SECTION 2 *The MPA management effectiveness indicators*

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Mangroves, as seen above in Antsiranana, Madagascar, are vital breeding areas for fish and help prevent coastal erosion. Yet many mangrove forests are inadequately protected, leading to reduced success of MPAs.

The MPA management effectiveness indicators

Introduction

There are 42 indicators presented in this Section: 10 biophysical, 16 socio-economic and 16 governance indicators. To make these indicators applicable to a range of MPA goals and objectives, the indicators were developed through a rigorous two-year process of research, expert review and field-testing, and revision.

To be useful and practical, the indicators were developed to meet several criteria. These criteria can be used to select the most appropriate indicators for your site, especially since a given goal or objective can have one or multiple indicators. Following best practices, a good indicator meets five criteria (see Margolius and Salafsky, 1998):

Measurable: Able to be recorded and analysed in quantitative or qualitative terms.

Precise: Defined the same way by all people.

Consistent: Not changing over time so that it always measures the same thing.

Sensitive: Changing proportionally in response to actual changes in the attribute or item being measured.

Simple: Simple indicators are generally preferred to complex ones.

To learn more about how the indicators were developed (including the process and timeline) go to http://effectiveMPA.2.gov/guidebook/ background.html

The difficulty rankings

Each indicator has a difficulty rating. This is to help you understand the relative ease with which the specified indicator can be measured using the most basic methods recommended (in some cases, more complex methods would reflect another one or two points in the difficulty ranking). This ranking takes into account the time, technical skills, finances and other resources necessary to measure the indicator.

1 – the indicator is easy to measure
2 – the indicator is fairly easy to measure
3 – measurement of the indicator requires moderate effort
4 – the indicator is fairly hard to measure
5 – the indicator is hard to measure

Box 10

USING THE INDICATORS

Heading	*Meaning*
▪ Name	Number and name of the indicator.
▪ Goal and objective	Which goals and objectives this indicator corresponds with (relating to the larger generic list of MPA goals and objectives developed by the project).
▪ Difficulty rating	A rank of how difficult the indicator is to measure (see above).
▪ What is "(indicator name)"?	Brief description of the indicator.
▪ Why measure it?	The purpose and rationale of the indicator.
▪ Requirements	Resources (people, equipment) needed to collect and analyse the information.
▪ How to collect the data	The method and approach used to collect information on the indicator.
▪ How to analyse and interpret the results	The methods and procedures to analyse the data and suggestions on how to present the results.
▪ Outputs	What are the results and how can they be used by the MPA?
▪ Strengths and limitations	How useful is the indicator overall and what problems may occur in using the indicator?
▪ Example from the field	An example of use of the indicator.
▪ Useful references and Internet links	Suggested sources of information on methods, and further explanation of the indicator.

Maximizing time and resources

Depending on which indicators you have selected, some may be collected concurrently. This requires that either a) the exact same data are collected for two or more indicators, or b) the same or similar methods are used to collect different data for two or more indicators. The box below shows clusters of indicators that could be measured or collected together.

Box 11

INDICATOR CLUSTERS

Biophysical clusters

- B1, B2 – same data collected on focal species counts and lengths.
- B1, B4 – same methods used to measure relative abundance.
- B1, B4, B7 – similar data collected on catch landings and target species.
- B2, B5 – similar methods used to measure recruits.
- B1, B2, B3, B4, B5 – similar survey approach and methods used.
- B1, B3 – similar data collected on habitat utilization.
- B4, B6 – both look at community composition.
- B10, B1 – B8, S3, S1, S5, S10, G1, G4, G14 – all look at human impacts.
- B10, B7 – both look at spill over effects on human activities.
- B7, B4, B6 – all look at trophic levels.
- B9, B10 – similar methods for aerial measures.

Socio-economic indicator clusters

- S2, S3, S6, S9, S10, S13, S14 – data can be collected from a household survey.
- S8, S11 – data can be collected from a key informant survey.

Governance indicator clusters

- G2, G3, G6, G7, G9, G14, G15, G16 – data are collected from interviews with MPA managers and/or staff.

Please note that while the other governance indicators all require interviews of stakeholders, there are different groups of stakeholders for each indicator.

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The biophysical indicators

Introduction

Regardless of their many social benefits and aims, MPAs are ultimately a tool for conserving the biophysical conditions of our oceans and coasts. As such, using indicators to measure these conditions is typically of primary interest to managers whose job it is to evaluate the effectiveness of an MPA.

In most cases, the link between the biological state of the marine environment and the livelihoods, income and food security of the people who use and depend upon the resource is explicit and intimate. It then follows that beyond characterizing natural systems, the measurement of biophysical indicators can also be useful when viewed in the context of the socio-economic and governance conditions that operate in and around the MPA. For example, the biological goods (such as fish) and ecological services (such as nutrient cycling) generated from effectively managed MPAs can be thought of in financial terms, where the MPA is a 'bank account' that preserves the natural 'capital' that society depends upon for the future. If this natural capital is left alone and allowed to grow over time, the 'income' generated from this 'principal' may be able to provide ecological goods and services that are of immediate use to people while also offering them future security. Without MPAs, too much of this natural capital may be 'spent' by society, draining away the 'principal' over time. In this regard, six of the biophysical indicators (B1, B2, B3, B4, B6, and B8) can be used to measure how much 'principal' is reserved and available, while the other four (B5, B7, B9, and B10) examine the degree of 'income' that may be influenced as a result of the MPA.

The 10 biophysical indicators included in this guidebook fall into one of three groupings: biotic, abiotic and aerial. The first six indicators (B1 – B6) are used to assess the biotic context in and around the MPA. B1 and B2 are used to examine the status of populations of species. Measurement of these two indicators is moderately difficult, depending on how large the area to be sampled is and how easy it is to observe or catch the organisms to be surveyed. B3 to B6 are used to characterize ecological conditions, and while important, are among the most challenging of all the indicators to measure. In particular, B5 and B6 require a level of capacity, time and labour that may be out of reach of many MPAs around the world. There was much debate and consideration about whether to eliminate B6 because of its complexity and questionable ability to demonstrate effective management in many large, multiple-use MPAs. In the end, consensus was reached to keep B6 because managers and experts felt that better understanding and addressing trophic relationships was critical to the successful design and use of MPAs.

Note that the biotic indicators (esp. B1, B2, and B3) rely heavily upon the comparison of data collected from within and outside the MPA. An appropriate approach to sampling in both areas must therefore be ensured.

B7 is a quasi-biotic indicator that measures the level of some of the biological goods that are generated from the marine environment (both inside and outside the MPA). B7 gauges trends in fisheries exploitation methods, yield, and effort as a reflection of how productive and healthy the exploited stocks are.

B8 is the only indicator offered in this guidebook that is used to assess the abiotic conditions of the marine environment.

Finally, B9 and B10 are spatially defined measures of observed biophysical change. Inclusion of these two 'aerial' indicators within the biophysical category was debated at length throughout their development and testing. Despite being the most closely linked to issues of MPA governance and requiring the collection of similar data, because the direct aim of B9 and B10 is to characterize the biological condition of the MPA, they were not moved into the governance indicator category.

Not all of the indicators will be appropriate for use in every MPA. Some indicators require a higher level of skill, labour, financing, and time to measure than others. Where possible, low-cost, basic methods have been provided for even the most challenging indicators, although such measures can be descriptive, highly subjective, and therefore less accurate and reliable.

All but two (B6 and B9) of the biophysical indicators were successfully tested by volunteer MPA sites. Although many of the eight other sets of measures were challenging, their results were nonetheless reported to be of use to the evaluation teams who tested them so as to gauge and report to what degree they were successful in furthering the achievement of the stated biophysical objectives of their MPAs.

Note that in some cases, measurement of the biophysical conditions in and around an MPA may not necessarily demonstrate management effectiveness because it may be outside the influence of even an ideally-managed MPA and beyond the control of its managers. In such cases, these indicators can be used to illustrate this point, allowing managers to openly communicate with decision-makers,

As at 11 other MPA pilot sites, several of the biophysical indicators were tested during 2002 and 2003 at Mafia Island Marine Park in Tanzania. Here a WWF officer tests a new net mesh on Mafia Island.

the public and donors that influencing some of the environmental conditions may be beyond the ability of the MPA and management team.

Attempting to adequately but succinctly summarise the numerous monitoring and assessment methodologies available for use by the evaluation team to measure biophysical attributes was not an easy undertaking for the contributors and authors. As most of these methods are thoroughly documented in the scientific literature, the biophysical indicators cannot and do not attempt to review them all. Rather, the indicator descriptions presented here deliberately focus on summarising several of the most basic, widely accepted and actively used methods in practice. A similar approach has been to introduce analytical considerations for the data collected. A few of the more advanced data collection and analysis techniques are acknowledged in the references, but are not the focus of the material summarised in this guidebook.

