always recorded. However, during active survey focus is directed to the 180° ahead of the ship. Further, the angle relative to the course of the ship and the direct distance in meters to marine mammals are always recorded (Johansen et. al., 2012)



Schematic representation of the survey methodology. In the illustrated case observation periods are 2 minutes long and snapshot counts are made every minute (two snapshots per observation period).

Schematic representation of the survey methodology. In the illustrated case observation periods are 2 minutes long and snapshot counts are made every minute (two snapshots per observation period).

31 Johansen, K.L., Boertmann, D., Mosbech, A. & Hansen, T.B. 2012. Manual for seabird and marine mammal survey on seismic vessels in Greenland. 3rd revised edition, May 2012. Aarhus University, DCE – Danish Centre for Environment and Energy, 74 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 38. <http://www.dmu.dk/Pub/SR38.pdf>

32 Hiby, A.R. & Hammond, P.S. (1989) Survey techniques for estimating abundance of cetaceans. Report of the International Whaling Commission (Spec. Issue), 11, 47–80.

6.6.10.2 Survey components

A marine mammal survey has three components:

- Number of transects
- Number of observation periods
- Observation period can hold a number of different sightings

Types of transects

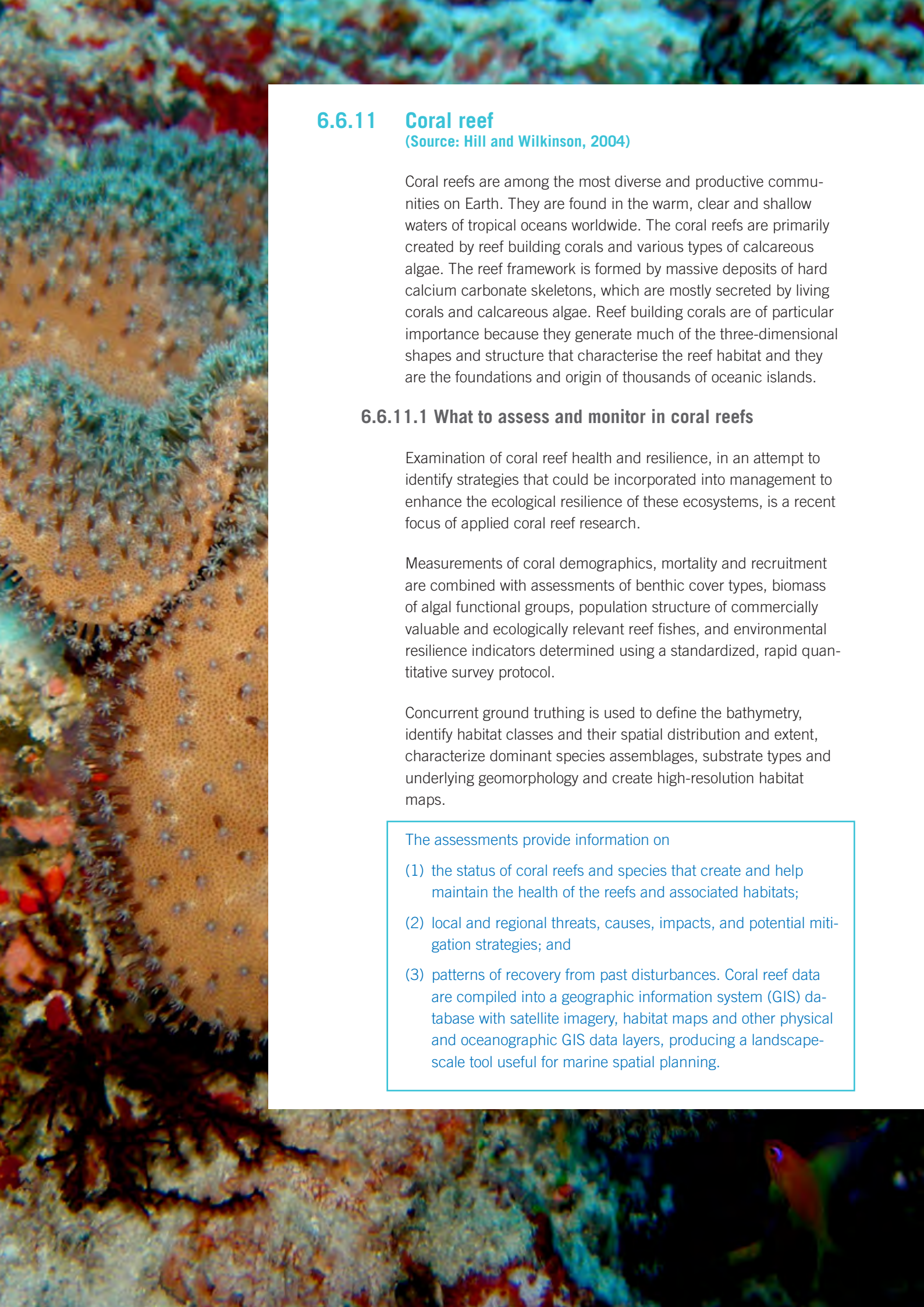
Two different transect types are used: one with a strip width of 300 metres (type A), and one with a strip width of 500 metres (type B). The use of type A as the default transect type is recommended. Type B is only to be used if the following conditions are true: the observer is experienced, visibility is excellent, and the encounter rate is low. The two different transect types should never be used on the same transect. If conditions change and it is decided to alter the transect type, then stop the current transect and start a new one using the new transect type. Don't forget to note the transect type on the recording sheets as it is essential in terms of knowing the size of the area covered (the strip width).

Visual census

The historical and still standard method for taking a census of marine mammals is visual surveying. This is done from aircraft, boats, or shore-stations, or on rare occasions from kites, balloons or remote-controlled planes. Visual surveys are normally done along line transects (e.g. Morgan 1986³³, Palka and Pollard 1999³⁴). Subsequent biostatistical modelling is used to estimate the total number of animals in a population from the number of animals seen.

33 Morgan, D.G., Estimating Vertebrate Population Densities by Line Transect Methods, Melbourne College of Advanced Education, Australia.

34 Palka, D., and J. Pollard (1999), "Adaptive line transect survey for harbor porpoises," pp. 3-11 in G.W. Garner, S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald and D.G. Robertson (eds.) Marine Mammal Survey and Assessment Methods, Proceedings of the Symposium on Surveys, Status & Trends of Marine Mammal Populations, Seattle WA, USA, 25-27 February 1998. A.A. Balkema, Rotterdam.



6.6.11 Coral reef

(Source: Hill and Wilkinson, 2004)

Coral reefs are among the most diverse and productive communities on Earth. They are found in the warm, clear and shallow waters of tropical oceans worldwide. The coral reefs are primarily created by reef building corals and various types of calcareous algae. The reef framework is formed by massive deposits of hard calcium carbonate skeletons, which are mostly secreted by living corals and calcareous algae. Reef building corals are of particular importance because they generate much of the three-dimensional shapes and structure that characterise the reef habitat and they are the foundations and origin of thousands of oceanic islands.

6.6.11.1 What to assess and monitor in coral reefs

Examination of coral reef health and resilience, in an attempt to identify strategies that could be incorporated into management to enhance the ecological resilience of these ecosystems, is a recent focus of applied coral reef research.

Measurements of coral demographics, mortality and recruitment are combined with assessments of benthic cover types, biomass of algal functional groups, population structure of commercially valuable and ecologically relevant reef fishes, and environmental resilience indicators determined using a standardized, rapid quantitative survey protocol.