Also, much consideration was given to whether or not to standardize the methods and citation for measurement of the biophysical indicators, thereby not allowing for methodological choices made by the reader. In the end, most reviewers, test sites and contributors agreed that allowing for multiple measurement options would be the most flexible and inclusive approach given: a) the reality of how site-specific the biophysical characteristics of most MPAs are, and b) the fact that evaluation teams will have differing levels of capacity and access to resources. As a result, this guidebook does not advocate that one method of indicator measurement be used over another. The responsibility to choose the 'right' method is placed on the evaluation team, who is encouraged to use its expertise, judgement and site familiarity to decide which method would be best suited for exploration and use at their MPA given the specifics of the organisms, communities and environment being assessed.

Note that the basic methods offered for measuring indicators are only a starting point. They may not always provide reliable or adequate evidence as to how effectively your MPA is operating. Rather, the methods listed are offered as a first attempt to assess some of the fundamental biophysical conditions in and around an MPA. Thus, these methods should not be seen as a finite list of how to measure such conditions. In some cases, the methods offered are still undergoing testing and review, continually being refined.

Don't celebrate or panic too soon after the results come in! Only through cautious and consistent observation and validation over many years may a team begin to clearly see the ecological effects of an MPA against natural background variability.

Useful references

Bell, J.D., Craik, G.J.S., Pollard, D.A. and Russell, B.C. (1985). "Estimating length frequency distribution of large reef fish underwater". *Coral Reefs* 4: 41–44.

Clarke, K.R. and Warwick, R.M. (2001). *Change in marine communities: An Approach to Statistical Analysis and Interpretation. 2nd edition*. Primer-E, Plymouth, UK.

Dartnall, H.J. and Jones, M. (1986). *A manual of survey methods of living resources in coastal areas.* ASEAN-Australia Cooperative Programme on Marine Science Hand Book. Australian Institute of Marine Science, Townsville, Queensland, Australia.

Done, T.J. and Reichelt, R.E. (1998). "Integrated coastal zone and fisheries ecosystem management: generic goals and performance indices". *Ecological Applications* 8 (supplement): 110–118.

Elliot, J.M. (1977). "Some methods for statistical analysis of benthic invertebrates". *Freshw. Biol. Assoc. Sci. Publ., U.K* 25: 1–156.

English, S., Wilkinson, C. and Baker, V. (eds.) (1997). *Survey Manual for Tropical Marine Resources. 2nd Edition*. Australian Institute for

Marine Science, Townsville, Queensland, Australia.

Grumbine, R.E. (1994). "What is Ecosystem Management?" *Conservation Biology* 8(1): 2738.

Hilborn, R. and Walters, C.J. (1992). *Quantitative Fisheries Stock Assessment: Choice, dynamics, and uncertainty*. Chapman and Hall, New York, NY, USA.

Lackey, R.T. (1995). "Ecosystem Management: Implications for Fisheries Management." *Renewable Resources Journal* 13 (4): 11–13.

Ludwig, D., Hilborn, R. and Walters, C.J. (1993). "Uncertainty, resource exploitation, and conservation: lessons from history". *Science* 260: 17–18.

Odum, E.P. (1971). *Fundamentals of ecology*. W.B. Saunders Co., Philadelphia, PA, USA.

Sale, P.F. (2002). "The science we need to develop for more effective management". In Sale, P.F. (ed.), *Coral Reef Fishes: Dynamics and diversity in a complex ecosystem*. Academic Press, San Diego, USA. pp. 361–376.

Tupper, M. (2002). "Marine reserves and fisheries management". *Science* 295: 1233

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Figure 2 Biophysical goals, objectives, indicators

Biophysical goals (n=5) and objectives (n=26) commonly associated with MPA use

GOAL 1	**Marine resources sustained or protected**
1A	*Populations of target species for extractive or non-extractive use restored to or maintained at desired reference points*
1B	*Losses to biodiversity and ecosystem functioning and structure prevented*
1C	*Populations of target species for extractive or non-extractive use protected from harvest at sites and/or life history stages where they become vulnerable*
1D	*Over-exploitation of living and/or non-living marine resources minimized, prevented or prohibited entirely*
1E	*Catch yields improved or sustained in fishing areas adjacent to the MPA*
1F	*Replenishment rate of fishery stocks increased or sustained within the MPA*
GOAL 2	**Biological diversity protected**
2A	*Resident ecosystems, communities, habitats, species, and gene pools adequately represented and protected*
2B	*Ecosystem functions maintained*
2C	*Rare, localized or endemic species protected*
2D	*Areas protected that are essential for life history phases of species*
2E	*Unnatural threats and human impacts eliminated or minimized inside and/or outside the MPA*
2F	*Risk from unmanageable disturbances adequately spread across the MPA*
2G	*Alien and invasive species and genotypes removed or prevented from becoming established*
GOAL 3	**Individual species protected**
3A	*Focal species abundance increased or maintained*
3B	*Habitat and ecosystem functions required for focal species' survival restored or maintained*
3C	*Unnatural threats and human impacts eliminated or minimized inside and/or outside the MPA*
3D	*Alien and invasive species and genotypes removed from area or prevented from becoming established*
GOAL 4	**Habitat protected**
4A	*Habitat quality and/or quantity restored or maintained*
4B	*Ecological processes essential to habitat existence protected*
4C	*Unnatural threats and human impacts eliminated or minimized inside and/or outside the MPA*
4D	*Alien and invasive species and genotypes removed or prevented from becoming established*
GOAL 5	**Degraded areas restored**
5A	*Populations of native species restored to desired reference points*
5B	*Ecosystem functions restored*
5C	*Habitat quality and/or quantity restored or rehabilitated*
5D	*Unnatural threats and human impacts eliminated or minimized inside and/or outside the MPA*
5E	*Alien and invasive species and genotypes removed or prevented from becoming established*

How the biophysical indicators relate to the common goals and objectives

	Focal species abundance B1	Focal species population structure B2	Habitat distribution and complexity B3	Composition and structure of the community B4	Recruitment success within the community B5	Food web integrity B6	Type, level and return on fishing effort B7	Water quality B8	Area showing signs of recovery B9	Area under no or reduced human impact B10
Goal 1										
1A	●	●				●	●			
1B			●	●	●			●		
1C	●	●		●		●	●		●	●
1D	●	●		●		●	●			●
1E	●				●		●		●	●
1F	●	●					●		●	
Goal 2										
2A				●	●		●		●	●
2B						●		●	●	
2C	●	●		●						
2D		●	●				●	●		●
2E				●				●		●
2F										
2G	●			●						
Goal 3										
3A	●	●	●			●	●		●	
3B			●	●		●	●	●	●	
3C							●	●		●
3D	●	●		●						
Goal 4										
4A			●	●	●			●	●	
4B			●	●	●			●	●	
4C			●	●	●			●		●
4D	●		●	●				●		
Goal 5										
5A	●					●	●		●	
5B	●	●		●				●	●	
5C		●	●	●				●	●	
5D	●			●				●	●	●
5E	●		●	●					●	

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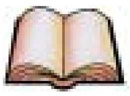
A bottlenose dolphin (*Tursiops truncatus*) in the Caribbean leaps from the sea. Marine mammals are useful symbols with which to represent MPAs to the general public.

Focal species abundance

What is 'focal species abundance'?

Species **abundance** is the number of individuals of a particular species found to occur within and outside the MPA. Species abundance is a commonly used proxy for population size and is thought to reflect the status of a species' population within a specific location; for example, whether or not the population is growing over time. The density of a species is determined by examining the abundance within a defined (unit) area. Species abundance is one of the most widely used biological 'success' measures of management effectiveness.

A **focal species** is an organism of ecological and/or human value whose management through the MPA is of priority interest. There are several different types of focal species that could potentially be identified for a particular MPA (see Box B1). With many MPAs, their goals and objectives relate directly to the need to protect certain focal species.



Focal species abundance can also be defined as how commonly a particular species is found relative to other species within the same community, i.e. B4.

Why measure it?

The protection, enhancement and/or maintenance of populations of focal species are among the most common reasons for using MPAs. Improved and sustained numbers of focal species in the MPA through time is widely seen to indicate effective MPA use. As a result, monitoring changes in the abundance of populations of focal species is one of the most common activities overseen by MPA managers. Fortunately, the basic methods used to compare the number of individuals of a population observed within versus outside an MPA are relatively uncomplicated and easily understood.

As populations of focal species residing within the MPA are protected and allowed to grow, individuals may migrate, or 'spill over', into adjacent, non-protected areas. This increases the biomass avail-

Box B1

TYPES OF 'FOCAL' SPECIES

(adapted from Noss, 1990)

- Endemics – species that are only found to occur naturally in the waters near the MPA.
- Exotics – non-native species that are of concern due to their negative effects on the local ecology. For example, introduced algae that aggressively spreads and smothers native habitat.
- Flagships – charismatic species that are of social or cultural significance and are therefore used by managers as symbols of MPA efforts to encourage public interest and support.
- Indicators – species that signal how disturbances may be impacting other organisms within the community. For example, sea otters in kelp forests.
- Keystones – species upon which others in the community directly depend. For example, top fish predators that maintain a coastal food chain, or a coral reef species that provides living space (habitat) for others.
- Targets – species of interest due to their extractive or non-extractive use value. For example, shellfish commonly harvested for local diet needs, or humpback whales that bring tourists to the area. As not all target species will be priorities for management, they will therefore not all be focal species.
- Vulnerables – species that are known to be less resilient to environmental change than others in the community and/or require careful management to sustain. For example, slow-growing organisms or those with few offspring, or threatened, endangered or rare species (such as those on IUCN's Red List of Threatened Species).