Concurrent ground truthing is used to define the bathymetry, identify habitat classes and their spatial distribution and extent, characterize dominant species assemblages, substrate types and underlying geomorphology and create high-resolution habitat maps.

The assessments provide information on

- (1) the status of coral reefs and species that create and help maintain the health of the reefs and associated habitats;
- (2) local and regional threats, causes, impacts, and potential mitigation strategies; and
- (3) patterns of recovery from past disturbances. Coral reef data are compiled into a geographic information system (GIS) database with satellite imagery, habitat maps and other physical and oceanographic GIS data layers, producing a landscape-scale tool useful for marine spatial planning.

6.6.11.2: Rapid assessment protocol:

The rapid assessment protocol can be adopted from Global Coral Reef Expedition protocol and the IUCN Resilience Assessment of Coral Reefs protocol, with additional parameters. Quantitative data can be obtained on the

- coral community structure (diversity, size structure, partial mortality and condition), using 10 m × 1 m belt transects, and coral recruitment (five 0.25 m quadrats per 10 m transect);
- diversity, size and abundance of over 100 commercially valuable reef fishes (food and ornamental fishes) and ecologically relevant functional groups of reef fishes (e.g. herbivores, invertebrate feeders and piscivores) using 30 m × 1 m belt transects;
- cover and abundance of major functional groups of algae (turf algae, macroalgae, crustose coralline algae and erect coralline algae), corals and other benthic invertebrates using a point intercept method (100 points per 10 m transect); and
- approximately 50 other ecological and environmental resilience indicators.

These could be quantified (e.g. abundance of corallivores, disease prevalence), ranked on a scale of 1 to 5 (e.g. rugosity, slope), measured off satellite imagery (e.g. reef direction and size, distance from land, to nearest reef and associated habitat and to deep water), or obtained from external sources (e.g. sea surface temperature).

Coral reef assessment data are incorporated into a GIS database with satellite imagery forming a base layer, high resolution bathymetric and habitat maps developed through this programme, and other available data layers.

The manta tow technique is a tool for rapid visual assessment of coral reefs at the scale of a reef or a section of a reef. It involves towing a snorkel diver at a constant speed, behind a small boat, using a rope and a manta board (a hydrodynamic plane angled by the diver's arms to control depth). One tow is carried out over 2 minutes, after which the boat stops and the observer records the cover of live coral, dead coral and sand and rubble, selecting one out of 11 possible categories (Figure 2). These categories follow the international standard for the Global Coral Reef Monitoring Network. Surveys carried out by the AIMS Long-term Monitoring Program (LTMP) involve three tasks: manta-tow surveys for Crown of Thorn Starfish (COTS), broad-scale surveys (reef cover) and surveys for benthic sessile organisms. The AIMS LTMP also includes independent detailed surveys of reef benthos (video transects) and fish (visual census using belt transects) on permanently marked sites in contiguous habitats. Historically, this technique has been used to characterize reefs at several sites throughout the Indo-Pacific.

6.6.11.3 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 sea grass 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 using 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%.

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.
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.
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.

Manta tow

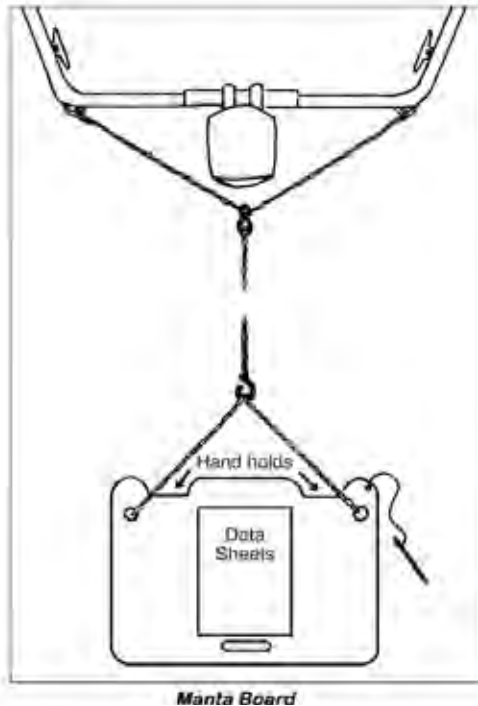
Programmes that use this method:

- Australian Institute of Marine Science Long-term Monitoring Program (AIMS LTMP);
- GCRMN.

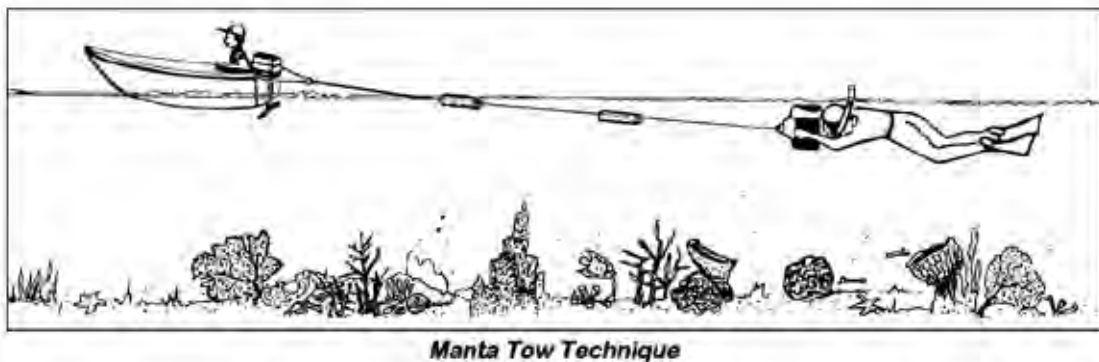
Description of method

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



Sample Manta Tow Survey Data Sheet				
Location:		Date:		
Observer:		Time:		
Tow	Percent Live Cover			Other Features
	Stony Corals	Octo-corals	Algae	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				



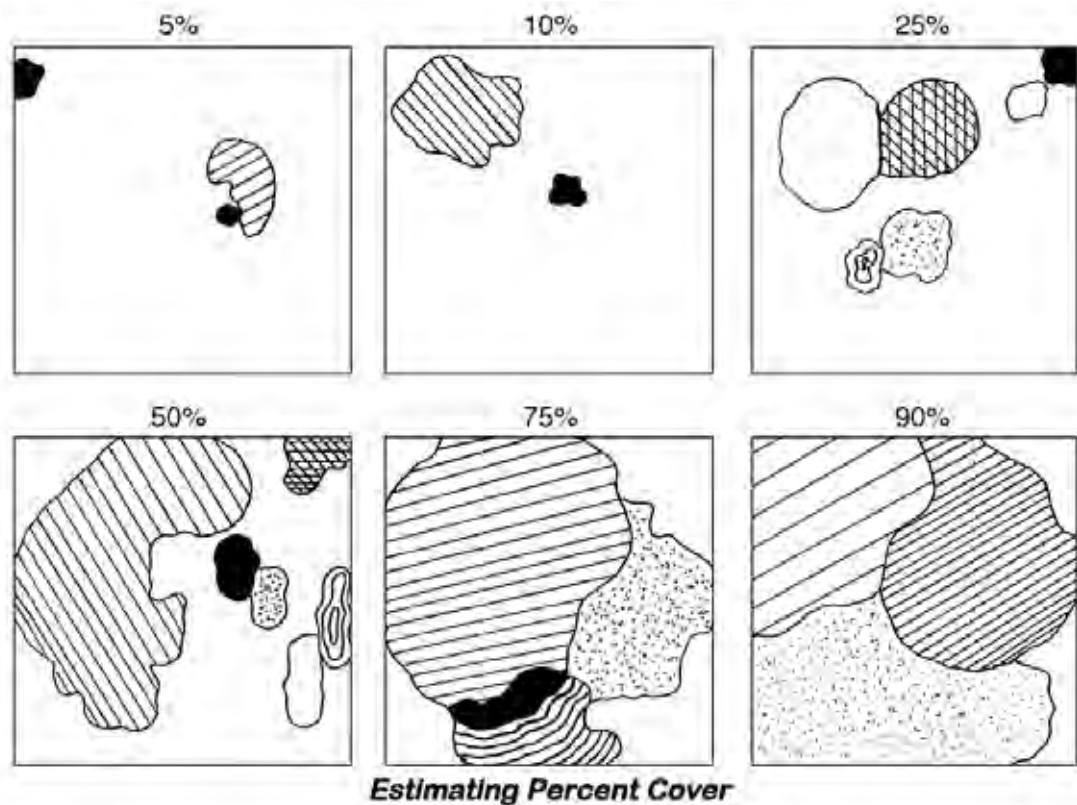
For site selection, the diver can only determine where there is continuous reef, and can provide an estimate of hard coral cover (collected as a % hard coral cover); see figure below.

Manta tows 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 tows 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 tend to underestimate abundance, but data can easily be calibrated using scuba surveys to produce more accurate results. 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;
- Manta board 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.

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;
- The tow path is parallel to the reef crest over a 5-10 m depth so that most of the slope is visible;

- The 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 the visibility, reef gradient, distance from the bottom and the distribution and density of the organisms being counted;
- The survey direction is determined by factors such as the wind, currents and the angle of the sun. The survey direction should be standardized to avoid the need to correct data for re-surveys.

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 manta boards 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;
- Includes few variables because the observer must remember all observations during each 2 minute tow;
- Can survey shallow reefs 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

Random swim

Programmes that use this method:

- Community monitoring programmes may use the random swim for monitoring;
- Management or research monitoring programmes may use the random swim for site selection.

Method description:

Site selection 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.

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.

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, whereas quadrats are more suitable for patch reefs; 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 programme

- Basic coral reef identification expertise in order to decide what things to count.

6.6.11.4 Ecological and socio-economic monitoring of coral reefs

There are two main types of monitoring:

- Ecological monitoring; and
- Socio-economic monitoring.

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

Ecological and socio-economic parameters are often closely linked; therefore ecological monitoring and socioeconomic 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.

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, crown of thorn starfish (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 is of use in making maps and in measuring changes in the environment. These parameters include:

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

6.6.11.5 Planning

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 managers 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.

What type of monitoring?

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

- What information do you need to know? Is your question general or specific?
- What do you need to monitor?
- What resources do you have available?
- What scale of monitoring programme do you want?
- What types of reef do you have in the area?
- What methods should you use?
- How often should you monitor?
- Quality control and training?
- Data handling and communicating results
- The need to involve the public
- 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. Threats to coral reefs can be categorized 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.

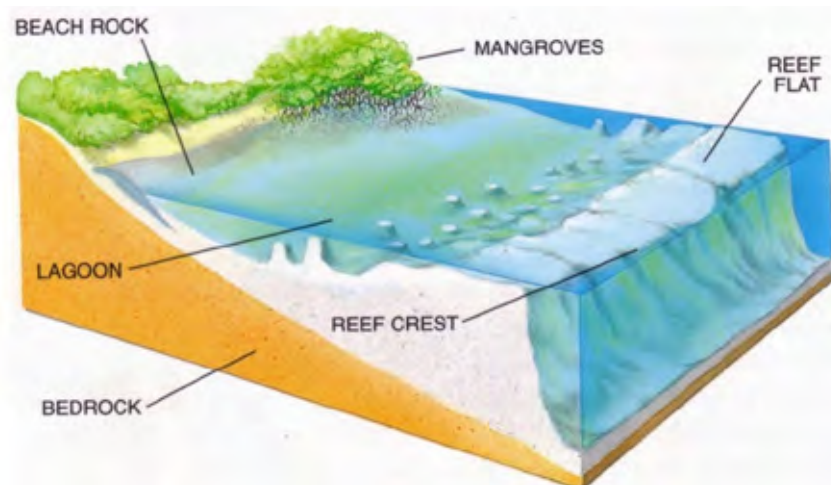
What do you need to monitor?

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).

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. to sedimentation traps or coral recruitment plates, 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. A continuous reef is better suited to most sampling methods, such as transects, which require tens of square metres of area.



What are the main ecological monitoring categories?

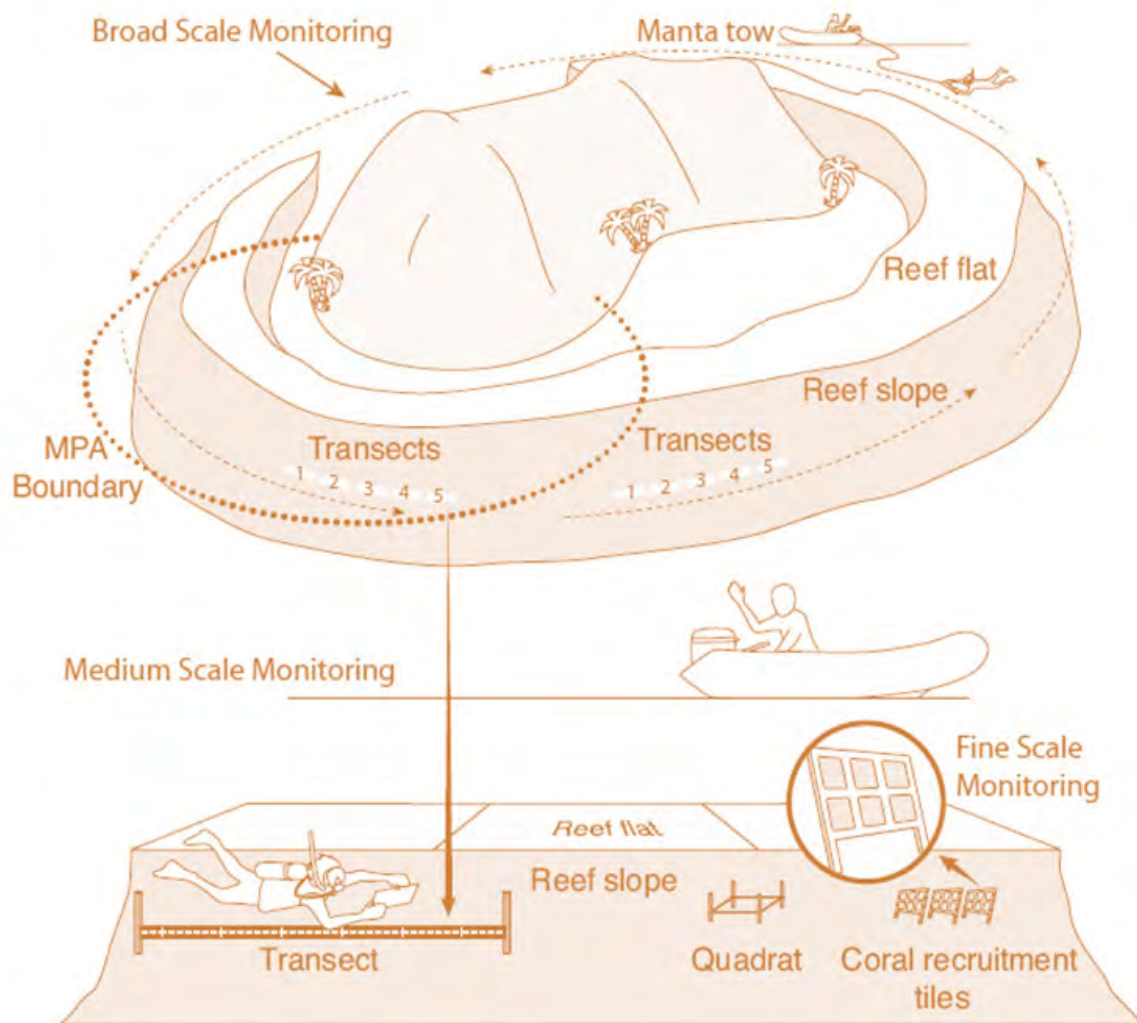
1. Physical parameters;
2. Water temperature, Salinity, pH, Turbidity, Heavy metals, K, Na, etc.,
3. Biological parameters;
 - Primary producers such as planktons
 - Sea grass
 - Sea weed
 - Mangroves
 - Benthic communities (living and non-living components);
 - Invertebrates;
 - Coral
 - Sea cucumber, etc
 - Shrimbs, Lobster, shells etc.,
 - Fishes.
 - Sea turtles, Sea snakes
 - Coastal and Oceanic Birds
 - Sea mammals