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▶ ***Sharks such as the white shark (Carcharodon carcharias) often serve as focal species in MPAs. Not only do many serve as keystone species being apex predators, but they are also used as flagship species to boost public interest in MPA management needs and activities.***

Relates to goals and objectives

GOAL 1
1A 1C
1D 1E
1F

GOAL 2
2C 2G

GOAL 3
3A 3D

GOAL 4
4D

GOAL 5
5A 5B
5D 5E

Difficulty Rating 3 (1–5)

able for human use. As a result, many managers are not only responsible for showing how more individuals of focal species can be found within an MPA through time, but also how there are increased numbers of focal species in waters surrounding the MPA.

Also, maintaining healthy populations of charismatic species such as whales or turtles may be of interest to recreation users, visitors and the general public, leading to increased tourism revenues and public support for the MPA's continued existence. Finally, clearly showing decision-makers how an MPA is leading to increased or maintained numbers of focal species can help secure the financial and political support required to sustain and/or expand management efforts into the future.

The indicator can also be a useful gauge of the presence/absence of invasive species and the extent (abundance) of their presence.

How to collect the data

Before data collection can begin, the evaluation team will need a list of which focal species in and around the MPA need to be observed during the evaluation period. In some cases, neither the evaluators nor the MPA management team may have an accurate understanding of which species these are. If so, a discrete number of focal species must be identified by the team and listed on paper. Reviewing the relevant types of focal species (see Box B1, above) in the MPA can help to do this. This list should be reviewed and approved by the primary stakeholders involved in the management of the MPA prior to the survey.

> *Note that there is some ongoing discussion within the scientific community over what taxonomic level abundance measures are best collected. Counts performed at the species (as opposed to genus or family) level are discussed here for organisms of focus within the MPA.*

While some MPAs may have only a handful of focal species to be monitored, other sites may have dozens of them to consider. The number of focal species that can be realistically surveyed to determine this indicator will depend largely on the capacity and resources available to the evaluation team.

There are a number of techniques that can be used to measure the abundance of a focal species population within a specified area. These are thoroughly documented elsewhere in the literature, and are therefore not repeated here. At the end of this section are listed several of the most commonly used citations in practice that can be of use to the evaluation team. Generally speaking however, three common approaches can be used to assess the abundance of populations of focal species:

a) Assessing the number of individuals observed *in situ*;

b) Assessing the extent of the observed population in terms of area (e.g. the total km^2 of seagrass beds estimated using GPS) or **biomass** (e.g. basal area or leaf litter of red mangroves) through *in situ* surveys or by using remote technologies (e.g. aerial photographs, satellite technology); and

c) Assessing the landings (fishing catch) of the focal species that has been harvested from the area concerned.

At the most basic level, the evaluation team should estimate the number of individuals observed *in situ* within the survey area according to classes of abundance. With some species, *in situ* observation may only require swimming in the water or being towed behind a boat. With highly mobile species, it may require observation from a boat, airplane or helicopter. An absolute count of individuals is a more precise measure than classes. Provided that

Requirements

- A list of the focal species (reviewed and approved by stakeholders).
- Designated sampling sites inside and outside the MPA.
- An adequate number of trained staff and/or volunteers in both survey methods and taxonomic identification.
- A boat (with safety equipment) and engine.
- Survey tools (e.g. tape measure, compass, towline, submersible writing slate).
- SCUBA or snorkelling equipment.
- A handheld global positioning system (GPS).
- Submersible digital camera (to verify species identifications).
- Advanced (if applicable): aerial photography, satellite imagery, and geographic information systems; small airplane or helicopter (for large, wide ranging organisms); tagging and telemetry equipment; and digital video camera and underwater housing.

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the evaluation team has the time, labour, and resources to do so, absolute counts should be preferred, particularly for species that lend themselves to this method (e.g. species that occur infrequently, have low population densities or are confined to a small survey area). Depending on the species density and the size of area sampled, absolute counts may be too time consuming and laborious to realistically undertake.

Selecting the appropriate survey technique for *in situ* counts of a particular focal species will largely depend on its behaviour and life history. However, the following rules-of-thumb can be used when considering which method is best:

a) **Sessile**, **sedentary**, and limited-ranging **benthic** species (such as abalone clams or the crown-of-thorns starfish) can be observed within or along a series of (ideally) randomly assigned or systematically and permanently stratified quadrats, plots, transects or point-counts at two or more locations at designated survey sites inside and outside the MPA.

b) Mobile species (such as fishes or sea otters) and wider-ranging benthic species (such as lobster) can be sampled through underwater visual census using multiple point-counts (fixed by GPS), belt transects (particularly for sedentary invertebrates) and timed swims (at a constant rate for 15 minute increments, counting 10m to either side of an imaginary line) along fixed depth profiles in relevant habitats inside and outside the MPA. More than one depth profile (i.e. shallower, deeper) should be surveyed respective to the bottom/habitat type being surveyed. Timed swims may be a preferable survey method for counting large, mobile fish, whereas point-counts and transects may be more useful for smaller fishes.

c) Wide-ranging and highly migratory species (such as sea birds, turtles or mammals) can be observed *in situ* using visual observation or tracked with radio tags and **telemetry**.

d) **Cryptic** and rare species may need to be surveyed using separate techniques from those used for other focal species of interest.

Measurement of the extent (area or biomass) or landings of a focal species are discussed further in B4 (pp. 76–82) and B8 (pp. 100–103).

▲ ***With highly mobile, wide-ranging focal species, such as the humpback whale, comparison of abundance data inside versus outside the MPA may not apply as individuals could all belong to the same population.***

The methodological specifics for these rules-of-thumb are well documented elsewhere and referenced at the end of this indicator description. Survey replication should be done at multiple, randomly-assigned or systematically distributed sampling sites and depths within both treatment and reference areas.

Where relevant and feasible, counts of different focal species should be attempted during the same survey to maximize time, labour and funding investments.

Beyond simple counts of individuals observed, where possible the evaluation team should also try to collect size data for the focal species population. Such information can allow managers to move beyond a simple estimate of how many individuals there are to a better understanding of the distribution of the sizes of individuals observed by size class – that is, how much of the population is comprised of smaller (juvenile) versus larger (adult) individuals. A spread of individuals observed evenly across size classes may indicate that there is

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▲ *In the Northwestern Hawaiian Islands, endemic monk seals (*Monachus schauinlandi*) are closely monitored throughout the year in an effort to better understand how the newly designated marine sanctuary is affecting resident populations.*

spawning stock present, and therefore that the abundance of the population may be increased or maintained in the future. The methods used to collect size data are presented in indicator B2. Size classes can be defined by fixed, equal intervals; e.g. 10cm diameter or 1m lengths. It may be easier to collect data on sedentary invertebrates than on mobile vertebrates, as they may lend themselves to handling and sizing. Fairly accurate length estimation can be learned with mobile vertebrates (such as fishes) with some practice (see below for references on this).

Data on measurement of abundance (and size, if relevant) of focal species should be collected regularly, depending on the life history and behaviour of the organism(s) involved. At a minimum, such data should be collected annually or every two years. Ideally, these data should be collected twice a year or quarterly. Data should be collected from both sampling sites inside (treatment site) and outside (reference site) the MPA, including areas immediately adjacent to the boundaries of the MPA to detect 'spill over' effects. The life history and seasonal behaviour of the species being surveyed need to be taken into account when considering the logical timing and frequency of surveys during the year. Repeat surveys should be conducted as close to the same time of month each year as possible.

Collecting size data from a population of a focal species will also allow evaluators to measure indicator B2.

If the evaluation team is to assess the abundance of exotic species, providing the evaluation team with an updated checklist of known and suspected invasive species that may inhabit the area being surveyed will help with their identification and perhaps also with the early detection of new species to the area. Information on suspected and known exotics can be obtained from IUCN regional invasive species working groups.

Where applicable, more sophisticated technologies can also allow for the monitoring of focal species abundance. For example, images captured through the use of underwater video and/or photography at fixed distances along a transect can later be analysed on land to carefully calculate frequency observations for focal species. This can be particularly useful in deeper waters where breathing compressed air for extended periods on SCUBA can be dangerous. Radio tags and telemetry may be necessary to track populations of large, migratory organisms. Aerial survey and remote sensing technologies may also assist evaluators to survey large populations of organisms and/or samples adequately across large MPAs. Such advanced techniques will require significantly more resources and capacity to undertake than *in situ* counts.

How to analyse and interpret the results

Collate, enter and manage data gathered within the MPA's evaluation database. Graph the frequency (y-axis) of individuals of a focal species observed both within and outside the MPA through time (x-axis). Are there any observable trends or changes between focal species within versus outside the MPA through time? Do areas outside but adjacent to the MPA indicate a 'spill over' effect? Using statistical techniques (e.g. student t-tests, analysis of variance), how do sampled populations of the same focal species within and outside the MPA compare against one another, and against themselves, through time? How reliable are perceived changes or trends observed inside the MPA compared to variability occurring outside the MPA? Were known or new invasive species observed during the survey?

Calculate a rough estimate of the density of focal species by dividing the total number of individuals observed (frequency) by the area sampled. Are densities changing through time within compared to outside the MPA? Spatially plot these densities

If size data is also collected, see B2 for guidance on analysis and interpretation of these data.

Outputs (for each focal species surveyed)

- A profile of the abundance (either as classes, absolute counts, area or biomass) inside and outside the MPA.
- Estimated population densities inside and outside the MPA.
- An idea of whether or not the population surveyed is clustered or uniformly distributed throughout the survey area.

Other outputs (if applicable)

- A profile of the abundance of smaller versus larger individuals (via size classes) within the focal species population inside and outside the MPA.
- The relative abundance of different focal species observed across the community surveyed.
- Known presence/absence and abundance of invasive species present in the community.

against the area surveyed. Look for patterns in the observed density: are the individuals uniformly distributed across the areas surveyed or are they clustered in certain areas sampled?

Plot the abundance (y-axis) of populations observed across different focal species (x-axis, as histograms) relative to one another within the community. Monitor changes in the relative abundance of these populations of focal species through time. Do any proportional relationships between the relative abundance of populations appear? Are the relative abundances of various focal species observed within the community changing or being maintained through time? Were known or newly arrived invasive species observed during the surveys?

Prepare results and conclusions for public dissemination. Orally and visually present results with target audiences, and distribute written reports (including graphs and tables of results). Encourage independent validation of findings by partners and outside parties within the sampled area in order to confirm or reject results and increase the understanding of the effects of MPA activities on the area. Be sure to include any stories or anecdotes that illustrate the results observed from stakeholders.

Strengths and limitations

The approach and general survey methods for measuring this indicator are relatively uncomplicated and commonly used. However, the degree of overall difficulty in measuring the indicator can range widely. In some cases, collecting abundance data can be done rapidly, inexpensively and with a minimum of specialists. In other cases, it may require several months and a large team to complete. The amount of time, financing, equipment and evaluator skill required for measurement in an MPA will depend in part on:

a) The size of the MPA needing to be surveyed;

b) The number of focal species being sampled;

c) The density with which the focal species occurs;

d) The migratory behaviour and home range size of the population observed;

e) The conspicuousness and degree to which the species is easily observable; and

f) The local/national capacity to conduct the survey and level of skill within the evaluation team.

For example, measuring the abundance of a colourful, sessile organism occurring in the shallow waters of a small MPA will require far less capacity to survey than the measurement of an highly migratory, pelagic species that is known to infrequently visit the seas included within and outside a large MPA.

Abundance observations for a focal species are difficult to infer beyond the sampled area. Large areas must be sampled to confidently characterize large-sized MPAs and surrounding waters. Also, as some populations may occur with a high level of spatial and seasonal variability, they may require a high level of sampling effort in terms of area and time to monitor.

At the most basic level, evaluators must have the capacity to undertake abundance counts or class estimates and be able to correctly identify focal species *in situ*. In some cases, abundance surveys may require a considerable amount of time and labour to undertake. More advanced skills will be needed to do length estimation, biomass estimation, and/or catch-landing surveys.

Finally, counts are limited to depths at which diving can be safely undertaken. To determine the focal species abundance of populations in deeper waters, catch-landing surveys of deep-water species caught should be undertaken.

Useful references and Internet links

Noss, R. F. (1990). "Indicators for monitoring biodiversity: a hierarchical approach". *Conservation Biology* 4(4): 355–364.

Abundance and length estimation methods

Bell, J.D., Craik, G.J.S., Pollard, D.A. and Russell, B.C. (1985). "Estimating length frequency distributions of large reef fish underwater". *Coral Reefs* 4: 41–44.

Dartnall, H.J. and Jones, M. (1986). *A manual of survey methods of living resources in coastal areas*. ASEAN-Australia Cooperative Programme on Marine Science Hand Book. Australian Institute of Marine Science, Townsville, Queensland, Australia.

English, S., Wilkinson, C. and Baker, V. (eds.) (1997). *Survey Manual for Tropical Marine Resources. 2nd Edition*. Australian Institute for Marine Science, Townsville, Queensland, Australia.

Gunderson, D.R. (1993). *Surveys of Fishery Resources*. John Wiley and Sons, Inc., New York, NY, USA.

Mapstone, B.D. and Ayling, A.M. (1993). *An Investigation of optimum methods and unit sizes for the visual estimation of abundances of some coral reef organisms: A report to the Great Barrier Reef Marine Park Authority*. Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia.

Mapstone, B.D., Ayling, A.M. and Choat, J.H. (1999). *A Visual Survey of Demersal Biota in the Cairns Section of the Great Barrier Reef Marine Park: A Report to the Great Barrier Reef Marine Park Authority*. Research Publication No. 60. Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia.

MPA MEI website: useful discussion thread between Tupper and Ellis regarding the appropriate sampling and design for *in situ* observation methods of focal species. [Online URL: effectiveMPA.noaa.gov]

Underwater visual census methods

Samoilys, M. (ed.) (1997). *Manual for Assessing Fish Stocks on Pacific Coral Reefs*. Training Series QE9700. Department of Primary Industries, Queensland, Australia.

Thompson, A.A. and Mapstone, B.D. (1997). "Observer effects and training in underwater visual surveys of reef fishes". *Marine Ecology Press Series* 154: 53–63.

Rapid assessment of fishes and habitat

McKenna, Sheila A., Allen, Gerald R. and Suryadi, Suer (eds.) (2002). "A Marine Rapid Assessment of the Raja Ampat Islands, Papua Province, Indonesia". *RAP Bulletin of Biological Assessment 22*. Center for Applied Biodiversity Science, Conservation International, Washington, DC, USA.

The Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program. [Online URL: www.cep.unep.org/programmes/spaw/icri/aggra.htm]

Timed swim methods

Donaldson, T.J. (2000). Testing the effectiveness of MPAs and other reef fish management strategies using agent-based models. Proposal to the United States National Oceanographic and Atmospheric Administration. Unpublished report. University of Guam Marine Laboratory. Mangilao, Guam. [Online at http://www.uog.edu/marinelab/mpa/abm.pdf]

Box B2

Example from the Field

At the Far Eastern Marine Reserve, the timing of when the evaluation team measures resident larga seal (*Phoca largha* – right) populations in the Bay of Peter the Great can be tricky. February is the peak breeding season when most individuals of this vulnerable, flagship focal species come onshore, thereby making for rather strict time requirements for performing censuses. Unfortunately this month also often hosts some of the most inhospitable weather and sea conditions of the year. The evaluation team has learned how to conduct their census work from small boats during this time of year, despite average daily temperatures of -10ºC and rough seas. The data collected over the past few years indicate that the protected rookeries are helping the species to make a local come-back from near extinction in Russia's South Primorye.

WWF Russia/Far Eastern Marine Reserve

What is 'population structure'?

Population structure is the probability with which different sizes and ages of individuals are likely to occur within a population of a focal species. A population experiencing no or reduced human impacts and influenced largely only by natural conditions is more likely to host the necessary number of reproducers in order to replenish and maintain itself through time than one whose individuals are being removed for human use.

In measuring this indicator, it is possible to go beyond simply assessing how much of a focal species there is at a single point in time (indicator B1) by further characterizing how the individuals in the population are structured by size and age, and by assessing the population's reproductive potential. In this respect, this indicator can be used by managers both as a 'snapshot' at a single point in time of what proportion of the focal species population is made up of reproducers, as well as a 'crystal ball' to help managers forecast population growth rates or predict declines that may occur within the focal species as a result of changes happening in the size/age structure.

Important factors that influence size and age distribution within a population include the regularity of spawning events, the variability in timing, amount and location of larval settlement and recruitment events, and the degree of juvenile survivorship and recruitment in the population.

Why measure it?

For the population of a species to continue to exist through time, an adequate number of reproductive adults must be present. A common rationale in using and supporting MPAs is that they can serve as a safe haven for the breeding stock of a focal species. Therefore, an effectively managed MPA is one that is thought to contain populations of focal species whose individuals are adequately distributed from juvenile to adult size classes so as to allow them to replenish themselves and be viable (i.e. persist in the area through time).

Further, by maintaining spawning stock, effectively-managed MPAs are also thought to:

a) Serve as a source of eggs, larvae and juveniles that are exported to areas outside the MPA; and

b) Increase the number of reproductive adults found in waters outside the MPA as a result of 'spill over' (migration of individuals).

As a consequence, managers are often entrusted not only with the responsibility of showing how the populations found in the MPA have the structure and potential to continue to persist through time, but also with the job of demonstrating how juveniles and adults exported into adjacent waters outside the MPA are helping to stabilize population structures and viability there as well.