What methods should you use?

Many methods have been developed to monitor the different reef components. Several major coral reef monitoring programmes have refined and integrated protocols and we recommend using the standard methods to develop your programme. This will enable comparisons with data collected by other monitoring teams in your region.

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.



An illustration of the three scales of monitoring: broad-scale covering large areas at lower resolution, e.g. with a 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. (Source: Hill J, Wilkinson C. 2004)

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

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 programme and will depend upon the objectives of your programme 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. This is called an impact study.

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.

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 the monitoring method?

1. First decide what method to use, i.e. transects, quadrats, 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 to use: 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 the size, 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.

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. The use of replicates is called replication.

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, qualitative information is collected where there is no control over the sample size.

The 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, e.g. patch reefs are not suitable for long transects.

How many replicates should you survey?

- How many samples (called replicates) should you make?
- Where should you locate your replicates?

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.

Where should you locate your replicates?

You should select sites that are representative of the coral reef. Statisticians would prefer all sites to be selected randomly, but this is often logistically difficult to achieve. In the real world the best method of selecting your sites 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 pseudo replicates.

Permanent versus haphazard sampling units

To measure change over time, you can either measure the same part of reef each time (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 changes in your results from one year to the next will be caused by human error rather than environmental change.

*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. *

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

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.

Should I do a pilot study?

Pilot studies can help you decide the size (e.g. length of transect or quadrat size) and the number of replicates 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.

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 with 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 metre intervals along a transect line or at the corners of a permanent quadrat. Observers can wrap a tape measure around these stakes to ensure that the transect is in the same position.

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.

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 with the controls.

6.6.11.6 Monitoring physical parameters

(Source: Rogers et. al. 1994)

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.
- Current

Water and air temperature

Corals require a water temperature range between 18 and 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 La Niña years, which stresses 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.

Salinity

Corals prefer a salinity range of 3.2% to 4.2%, and the surface salinity can decrease when fresh water is added e.g. if there are floods or there is pollution from industries, or increase if surface water evaporates. Changes may cause stress to corals. Therefore it is useful to monitor the salinity using a refractometer. Water samples from the surface and survey depth can be collected in sealed plastic containers and the salinity measured at the surface.

Wind strength and sea state

This is useful when monitoring fish as the abundance of fish at a site changes according to the weather conditions.

The measurement scales are listed here.

Wind strength category	Wind strength (knots)
0	0
1	1-5
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 metres, white caps

Water quality

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 a 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.

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 if there is an influx of zooplankton (food for corals, etc.).

Sedimentation traps

Method description

This involves attaching a PVC sediment trap to the reef and leaving it for up to 3 months to collect sediments settling on the reef. This method can be used to detect temporal changes, for example, impact assessment.

Information obtained

Sedimentation rates. These are presented as the weight of sediment (g) per unit time.

Equipment required

- PVC pipe of diameter 5 centimetres and length 11.5 centimetres 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 of sensitivity 1 milligram;
- Field personnel:
- 1 boat driver/surface watch

Lab personnel

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

General procedure

- Hammer steel rods deep into the substratum;
- Attach 3 sedimentation traps to each rod 20 centimetres 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 month 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).
- velocities greater than 20 centimetres per second.
- Frequent visits to field sites to collect and replace traps.

Training required

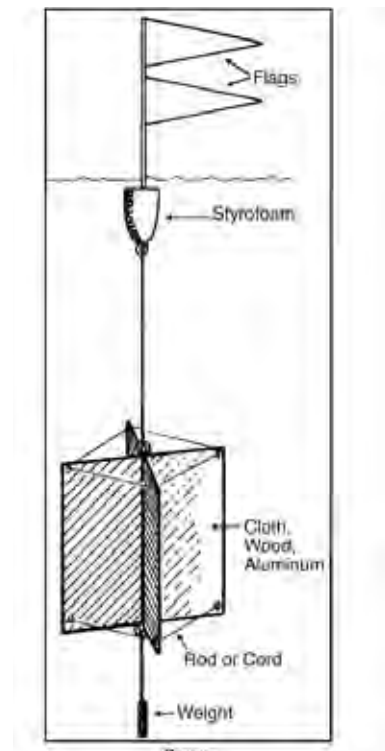
- Minimal field and lab training

Currents

It is important to know the direction and velocity of the prevailing currents in the area of your study site because they transport larval reef organisms as well as harmful sediments and pollutants such as oil.

Current meters that can be left in situ at a study site are very expensive. To get an approximate idea of current direction and velocity, you can release Rhodamine B or a fluorescein dye and time its passage through the water or release drift devices ('drogues') and take sightings of their successive positions. Drogues are probably the best indicators of currents in small, semi-contained water masses with sluggish or slow currents.

Many types of drogues can be purchased or constructed. The drogue apparatus should include a buoy that is large enough to support a flagpole, radar reflector mast or radio antenna, and to prevent the weight of the drogue from pulling it underwater. To ensure that the drogue is influenced more by water currents than wind, the surface area of the parts in the water must be greater than the surface area of parts exposed to the air. The larger the drogue, the more precise the measurements can be. So use as large a drogue as practical.



6.6.11.7 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.

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. A manta tow is better for widely spaced organisms.

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 are better suited for patchy reef habitats.

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.

Manta tow data sheet

[illegible]

Entered by:

Date:

Statistical analysis by:

Date:

Transects

Transects provide medium-scale information. They are lines marked on the reef floor, where the corals and other objects underneath are counted. 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, 20, 30 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 refers to variation in the animal and plant types across space. If the 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. Transects are generally positioned parallel to the reef crest along a constant depth contour. A transect laid perpendicular to the 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 relating to habitat types.

There are 4 ways to survey transects:

1. Line transects (including 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, which measure things in a belt inside 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, and 'chain intercept transects' (CIT), which measure the benthic cover in 3-dimensional terms as the chain follows the contour of the reef. 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 the reef surface contour distance to the linear distance. As part of a long-term monitoring programme, the spatial index provides a way of quantifying 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 a sufficient number of points, PIT can provide information comparable with that provided by LIT.