In many places, these phenomena are seen as some of the most important benefits arising from MPA use. Therefore, in order to secure and sustain long-term support for MPA efforts, these benefits must be clearly shown.

> Note that a network of multiple MPAs may be required to adequately sustain some populations of focal species that exhibit wide-ranging life history characteristics, such as:
>
> - Lengthy larval stages.
> - Large home ranges.
> - Aggregation from a wide area to a specific site for certain life events.
> - Simply being highly migratory in nature.

How to collect the data

The presence and reproductive potential of breeding stock and future viability of populations of a focal species can be assessed by collecting size, age, reproductive potential, and recruitment data from sample areas within and outside the MPA. Because many coastal species occur in various habitats throughout different phases during their lifetime, multiple habitats are likely to require sampling for populations of some focal species. In some cases, distinctive markings and coloration in focal species may also assist evaluators to clearly distinguish between juveniles versus reproductive adults. Also, scientific literature may already exist that shows or suggests the size and/or age of first reproduction of the focal species concerned.

At the most basic level, information on the size of individuals observed within surveyed areas both within and outside the MPA should be collected. Collecting size data on individuals sampled from a

As the number of individuals found in a population is closely related to its size and age structure, indicators B1 and B2 are closely associated and data can be concurrently collected for both.

Relates to goals and objectives

GOAL 1
1A 1C 1D 1F

GOAL 2
2C 2D

GOAL 3
3A 3D

GOAL 5
5B 5C

Difficulty Rating 4 (1–5)

Requirements

- The same requirements as listed under indicator B1.
- Capture nets, lines, and traps.
- Sizing equipment, such as a fish measuring board, a soft tape measure, sizing sticks, callipers and a set of balances.
- Basic capture-mark-recapture: plastic tagging kit.
- Advanced capture-mark-recapture: radio telemetry tracking system.
- Age: collection and holding equipment for specimens.
- Age: laboratory facilities and equipment to analyse specimens.
- Recruitment: collection plates, nets and traps.

population of a focal species is particularly useful when the organism is both known to have a fixed size to age relationship and when the age (or size) of first reproduction is known. In such cases, a reliable distinction between breeding stock and juveniles can be made based on accurate size data.

The *in situ* survey methods on how to observe and sample individuals for sizing are the same as those described under indicator B1. In most cases, size data can be collected from focal species through *in situ* survey as follows:

a) By estimating the length or size of mobile individuals observed at distance from within the sampled area (both in or on the water or from the air), such as fishes, marine mammals or seabirds;

b) By collecting, handling and measuring actual length or size of live individuals (prior to their release); and

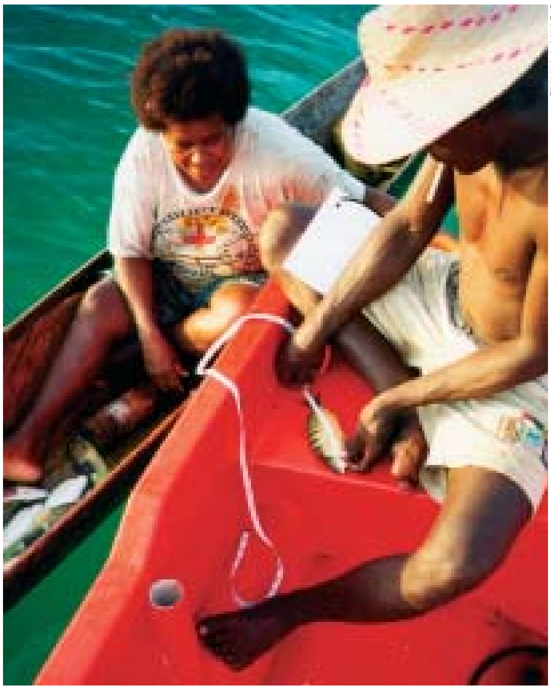
c) By measuring the actual length or size of individuals harvested.

While the collection of age data from individuals surveyed requires a more advanced level of skill, it may be desirable, particularly with focal species where the age of sexual maturation in the organism is known and where size is not a good predictor of reproductive potential. Timed growth studies can be conducted using capture-mark-recapture (CMR) methods on live individuals that have been recaptured after being previously tagged and released. This can be done using simple and inexpensive plastic tags and minimal skill, or through more sophisticated monitored techniques such as submersible radio tags and telemetry equipment. CMR study can not only provide important information on the rate at which individuals grow over

Actual or estimated length/size data are measured differently depending on the type of organism surveyed, for example:

- Fish by their total or caudal length (cm or m).
- Marine mammals by their total length or fluke width (m).
- Bivalves by their dorsoventral length (cm).
- Crustaceans by their carapace length (cm).
- Marine reptiles by their straight line carapace (shell) length (cm).
- Mangroves by their trunk's girth at breast height (cm).

In Marovo Lagoon in the Solomon Islands, village fishers help local managers monitor focal populations of coral reef fish by allowing them to measure fork length data on individuals caught in waters surrounding several locally managed MPAs.



JOHN PARKS

time (i.e. the size-age relationship), but also help managers to better understand how populations of focal species move within and outside the MPA.

In many cases, confidently profiling the age structure of a population will require a sophisticated level of scientific study, such as dissection, biopsy, and genetic analysis of the reproductive organs, dissection and analysis of fish otoliths, and study of other morphological characteristics in the species. Such studies can be particularly useful if the size or age of first reproduction are not known for the focal species being assessed.

Note that with some organisms, such as coral reef fishes, growth rates are not always constant throughout an individual's lifetime. Also, correlations between body size and age may not necessarily be consistent through time. Therefore, an understanding of a population's size structure at a few specific points in time may not allow evaluators to fully or accurately understand population growth rates, ages or reproductive capacity.

Another measure to assess population structure is to estimate the reproductive potential of a population. This can be characterized in part by:

a) The presence of breeding stock;

b) The amount (biomass, number) of breeders;

c) The timing of spawning behaviour and frequency of breeding events; and

d) The breeding stock's potential fecundity (defined as the number of eggs produced by the population during spawning).

Finally, recruitment and survivorship studies of the focal species can also be conducted to assist in assessing the viability of the population through time. Recruitment data can be collected using visual census or through the capture and sizing of individuals (note that this may lead to specimen mortality). Nets, lines and traps are commonly used to sample juvenile fish and some shellfish. Collection plates, nets and traps can be used to capture smaller individuals of soft- and hard-bodied invertebrate focal species, such as coral recruits and juveniles. Traps are useful for settling lobster, conch, beche-de-mer, or other invertebrate larvae.

Data collection on larval settlement and juvenile recruitment data can be done concurrently with indicator B5.

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▲ ***Monitoring the timing and frequency of known reproductive events and sites of a focal species can assist the evaluation team to more accurately characterize the structure and viability of the population.***

Note that because the collection of recruitment data within the MPA may require landing and some mortality of live specimens, this may not be compatible with the goals or rules of your MPA (e.g. in a no-take area).

Information used to characterize population structure (at a minimum, size data) should be collected ideally once or twice a year, and at least every two years (depending on the focal species). The ideal timing for measurement will depend on the life history of the organism(s) being assessed. Size data should be collected concurrently with abundance data (indicator B1) for each focal species.

How to analyse and interpret results

The analysis and interpretation of data collected for this indicator are the same as those presented under indicator B1. Enter size and age data into the MPA's evaluation database so that it can be organized and/or exported within defined size or age classes of fixed, equal intervals; for example, 10cm increments, 0.5m lengths, or one year. Enter into a table the frequency with which individuals of each size or age class are observed within and outside the MPA. The distribution of individuals across size/age classes can also be viewed on a graph by plotting the frequency of individuals observed (y-axis) against their respective size/age class (x-axis).

Note that confidently building an understanding of a population's structure using this *indicator will take several years. It is dangerous to attempt to characterize a resident population and/or make management decisions based on a single data set or limited time series of information.*

Using catch data, profile the annual average frequency of sizes (lengths) of organisms harvested through time. From this, plot out a length-converted catch curve on a graph. Use results to form an estimate of the total mortality rate prevailing in successive classes. Compare results with those of other sample populations of the same species.

Compare size/age class structures of the population both within and outside the MPA, through time. Assuming that an adequate and stable number of surviving juveniles and reproductive adults within a population will improve its likelihood of persistence, and allowing for natural variability (which may be high in some cases), try and address the following questions. Are there any observable trends or changes in the size/age class distribution of individuals of a focal species within versus outside the MPA? Do individuals measured outside but adjacent to the MPA indicate a 'spill over' effect of certain size/age classes? If size/age of first reproduction is known, are there any observable changes in the abundance of juveniles versus reproducers within versus outside the MPA? When interpreting size class results, remember that the size structure within many species (such as coral reef fish) is not an accurate gauge of their ages or when reproductive maturity is achieved.

Using statistical techniques (e.g. student t-tests, analysis of variance), how do sampled populations of the same focal species within and outside the MPA compare against one another, and against oneself, through time? How reliable are perceived changes or trends observed inside the MPA compared to variability occurring outside the MPA?

Do the size/age class data gathered provide an improved understanding of whether or not management actions in the MPA are leading to a more balanced population structure compared to outside the MPA? Over time, are size/age 'thresholds' or requirements for the population's sustainability becoming apparent? If so, can this be developed further to inform management needs and processes? Based on the overall results generated for this indicator, how likely does it appear that the population will be able to regenerate itself and be viable through time? When sharing results with primary audiences, it may be useful to provide responses to these questions using a qualitative

▲ ***Blackbar soldierfish (*Myripristus jacobus*) within a coral reef nook.***

Outputs (for each focal species)

- A profile of how the population surveyed is structured by size (inside and outside the MPA) at a certain point in time. This may include an understanding of what proportion of the population is sexually mature.
- A graph of the size/class distribution for each focal species studied.
- An improved understanding of how likely the population is able to replenish itself based on hosting adequate spawning stock.

Other outputs (if applicable)

- The age structure of the population surveyed (inside and outside the MPA).
- Improved understanding of the age of sexual maturation in the focal species.
- A characterization of the reproductive potential (including spawning and breeding ability) of the focal species compared to known life history.
- An improved understanding of how viable, or potentially persistent, the population is based on its ability to replenish itself and host adequate spawning stock.
- A length-converted catch curve and estimated mortality rate.

scale (e.g. lower, unchanged, or higher) and/or quantitative measure (e.g. probability of reproductive capacity or fecundity).

Prepare results and interpreted findings for public dissemination. Orally and visually present results, and distribute written reports (including graphs and tables of results). Encourage independent validation of findings by partners and outside parties within the sampled area in order to confirm or reject results and increase the understanding of the effects of MPA activities on the area. Be sure to include any stories or anecdotes that illustrate the results observed from stakeholders.

Because of the often challenging nature of collecting and analysing biological information and the effects of spatial and temporal variability on interpreting results, it is strongly recommended that if there are no qualified specialists trained to address these issues on the evaluation team or the MPA staff, input and assistance should be sought from outside experts.

Develop a profile of the reproductive potential (if applicable) of the focal species population and how this profile compares against what is known about the life history of the species. How does this profile predict the ability of the population to maintain itself through time? Finally, if applicable, present the number/density of recruits and juvenile sizes resulting from the recruitment survey and discuss how they relate to the observed size class distribution.

Strengths and limitations

Many of the strengths and limitations of this indicator are similar to those described under indicator B1. Size and age class information are accepted and widely understood standards in profiling and better understanding the structure and viability of a population. Also, regular collection of size class information can be useful in understanding and predicting the sustainability threshold of focal species that are targeted for fisheries' harvest within or outside the MPA. In this sense, the indicator can both serve to measure MPA effectiveness as well as improve understanding of *in situ* fisheries management and help to set harvest limits.

Size and age measurement require more skills than merely *in situ* observation. Accurate estimates of individuals' sizes through remote estimation requires skill and experience and is not easily undertaken by novices or managers without existing training. Conducting size measurements of live specimens requires that staff have experience and training in sensitively and non-destructively capturing, handling, sizing and returning live specimens. Scientific age assessments will require: a) staff with a comparatively larger set of technical skills, b) increased time and c) more equipment and finances.

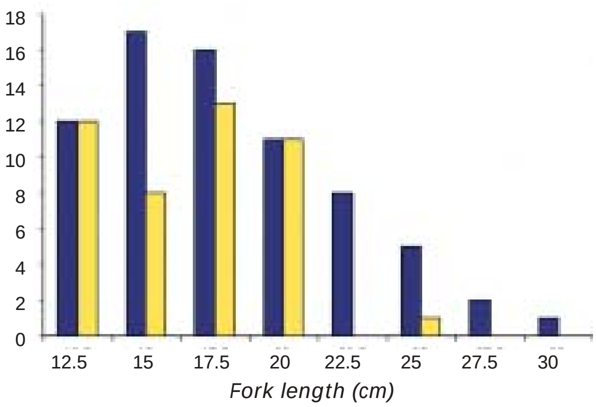
While useful, the capture of reproductive potential and recruitment information will largely multiply the complexity, labour, time and cost requirements of data collection under this indicator.

Also, a useful interpretation of this indicator inherently requires several years of comparable information.

Box B3

EXAMPLE FROM THE FIELD

A primary objective of Guam's Marine Preserve Network is to restore declining reef fish populations. At the Achang Reef Flat Preserve, an evaluation was conducted of the population structure of the bullethead parrotfish (*Chlorurus sordidus*), one of the most commonly fished species in Guam's inshore reef fishery. The evaluation team's results (right) show how larger and more abundant size classes of bullethead parrotfish were observed within the Achang Reef Flat Preserve than in adjacent control (non-protected) sites. Data collected suggest that this species appears to be experiencing population recovery within the Reef Flat Preserve, which was the Reserve Network's primary objective.



The observed size class distribution of bullethead parrotfish within (purple bars) and outside (yellow bars) the Achang Reef Flat Preserve.

Useful references and Internet links

Bell, J. D., Craik, G.J.S., Pollard, D.A. and Russell, B.C. (1985). "Estimating length frequency distributions of large reef fish underwater". *Coral Reefs* 4: 41–44.

English, S., Wilkinson, C. and Baker, V. (eds) (1997). *Survey Manual for Tropical Marine Resources. 2nd Edition*. Australian Institute for Marine Science, Townsville, Queensland, Australia.

Munro, J.L. and Pauly, D. (1983). "A simple method for comparing the growth of fishes and invertebrates". *ICLARM Fishbyte* 1(1): 5–6.

Age estimation

Choat, J.H. and Axe, L.M. (1996). "Growth and longevity in acanthurid fishes; an analysis of otolith increments". *Mar. Ecol. Prog. Ser.* 134: 15–26.

Ferreira, B.P. and Russ, G.R. (1994). "Age validation and estimation of the growth rate of the coral trout, *Plectropomous leopardus* (Lacepede 1802) from Lizard Island, Northern Great Barrier Reef". *Fish. Bull. U.S.* 92: 46–57.

Fournier, D. and Archibald, C.P. (1982). "A general theory for analyzing catch at age data". *Can. J. Fish. Aquat. Sci.* 39: 1195–1207.

Fowler, A.J. (1990). "Validation of annual growth increments in the otoliths of a small tropical coral reef fish". *Marine Ecology Progress Series* 64: 25–38.

Hilborn, R. (1990). "Estimating the parameters of full age-structured models from catch and abundance data". *Bull. Int. North Pac. Fish. Comm.* 50: 207–213.

Size-class data in a small MPA

Tawake, A., Parks, J., Radikedike, P., Aalbersberg, B., Vuki, V. and Salafsky, N. (2002). "Harvesting clams and data: involving local communities in monitoring – a Case in Fiji". *Conservation in Practice* 2(4): 32–35.

Recruitment

Sale, P.F., Doherty, P.J., Eckert, G.J., Douglas, W.A. and Ferrell, D.J. (1984). "Large scale spatial and temporal variation in recruitment to fish populations on coral reefs". *Oecologia* (Berlin) 64: 191–198.

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What is 'habitat distribution and complexity'?

Habitat is defined as the living space of an organism, population, or community, as characterized by both its biotic and physical properties. Habitat types are distinguished from one another by their distinct biotic and abiotic composition and structure that forms living space.

The **habitat distribution** within a specified area or ecosystem is the structural and spatial characterization of all habitat types represented, based on their:

- ❑ Physical location (including depth);
- ❑ Configuration (i.e. placement next to one another); and
- ❑ Extent in terms of total area (in km^2).

Habitat distribution varies widely with each MPA. For example, the boundaries of a very small, relatively homogenous MPA may only encompass one or two different habitat types. At the other end, large-scale ecosystem MPAs may host dozens of different habitats.

Seascapes are dynamic, biotic mosaics comprised of patterns of habitat and characteristic patchiness due to spatial and temporal variability. Some habitat mosaics are more complex than others. **Habitat complexity** is defined as the extent (area in km^2) and diversity (number) of habitat types and distinct zones found within a specified area. Higher habitat complexity does not necessarily indicate a 'better' or healthier ecosystem; the 'right' level of complexity all depends on what would occur naturally in the absence of human impacts. However, a highly complex habitat structure hosts a wider variety of habitat types and zones within the ecosystem than one of a uniformly distributed structure of low diversity. Highly complex habitat structures hosting a wide diversity of organisms are commonly cited as priorities for protection by management and conservation groups.

Note that under natural conditions, habitat distribution and complexity do not remain static through time and space. For example, reduced habitat complexity observed in an MPA due to increased algal dominance may be within the range of natural variability and not the consequence of human activity.

Habitat integrity can be defined as the likelihood that the distribution and complexity of living space in an area will persist through time. A 'healthy' habitat is therefore one that is considered to have strong integrity and is resilient to pronounced change. Habitat integrity offers a more dynamic perspective to this indicator than simply assessing a 'snapshot' of habitat structure (i.e. at a single point in time).