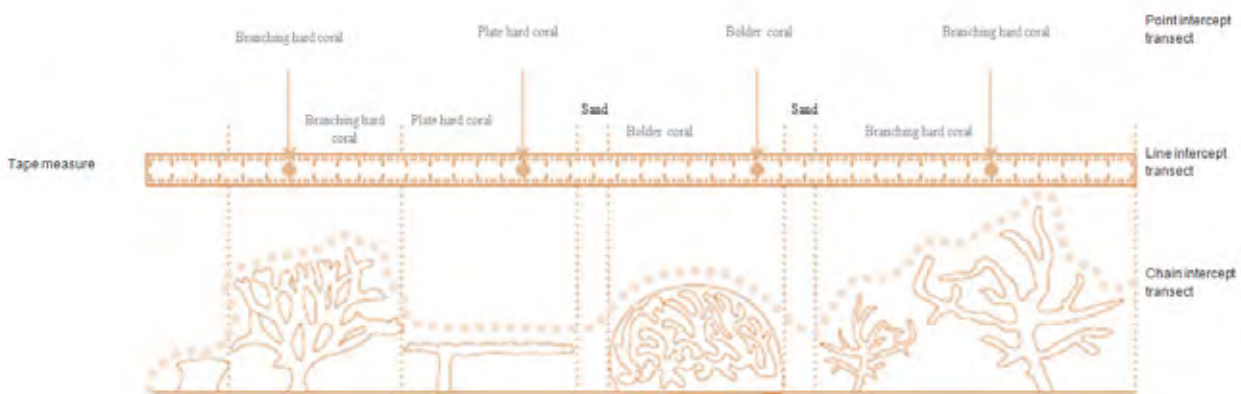
3. Belt transects

Belt transects are the same as line transects but wider and are often used for surveying specific impacts on the benthos, such as bleaching or disease, or counting invertebrates and fishes. The appropriate width depends upon what you are measuring. For small species or fish recruits, narrow belt transects (e.g. 2 metres wide) are often used, and for impacts such as coral disease and *Drupella* snails, a 4 metre width is used. For other key macro-invertebrates wider transects may be used, e.g. 5 metres.

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.



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 CIT records the number of chain links covering each object (or substrate type).

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 of 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 centimetre links are easiest).

How do you measure the belt transect width?

The 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 metres) are commonly used;
 2. The stretched distance from your fin-tip to your hand is a useful body length measure to check your estimates of transect width throughout the survey;
 3. Tape measures can be laid out at the start of each replicate to provide a reference for belt estimates. 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.

Line Intercept Transect Data Sheet			
Name of Surveyor:		Station:	LIT Specifications
Assistant:	Date:	Site:	
	Time:	Wind:	Cloud:
		Depth:	Special feature of station:
HC: Hard Coral		Al: Algae	SD: Sand
SC: Soft Coral		SP: Sponge	SCL: Silt/Clay
RKC: Recently Coral		RC: Rock	OT: Other
BC: Bleached coral		RB: Rubble	
Intercept Length(cm)	Lifeform	Species	Other Comments

Quadrats

The term “quadrat” generally refers to a square or rectangular sampling unit within which organisms are counted and measured, or to the form which marks this area. Quadrats can be used to estimate the percent cover of each species or other reef components and obtain information about density, abundance, diversity, and colony size.

The appropriate quadrat size is dependent upon the size and spatial abundance of the organism being counted. Generic quadrat sizes that are used include:

- 0.5-1 square metre or larger quadrats to assess species diversity. This is the most common size for general benthic community surveys.
- 25 centimetres by 25 centimetres to measure coral recruits and other small organisms like algae species, *Diadema* or *Drupella*.

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 damage carrying these underwater and 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 with 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 and 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 over time.

Limitations of quadrats

- Quadrats provide data from the projected surface area only and cannot be used to measure rugosity. This is a problem with complex reef surfaces. Plate-shaped corals tend to be overrepresented 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.
- They are 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

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

Types of data obtained from quadrats

- Estimates of percent cover (visual quadrats);
- Precise measures 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 of quadrats

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

Generic equipment for quadrats

- Quadrats can be made from a variety of materials, such as iron re-bars, PVC or stainless steel pipes, etc. PVC pipes are good for larger quadrats as they are easier to handle but it is important to drill holes in them 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. For irregular surfaces, grid positions can be estimated from painted reference marks at known distances (e.g. 10 centimetres) along the quadrat frame. Entry into the water is easier with collapsible quadrats.

Coral Reef Quadrat Data Sheet					
	Name of Surveyor:			Station: Site:	Quadrat Specifications: Quadrat No
	Assistant:	Date:	Wind:	Cloud:	
		Time:	Depth:	Special feature of station:	
Quadrat No.	Species/ Life form	Diameter (cm)	Height (cm)	Morphology	Other Comments

Entered by:

Date:

Statistical analysis by:

Date:

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 underwater compared with visual methods, and they can be used by experienced divers who may not be scientists.

How do you analyze photographs or video frames?

- Dot grid – this involves placing random or sequenced dots over the photograph or frame. The benthos beneath is identified;
- Digitizing – this involves manually drawing the different benthic items on a digital image with digitizing software. The software can be used to calculate the percentage cover very precisely. Although this is the most accurate method, the equipment required is expensive, expertise is necessary, and it is the most time consuming method.

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 camera 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 maintain a constant distance, but this is expensive and therefore impractical in most situations.

Advantages and limitations of visual counts and photography/video

Underwater visual counts

Advantages

- Data are ready to be analyzed immediately after 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 metre 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 the use of photography or video unsuitable for programmes 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 for estimating 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 minimized by the use of monopod frames;
- 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.

Benthic communities

Coral reef managers need information on the status and trends in benthic communities to effectively manage resources. The focus is mostly on hard corals, but managers also need data on soft corals, algae, sponges and other invertebrates. 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. Malvan, Goa, Netrani Island, or where a few species are very dominant. In the Andaman and Nicobar Islands, Lakshadweep, Gulf of Mannar or Gulf of Kachchh, it is often necessary to assess coral growth form as a substitute for diversity. Other 'species diversity' measures are for fish.

Percent cover

The 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 and coral diseases are apparently increasing in frequency and distribution.

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, and if so what is the type and abundance?
- How has coral bleaching affected corals?

Coral bleaching-specific methods

To further our 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 get bleached, and then subsequently die or survive.

All the methods described previously for percentage cover or coral health can be used to monitor bleaching.

However, the methods following methods 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 a reef is useful in determining how the structure of the coral reef changes over time. Chain intercept transect methods (CIT) provide a good measure of rugosity but are more time consuming and cumbersome.

‘Line intercept transect (LIT) methods are an alternative to the chain methods. The growth form (coral shape) information obtained using LIT methods can be used to determine how the topography of a reef changes over time. Note that growth form data provide less detailed information on topography compared with CIT methods.

Coral recruitment

Information on coral cover or coral mortality over a long period 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 the 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 their first year. At this point they are visible to observers in the field.

Coral monitoring data sheet

Reef Check Line Transect- Substrate

Site Name:		Country/Island:	
Transect Depth:		Date:	
Team Leader:		Data recorded by	
Start Time:		(full name):	

Enter the Substrate Codes into the white boxes below - just like your field sheet.