◀ The distribution of habitat and habitat types in an MPA depends on the physical and biological characteristics of the living space. For example, this atoll in Yap, south Pacific, demonstrates zones of habitats associated with coral reef, from onshore out to offshore waters by depth and substrate type. These habitats can include:

a) Onshore sandy beach
b) Intertidal mud flats and reef rubble zone
c) Shallow water patch reef and seagrass meadow
d) Inshore back reef flat and reef crest
e) Spur-and-groove reef channels and fore reef slope
f) Nearshore coastal waters.

Why measure it?

Communities of organisms are dependent on the presence of adequate living space within which to exist and reproduce. Disturbance events in the community, whether natural or man-made, can lead to changes in habitat structure and declines in complexity. Such changes may in turn cause reductions in focal species abundance and changes in population structure and community composition.

MPAs are often used in an attempt to prevent or reduce the frequency and intensity of man-made disturbances in an area so as to arrest deleterious change on the habitat within them. This assumes that such disturbance events are localized within or nearby the MPA and are not outside the influence of management action. 'Broadcast' disturbance events beyond the control of managers, such as a rise in sea surface temperature and downstream sedimentation from inland logging activities, can threaten the effectiveness of MPA management actions. It is not surprising that the maintenance of habitat complexity and 'health' (integrity) is considered a critical measure of success in many MPAs, particularly in large-scale, ecosystem-level MPAs that are representative of multiple habitats. Awareness and an improved understanding of the sources and levels of change to habitat structure can not only allow managers to identify and potentially address them, but also re-evaluate and adjust MPA boundaries and activity zoning intuitively through time to adapt to such change.

Relates to goals and objectives

GOAL 1	1B
GOAL 2	2D
GOAL 3	3A 3B
GOAL 4	4A 4B 4C 4D
GOAL 5	5C 5E

Difficulty Rating 5 1–5

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Jurgen Freund /naturepl.com

▲ ***Examples of natural disturbance events that are known to lead to changes in habitat distribution and complexity are storms and cyclones (inset). Bottom trawling, dynamite fishing (main picture) and cyanide fishing are examples of localized, man-made events known to reduce habitat complexity.***

This indicator relates closely to all five biophysical goals identified for MPAs (see Figure B1), particularly goals 4 (habitat protected) and 5 (degraded areas restored).

How to collect the data

Data collection for this indicator requires an in-depth process of survey and characterization in and around the MPA.

A full inventory of habitats found in and around the entire area of the MPA can be done if the evaluation team has adequate time and resources to do it. Otherwise, a minimum of 20 to 30% of the total area in and around the MPA should be randomly sampled and characterized, with surveys being stratified by depth and substrate type. The evaluation team should at least aim to characterize 'priority' habitat types; that is, those habitats that make up a majority of the total area represented

Requirements

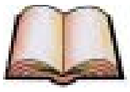
- Designated sampling sites inside and outside the MPA.
- An adequate number of trained staff and/or volunteers.
- Evaluation team ability to recognise, distinguish between and delineate distinct habitat types/zones and **ecotones** (areas of overlapping habitat).
- Evaluation team familiarity with the types and extent of active anthropogenic threats; ability to recognise the effects of man-made disturbance.
- Participation from or access to an experienced community ecologist and/or habitat survey and mapping specialist.
- A boat (with safety equipment) and engine.
- Survey tools (e.g. tape measure, compass, towline, submersible writing slate) for *in situ* characterization of substrate and assemblages of organisms that comprise habitat.
- SCUBA or snorkelling equipment.
- Base maps (ideally digitized) for the larger area being surveyed, at various (high to low) resolutions.
- A handheld global positioning system (GPS).
- Geographic information systems (GIS) software and relevant hardware (e.g. computers, digital plotter and large printer).
- Advanced (if applicable): access to remote sensing technologies (e.g. satellite imagery and/or completed aerial photography); small airplane or helicopter to do aerial photography; digital video camera and underwater housing; remote operated vehicle (ROV) and other robotics; bottom-profiling sonar; evaluation team familiarity with habitat utilization patterns.

within the MPA or are known to be of important conservation and management value for focal species occurring within the MPA (for example, in estuarine habitats where juveniles of focal species recruit to and grow out). Ideally, most MPAs will have the time and resources to conduct an *in situ* inventory and characterization of all habitat types (not just priority ones) represented within and around the MPA. In some cases, all of the habitat types represented within the MPA will be viewed as management priorities and therefore will need to be surveyed.

Habitat characterization is done through *in situ* and/or *ex situ* surveys in and around the MPA. Three categories of data are collected through the habitat characterization survey: 1) habitat composition data, 2) habitat status data and 3) habitat distribution data. Data collection methods for all three categories are described below.

Habitat composition data are collected through a survey of the biotic (species, community composition) and abiotic (substrate, water conditions) characteristics of the sampled area. Allowing for distinctions to be made between patterns of biotic and abiotic characteristics observed, the different habitat types and ecotones occurring can be identified. *In situ* methods of shallow-water surveys to characterize substrate and single- or multiple-species assemblages of organisms are discussed under indicators B1 and B2. Survey methods used to collect data on water conditions are described under indicator B8.

Where these *in situ* sampling methods are not feasible, a qualitative generalization of observed substrate type and species composition can be performed within the area surveyed through timed or random swims with skin diving gear. More advanced technologies for alternative *in situ* habitat profiling may be available at some MPAs, including shallow-water video survey, remotely operated vehicle videography, use of manned submersibles, use of side-scan and bottom penetrating sonar, use of multibeam bathymetry and echo sounding, and bottom sampling. Such alternative *in situ* survey technologies are particularly useful in deep waters.



In situ data collection methods for this indicator are similar to those of indicators B1, B2, B4 and B5. They should therefore be measured together.

Characterization of habitat composition can also be done *ex situ* using remote sensing technologies, such as satellite imagery and aerial photography. Such *ex situ* methods may be particularly useful within large or deepwater MPAs where *in situ* sampling is not feasible or efficient. It is recommended that where possible, a minimum level of *in situ* survey should be done to validate data collected through *ex situ* characterization.

In some cases, habitat composition may be difficult to undertake using either *in situ* or *ex situ* methods. In such cases, an approximation of habitat composition, status and distribution should be made using the best available information and knowledge (for example, from the examination of bottom trawl catches outside the MPA and interviews with fishers using the area).

Next, habitat status data should be collected at survey sites. Habitat status is measured as the quantity and quality of live habitat observed within a sampled area. Habitat quantity is typically estimated as the percentage of habitat cover (live or otherwise; e.g. percentage (%) live cover of coral reefs, percentage (%) cover of reef rubble) and/or the density of live organisms (e.g. live seagrass bunches) observed within a sampled area (in m^2 or km^2). It can also be measured as the volume (grams per m^2) of live biomass, such as with kelp or mangrove forests. *In situ* sampling of benthic habitat is often done using transects, quadrats, plots, point-counts or timed swims. Habitat quality is a measure of the robustness or vitality of live habitat encountered during a survey. At a minimum, a subjective characterization of the apparent vitality of the live habitat observed within the surveyed area can be made. A more structured characterization of this would use a standardized

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Within deep water MPAs,* in situ *habitat characterization may only be possible through the use of technologies such as manned submersibles or remotely operated robotics.

ordinal scale of habitat quality; for example a 3-point scale from "dying" (lowest) to "deteriorating" (middle) and "healthy" (highest). A diagnostic checklist of known indicators related to the health of the habitat type being assessed (e.g. coloration, morphology, frequency or volume) may also be useful to review when live habitat is encountered within the survey area. *Ex situ* methods of habitat status typically involve aerial estimates of habitat quantity (total km^2) generated through remote sensing data.

Finally, data on the physical distribution of habitat observed are collected through measurement of the habitat's:

- location (depth and position) within the area surveyed,
- structure (height from the seafloor/substrate, density and volume), and
- configuration (placement relative to other habitats within the area surveyed).

Structure and configuration data collected are measured as units of size (cm^2 or m^2) or area (m^2 or km^2). Location data collected are measured as either a unit of depth (m^2 or km^2) or as geographically referenced coordinates.

These data are collected either:

- *in situ* using a handheld GPS and natural land and sea reference points, or
- *ex situ* via aerial photography or satellite imagery.

Geo-referenced data allow for the demarcation of distinct habitat types observed within the area surveyed. Where the use of a handheld GPS is not possible, compass bearings run from permanent buoys at known and easily referenced locations on a map can serve to help demarcate habitat boundaries. Likewise, the use of land and sea markers can provide a rough estimate as to the distribution and extent of habitat types within the MPA area. Habitat distribution data reflect the physical positions of the various habitat types within the area surveyed, including their structure and zonation across it.

Periodic re-evaluation of the composition, location, quantity and quality of habitat types in the future will help the evaluation team to determine whether or not changes in the distribution and complexity of the habitat are occurring, and if so, to what degree. Ideally, data on habitat characterization should be collected annually, at least within priority habitat types. In many MPAs this may be

The identification, monitoring and impact of human-induced disturbance events can be documented through the measurement of indicator B10.