HC hard coral	SC soft coral	RKC recently killed coral
NIA nutrient indicator algae	SP sponge	RC rock
RB rubble	SD sand	SI silt/clay
OT other		

(For first segment, if start point is 0 m, last point is 19.5 m)

SEGMENT 1				SEGMENT 2				SEGMENT 3				SEGMENT 4			
0 - 19.5 m				25 - 44.5 m				50 - 69.5 m				75 - 94.5 m			
0		10		25		35		50		60		75		85	
0.5		10.5		25.5		35.5		50.5		60.5		75.5		85.5	
1		11		26		36		51		61		76		86	
1.5		11.5		26.5		36.5		51.5		61.5		76.5		86.5	
2		12		27		37		52		62		77		87	
2.5		12.5		27.5		37.5		52.5		62.5		77.5		87.5	
3		13		28		38		53		63		78		88	
3.5		13.5		28.5		38.5		53.5		63.5		78.5		88.5	
4		14		29		39		54		64		79		89	
4.5		14.5		29.5		39.5		54.5		64.5		79.5		89.5	
5		15		30		40		55		65		80		90	
5.5		15.5		30.5		40.5		55.5		65.5		80.5		90.5	
6		16		31		41		56		66		81		91	
6.5		16.5		31.5		41.5		56.5		66.5		81.5		91.5	
7		17		32		42		57		67		82		92	
7.5		17.5		32.5		42.5		57.5		67.5		82.5		92.5	
8		18		33		43		58		68		83		93	
8.5		18.5		33.5		43.5		58.5		68.5		83.5		93.5	
9		19		34		44		59		69		84		94	
9.5		19.5		34.5		44.5		59.5		69.5		84.5		94.5	

	S1	S2	S3	S4	Segment Mean	
# of HC with disease:					#DIV/0!	copy counts from field sheet
# of HC with bleaching:					#DIV/0!	copy counts from field sheet
% of HC with disease:	0	0	0	0	0%	
% of HC with bleaching:	0	0	0	0	0%	
% of RKC:	0%	0%	0%	0%	0%	

If mean RKC is > 10%, is the primary cause: ☐ Bleaching ☐ COTS ☐ Storm ☒ Other

Comments:

Reef Check Summary Data

DO NOT TYPE DATA BELOW THIS LINE

Total S1	Total S2	Total S3	Total S4	Grand total
HC	0	0	0	0
SC	0	0	0	0
RKC	0	0	0	0
NIA	0	0	0	0
SP	0	0	0	0
RC	0	0	0	0
RB	0	0	0	0
SD	0	0	0	0
SI	0	0	0	0
OT	0	0	0	0
#	0	0	0	0

TOTALS MUST = 40 FOR EACH SEGMENT

	Mean count	Mean % per segment	SD	% S1	% S2	% S3	% S4
HC	0	0%	0%	0%	0%	0%	0%
SC	0	0%	0%	0%	0%	0%	0%
RKC	0	0%	0%	0%	0%	0%	0%
NIA	0	0%	0%	0%	0%	0%	0%
SP	0	0%	0%	0%	0%	0%	0%
RC	0	0%	0%	0%	0%	0%	0%
RB	0	0%	0%	0%	0%	0%	0%
SD	0	0%	0%	0%	0%	0%	0%
SI	0	0%	0%	0%	0%	0%	0%
OT	0	0%	0%	0%	0%	0%	0%

Sample of data sheet for REA transect survey: Hard coral colonies

No	Species	Transect No	Position on transect	Size (Length X Width, CM Sedimentation	Sedimentation %	Mortality %	Type and size (diameter, CM) of associated substrate
H1							
H2							
H3							
H4							
H5							
H6							
H7							
H8							
H9							
H10							
H11							
H12							
H13							
H14							
H15							
H16							
H17							
H18							
H19							
H20							

Sample of data sheet for REA transect survey: Soft coral colonies

No	Species	Transect No	Position on transect	Size (Length X Width, CM Sedimentation	Sedimentation %	Mortality %	Type and size (diameter, CM) of associated substrate
S1							
S2							
S3							
S4							
S5							
S6							
S7							
S8							
S9							
S10							
S11							
S12							
S13							
S14							
S15							
S16							
S17							
S18							
S19							
S20							

Monitoring Category & Scale	When should you choose this method?
Broad scale	Choose this method for mapping and site selection and to cover a large area quickly.
Manta tow or video towed diver	Percent cover: Estimates percent coral cover over large areas in a short time, at low detail; limited to shallow, snorkel depths Coral health: Estimates only bleaching percent cover of live.
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.
Timed swim	Percent cover: Estimates the coral cover or abundance of large invertebrates of a large area, at various depths if scuba is used; not as quick and cost-effective as a manta tow but more detailed. Disease-specific: Easy to carry out; information on extent of bleaching and types of corals affected; lower precision compared with belt transects.
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.
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 be as precise 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).
Belt transect	Coral health: Medium detail and fairly quick; low to high expertise required depending on level of detail wanted; 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.
Chain transect	Percent cover: experienced staff, low to high detail, precise information; more time consuming than LIT. Disease specific: Difficult to carry out; experience required; detailed information on extent of bleaching and types of corals affected. Structural complexity: Difficult to carry out; experience required.
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 are available.
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 less precise 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. Provides 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.
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.
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.
Recruitment tiles or plates	Coral recruitment: Provides information on coral recruits that are newly arrived on a reef.



6.6.12 Assessment of biodiversity of rocky shores

Apart from the better known habitats, there are several rocky outcrops around the Indian sub-continent. These rocky islands/outcrops frequently have a rocky substratum in the form of rocky beds, caves, crevices, etc. These features provide varied habitats for fishes just as a coral reef does. They attract fish from all around and provide refuge. Thus the fish diversity of these rocky areas is high, and they are known as rocky biodiversity habitats.

Long-term monitoring of the rock fauna is important for conserving them. Quadrats, line transects, belt transects and point counts are some of the methods used commonly to monitor the fauna along the rocky coasts. The quadrat and belt transect methods are nothing but counting all the animals in a fixed area. Line transects and point counts are used to estimate animal abundance using distance sampling. Software packages such as 'Distance' need to be used to analyse the distance sampling data. Crabs that largely use rocky shores can be monitored using these techniques. Sea urchins, barnacles, etc. can also be monitored using these methods. It is important to monitor the rocky fauna seasonally to understand the population dynamics better.

In assessing the ecological status of these areas, the prime goal should be to assess the fish diversity and abundance.

The main objectives in monitoring rocky biodiversity hotspots are assessing the status of the fish assemblages, comparing them with those of other areas, and monitoring the species composition and relative abundance over time. A reduction in the number of top predators (*piscivores*), declines in species abundance, and shifts to smaller average sizes may indicate fishing pressure. Fish censusing is difficult in such environments because of the structural complexity of the habitat and the diversity, mobility, and abundance of fishes. Fish censusing also requires extensive training, as it may be necessary to recognise over 100 different species.

6.6.13 Fish census

(Source: Rogers et. al., 1994)

The different fish species that appear together are referred to as a "fish assemblage." Three aspects of reef fish assemblages that can be monitored are:

- Diversity: the number of different species;
- Structure: species composition and relative abundance; and
- Population density: the number of fish of a given species per unit area.

Although attempts have been made to develop a single census method that will accurately measure all three characteristics, fish biologists generally agree that no such single method exists. You will need to decide what information is most important for your management needs and then select one or more appropriate methods.

6.6.13.1 Census methods

The most common methods for visual fish censuses are: stationary counts, belt transects, and random swim techniques. In choosing a method, be sure to consider the behaviour of the relevant fish species (e.g., cryptic, schooling, attracted or repelled by divers).

- The stationary census focuses on the relative abundance and frequency of occurrence of all the species observed at the site.



- The belt transect method yields better density estimates and covers a larger area per census.
- The random swim technique provides more complete information on the total species richness.

6.6.13.2 Limitations

All visual census methods have the following limitations:

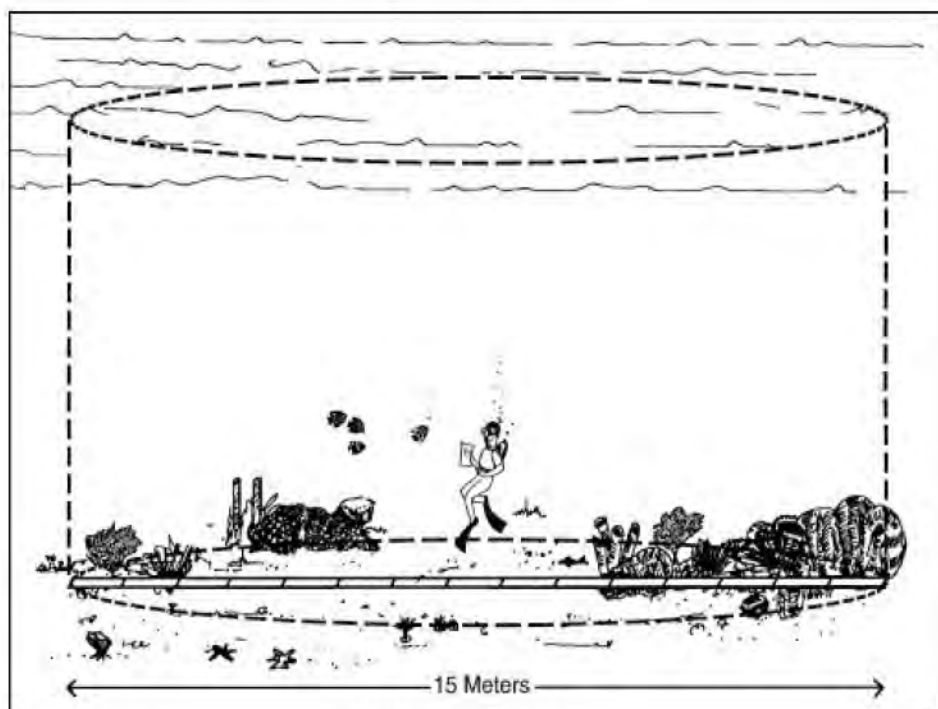
- Observers generally underestimate the abundance of most species.
- Only the “observable” portion of the fauna is counted. So cryptic, nocturnal and pelagic species are likely to be underestimated.
- The presence of a diver will affect the behaviour of fish.

6.6.13.3 Frequency and number of censuses for effective monitoring

How many censuses, how many sites and how often to sample will depend on your monitoring objectives. Initially, you may want to census fish over several consecutive days to determine if there is any short-term variability. To detect seasonal changes in abundance and species richness, fish should be censused monthly until a baseline is established. To detect long-term changes, sampling should be conducted at least once a year, at approximately the same time of day. It is preferable to census during the same month or at least in the same season each year, with at least 10 censuses conducted each time at each site. Statistical analysis may indicate more samples are necessary to optimize sampling

6.6.13.4 Stationary fish census

The stationary fish census method has been very widely used throughout the Indo-Pacific region. The basic technique is presented here, although you may find a variation of this method better for your particular area. Appropriate modifications (e.g., changing the size of area sampled, the amount of time spent per census, how the time is allocated while underwater) will depend on local conditions (e.g., visibility, depth) and management needs.



1. **Establish a sampling radius.** At each randomly selected site, record the depth, maximum relief of the site, and percent cover by various bottom type classifications (e.g., sand/clay, rock structure, algae, rubble, etc.). Stretch a tape measure out 15 metres along the desired area to mark the sampling diameter; take up a position at the 7.5-metre mark.
2. **Make a species list.** While turning around at the 7.5-metre mark, scan the field of view within an imaginary cylinder extending from the bottom up to the water surface and having a radius of 7.5 m. Record all species observed during the first 5 minutes. To simplify data collection, abbreviate each species name by using the first two letters of the genus and species names (e.g., Black tailed snapper *Lutjanus fulvus*, would be LUFU) or the first three letters, if necessary to distinguish between similar names.

During this initial 5 minute period, list only the different species you observe within the cylinder. Do not record data on fish size or numbers of individuals – except for species that are moving through the cylinder and are unlikely to remain there, e.g. sharks, rays, mackerels, jacks.

3. **Record the number and size of each species on the list.** When the initial 5-minute period is over, begin recording data on the size and abundance of the species you have listed
 - Working up from the bottom of your species list, count and measure the number of fish of each species, one species at a time, turning around at the 7.5 metre mark until the entire area is scanned.
 - When large schools are present, the number of fish may be estimated by counting in 10s, 20s, 50s, or even 100s.
 - To estimate the fish fork length (from the tip of the upper jaw to the end of the middle caudal rays), compare it to a ruler. Divide each species into size classes based on the minimum and maximum fork length to the nearest centimetre. The number of class may depend on the number of fish and the variation in size, but generally each classes should include a size range of no more than 5 centimetres.
 - If a species listed during the initial 5-minute sampling period is no longer present, record data from memory.
 - Any additional fish species observed in the sampling cylinder after the initial 5 minute listing period are ignored unless you want to include them on a site species list.

Each census should take no longer than 15 minutes, including the time needed to record the depth, relief of the site, structure of the rocky habitat, sand/clay, and algae. Your underwater data record may look something like the sample shown below, listing the species and the number of individuals of that species counted in each size category. In this example, the observer saw one *Lutjanus fulvus* that was 15 centimetres long and two that were 5-7 centimetres long.

Sample Fish Census Data Sheet			
Species	No. And length of fish by size category		
LOSUR	3 (1-2)	43 (2-6)	45 (3-7)
MUCE	2 (5-9)	12 (13-15)	
PLCHU	2 (130)	2 (10-13)	
DRPU	1 (3-4)		

When you enter the data into a computer spreadsheet, record the number of each species and the minimum, maximum and average sizes of fish in each size class.

Modifications: Some investigators have found a smaller radius is preferable in locations where the visibility is low. This situation is common in areas near the Indian subcontinent. The only drawback with a reduced radius is that it is difficult to compare the data with those of other areas obtained.

One modification reduces the cylinder radius to 5 metres and includes any species observed during the entire 15 minute period. Because many fish adapt to the presence of a diver during the 15 minute period, this modification results in the inclusion of more small, cryptic, and sedentary fish (e.g., gobies, blennies, morays). This method may also yield better density estimates for small, abundant territorial species.

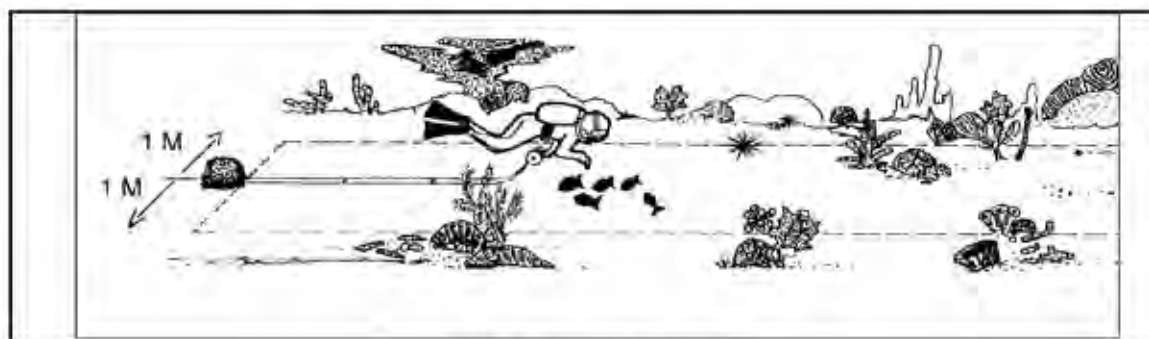
6.6.13.5 Belt transect census

Belt transects cover a larger area per census compared with stationary counts and are considered most useful for counting patchily distributed species. They can be conducted along permanent transects marked with survey stakes or other markers that are randomly selected each time.

The length and width of a belt transect may vary according to the species targeted by the census, but you must use the same dimensions for all transects sampled. A narrow transect (2 metres wide) may be good for small, cryptic species, while a wider transect (4 to 5 metres) can be useful for groupers, snappers, and parrotfish. Here is the basic technique:

1. Swim at a constant speed along the selected area while stretching a fibreglass measuring tape 50 or 100 metres along the bottom.
2. As you swim along the transect and unreel the tape, record the fish species, number of individuals, and the minimum and maximum lengths of species within a prescribed distance (1 to 5 metres) on either side and above the line, including species that are underneath you or cross in front of you. Do not record fish entering the transect area behind you.

The swimming speed must be standardized for repeated censuses; highly mobile species may be over-estimated at slow speeds, while cryptic species may be overlooked at faster speeds.



Belt Transect Census

6.6.13.6 Random swim technique

The random swim technique provides good information on relative abundance and species richness, but not on population density. The entire census period is spent searching for unrecorded fish species rather than recording other data about the fish. To obtain reliable data, replicate sample censuses must be conducted.

The basic technique for a 50 minute census is presented below.

1. Begin the census at a random location in the selected area
2. The census period is divided into five 10 minute intervals. Record the name of each species in the interval in which it is first seen.
3. To estimate its abundance, each species is given a score based on the interval within which it is first observed. (More abundant species are likely to be recorded in the earlier intervals, and the more cryptic or rare species later on.) Species observed in the first interval receive a score of 5, in the second 4, and so on.

6.6.13.7 Fish census datasheet

Your data sheet may look something like this:

Sample Random Swim Data Sheet				
2/5/94: Upper platform, Coral cover: 21%, Depth: 52'				
0-10 min	11-20 min	21-30 min	31-40 min	41-50 min
GOEV STPL STDO SCVI SPRU OCCH HYPV CARU CARO	HARA HAMA HABI CHCY ABSA CHMU STPA	POPA HOTR CHCA ANVI CAPU	CHAN SAVE OPMA SCCO	EPCR LAGO SETO
Score: 5	Score: 4	Score: 3	Score: 2	Score: 1

6.6.13.8 Monitoring the abundance of fishes

Date: **Time:** **GPS Location:**
Weather: **Gird No:** **Plot No:** **Salinity:**
Air Temp: **Water Temp:** **Depth:** **Velocity:**

Description of Effort: (Net, boat, number of fishermen etc) ..

Sl.No.	Species	Total length (this column may not be required!!!)	Body Length (Max and Min)	Weight	Remarks

6.6.13.9 Fish survey data sheet

[illegible]

Entered by:

Date:

Statistical analysis by:

Date:

6.6.13.10 A comparison of different fish census methods

Comparisons of fish census methods		
	Advantages	Disadvantages
Stationary Census	Good for relative abundance; allows large sample sizes in distinct habitats	Takes longer to train people; less likely to provide a complete site species list (unless modified)
Belt Transect	Large area can be sampled per census; can target more mobile species; may provide more accurate density estimates for species such as snappers and groupers	Fewer samples per unit of time compared with stationary methods; may not provide data on small habitats
Random Swim	Mostly likely to provide complete species list; describes a larger portion of species per sample	Fewer samples per unit of time; provides fewer quantitative data and no density estimates.

6.6.13.11 Data analysis of fish census

You need to consider how you will analyze the data when you design your fish censusing method. It is usually important to analyse data on frequency of occurrence, abundance, richness, evenness and diversity of species at individual sites and among sites. Data on changes in relative abundance and frequency of occurrence can provide information on population changes for individual species. Changes in average size and structure of size classes of important species can also be evaluated.

Several statistical techniques are available to analyse the data when you have multiple variables (cluster analysis or detrended correspondence analysis) and test for differences among sites (parametric/non-parametric techniques) or over time (time-series analysis).



6.7 Overview of data analysis

There are some standard methods to analyse the relative abundance of various substrate categories such as live coral cover, dead coral cover and their coral life forms, sponge, zooanthids, macro and micro algae, sand and other benthic categories following formula were used.

Percent cover = Total length of category/length of transect X 100

The relative abundance of each coral is calculated using the following formula

Relative abundance = cover of the species/total live coral cover X 100

Same formula can be adopted for other lifeforms such as macro invertebrates, fish, algae, sea grass etc.

Diversity, evenness and dominance

Species diversity and evenness Shannon Weaver and Simpson diversity indices can be used, as Shannon diversity index emphasizes on rare species and Simpson index on most common species.

The Shannon-Weaver formula for diversity can be calculated as follows, with a projection of 1 cm under the line being considered as an 'individual'

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

where $p_i = n_i/N$, N = total number of centimetres (individuals) of all species under the line, and n_i = the number of centimetres of species i under the line.

Evenness can be calculated as $J' = H'/H_{max}$, which is the diversity of the total number of individuals (centimetres) under consideration divided by the diversity which would exist if all the species present are distributed equally. A value of 1.00 represents maximum evenness. Diversity and evenness for each sampling site can be calculated from the combined data from all transects.

In order to compare Simpson's index to Shannon and Weaver's index, following Simpson's index can be used:

$$D = \frac{1}{\sum_{i=1}^S P_i^2}$$

P_i = Proportion of individual species i

where, N = Total number of individuals in the plot

S = Number of species in the plot

Calculation of dominance index

Index of dominance = Abundance of dominant coral species / Total coral cover

For inter-station comparison, the data on relative abundance and absolute change in abundance of corals and other lifeforms are subjected to agglomerative hierarchical analysis using the Ward method of linkage with the Block distance measure. Percent values are arcsine transformed for ANOVAs. For data analysis, software such as Microsoft Excel, SPSS 10.0, Statistica, Origin are used.







6.8 Application in management

How can rangers use these data?

- in their management plans
- day to day monitoring plans/ operational plans/ EIA reports
- Online databases like fish base
- Social media
- Their personal database/ site based management
- supporting scientific community
- publications

Application in management

The charts below summarize the suggested components of a basic monitoring programme that will address a variety of situations. In all cases, it is a good idea to use photography to document

The management question/ Situation	The type of monitoring programme to get answers
Coral bleaching	Monitor individual coral colonies; measure water temperature, photosynthetically active radiation (PAR) and UV
Damage by boats, snorkelers, divers	Measure physically damaged area; record number of broken coral branches/plates
Over fishing	Fish census
Sediments from dredging or runoff	Measure sedimentation rates and bacterial concentration

In these situations, you should be monitoring at established quadrats or transects in the affected areas and at control sites.

Baseline monitoring	Monitor individual coral colonies and live coral cover; measure water temperature, algal biomass, water transparency, and salinity; census reef fishes.
Sewage or other nutrient influx	Monitor individual coral colonies, measure nutrients, water temperature, algal biomass, live coral cover, salinity, dissolved oxygen and bacterial concentrations.
Desalination plant effluent	Measure water temperature and salinity
Storm damage	Monitor individual coral colonies; measure algal biomass; census reef fishes
Oil spill	Monitor individual coral colonies

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