▼ ***Vertically stratified habitats, such as kelp forests, will require more survey effort than habitats which can be characterized simply as seafloor habitat.***

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▲ ***Completing the habitat map for Tubbataha Reef National Marine Park, one of the MPA pilot sites for this book.***

unrealistic. In such cases, repeat surveys can be attempted every two to three years, but no later than five years. Monitoring habitat types with annual or perennial life histories may require more frequent observation. Repeat surveys should be conducted more frequently following natural or human disturbance events that are known by MPA staff and stakeholders to have impacted the area in or around the MPA. Determining the correct timing of when during year the repeat surveys should be conducted may depend on the growth period and **phenology** of the organisms that make up the habitat.

How to analyse and interpret results

The analytical challenge of this indicator is to determine whether or not changes observed in habitat location, composition, quantity and quality inside the MPA are due to naturally occurring phenomena (such as ecological succession) or are enhanced by or a consequence of human perturbation. In order to do this, the habitat types characterized through the survey need to be mapped, labelled and monitored.

Mapping is done by plotting collected habitat characterization data onto a geo-referenced **basemap** of suitable resolution for the entire survey area. The demarcation of observed habitat boundaries onto the basemap is done using the GPS-referenced data that were collected through the habitat

Table B1

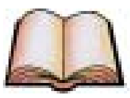
An example table of data entered on the mean % total benthic cover for observed habitat types within coral reef habitat inside and outside the MPA

	MPA			*Control Area 1*			*Control Area 2*		
Habitat type	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*n*
Hard corals	17.64	12.59	16	43.65	14.14	20	36.63	8.62	16
Coralline algae	13.07	15.61	16	8.13	7.32	20	2.60	2.25	16
Fleshy algae	44.86	15.51	16	10.08	6.97	20	2.28	2.26	16
Soft corals	10.05	15.22	16	4.38	5.93	20	39.54	13.21	16
Sponges	0.22	0.61	16	2.15	2.33	20	1.09	1.13	16
Sand	0.48	1.37	16	0.29	0.49	20	0.15	0.30	16
Reef rubble and dead rock	13.68	13.78	16	31.33	15.64	20	17.71	10.23	16

characterization survey. Boundary delineation should be done at a scale that is meaningful for decision-making purposes by the MPA; in some cases this may be as high resolution as a few metres. At a minimum, the boundaries, distribution and overlap of all priority habitat types should be mapped and labelled appropriately against the basemap. Ideally, a precise delineation and labelling of all habitats occurring within and around the MPA should occur using high-resolution basemaps. Boundary delineation should be referenced against other existing habitat maps, if available. Consult MPA staff and local stakeholders to compare generated results against knowledge and experience in order to check for accuracy and identify any potential needs to ground-truth questionable habitat boundaries. Encourage the process of boundary- and fact-checking to be inclusive and participatory.

In some cases, digital basemaps will be available. In other cases, only hard copies of the necessary basemaps will be available, sourced perhaps from government offices or private surveyors. If possible, hard copies of basemaps should be digitally scanned into a computer so that data collected can be exported from database storage and plotted out spatially against the digitized map using image editing or **geographic information system** (GIS) software. Where possible, mapping results should be triangulated through the use of data collected both *in situ* and *ex situ* and validated through stakeholder interviews and discussions. In addition to habitat characterization data, you should attempt to map the spatial extent of known disturbance events and threats.

Other geo-referenced biological and social data collected from other indicators outlined in this guidebook may be useful to overlay against habitat characterization data collected. From such multi-indicator data overlays, patterns between biological processes, human behaviour and habitat distribution may be elucidated spatially. Such spatial overlay and analysis of data from multiple indicators is a process that will not only necessitate access to GIS technologies, but also to additional time, skills and resources.



Changes observed in habitat distribution and complexity may relate to the abundance of populations of focal species and how they utilize the habitat (e.g. for foraging or nesting). Recognising this, in the absence of existing and sufficient baseline information on populations of focal species and their habitat utilization patterns, this indicator may need to be measured concurrently with indicator B1.

Where no basemaps, GPS-referenced data or GIS technologies are available, at a minimum spatial data on habitats collected through the use of reference buoys, compass bearings, and land and sea markers can be mapped out by hand on to graph paper. Mapped results created by hand can then be photocopied and checked against MPA staff and/or stakeholder knowledge.

Once mapped, calculate the extent, or the mean % benthic cover of the total area, for each habitat type observed within the overall habitat surveyed. Record these figures for each habitat type in a table (see example table, above), along with their standard deviations and the number of replicate surveys completed within the area sampled. Include data for both the MPA and control areas studied. Periodically update the table as new data are collected through time. Considering the spatial extent and distribution of each habitat type on a regular basis (as repeat data are collected) will allow for comparison and monitoring of changes in the extent of habitats through time.

Compare the extent (total area) of each habitat type through time and determine whether or not there are observable changes or trends in the amount of habitat that is present. Are any trends in the reduction or increase of the total area of a habitat type evident? If so, how can such changes be explained (for example, as the result of a recent cyclone)? In some cases it may take several years to detect observable changes or trends; in other cases it make take only a few months after a disturbance to see marked changes. How do total areas of habitat within versus outside the MPA compare?

In addition to the extent of habitat, are there any observable changes in terms of the spatial distribution and configuration of habitats present within versus outside the MPA? If so, what if anything can be deduced from the apparent movement of these habitat types and their boundaries? If reductions are observed in the extent of certain habitat types, is the area lost being 'replaced' with other habitat types? If so, what could possibly explain this? How are rates of change different between habitats located inside and outside the MPA?

How do the other characteristics of each habitat change through time, if at all? What trends can be observed in terms of the make up (composition) of each habitat type? Are there composition differences within versus outside the MPA? What does the presence or absence of a species that contributes to the composition of the habitat tell you? Are any changes in habitat quality being generally observed? How is the location and distribution of the habitat in the environment changing?

In overlaying the estimated spatial extent of known threats and disturbance events (see indicator B10), how are observed changes in habitat extent and quality related to the location and movement of such threats? If habitat reductions observed are believed to be the result of deleterious human activities, based on the nature and location of such activities, is it realistically within the ability of the management team and the activities of the MPA to reduce or halt them? If not, how will such deleterious activities be addressed, if at all?

Next, estimate the habitat complexity inside and outside the MPA by dividing the diversity (number) of habitat types and distinct zones found within the surveyed area by the total area (in km^2) and summing the total length of all boundaries dividing adjacent or overlapping habitat types. Record and monitor changes in these two measures of habitat complexity through time. In viewing the spatial distribution of habitat types and groups of habitat types, do particular patterns, clusters or zones of habitat appear? Through time, is the pattern and diversity of this mosaic being changed or reduced? Is the physical distribution and overlap among groups of habitats becoming more uniform or heterogeneous? In analysing composition data, how are the physical (location, height, area and volume) and biological (composition) dimensions of each habitat type changing in space and time? Are these dimensions becoming more complex or homogenous? Do inter-dependencies appear between constituent dimensions of each habitat type? If so, is it possible to generalize such inter-dependencies across other habitat types? How do habitat complexities compare inside and outside the MPA?

Directly determining habitat integrity is a highly complex process that in most cases would be unrealistic to expect a team to conduct as part of an MPA evaluation. However, estimating the rate of change of habitat extent and complexity within the MPA through time can serve as a proxy for habitat integrity. To estimate the rate of change, calculate the percentage of incremental change observed in the extent, quality (of live cover) and complexity (diversity) between present and last, and present and baseline measures. Score these values as the difference from 100 in observed percentage change and compare them against the rate of average incremental (yearly) change. Qualitatively describe how likely the habitat type will persist based on trends in observed change, observed changes in the rate of change, and as a description of how far away observed habitat distribution and complexity is from what had formerly or could likely be found under only natural conditions. Low rates of change or maintenance of the extent and complexity of habitat may indicate strong integrity. A sustained rate of decline observed in habitat distribution and complexity over a consecutive number of years may be indicative of recent or ongoing disturbance. Such dynamic observations may help to interpret early-warning signals that habitat integrity is deteriorating. On the other hand, documenting only marginal changes in habitat structure and complexity over time within an MPA in comparison to outside it may demonstrate effective management.

As further exploration of habitat integrity, explore correlating results from indicator B1 against habitat quantity and quality results. For example, how do the abundance data collected on a focal species that is known to be an indicator of habitat quality and integrity correlate with data collected on the percentage of live habitat cover observed, if at all? Habitat characterization and mapping results generated from this indicator should be summarized within a habitat inventory report. This report

Outputs

- A table with % cover of observed habitat types.
- A habitat inventory report: a) delineating the identified habitat types and zones present within and around the MPA (including their location and extent), and b) profiling the biotic and abiotic composition, structure, and quantity and quality of each.
- A geo-referenced map of all habitats observed, their boundaries, and their distribution.
- A description of habitat complexity.
- An improved understanding of habitat integrity.
- For repeat surveys: a spatial analysis of the extent of observed change (if any noticeable) in habitat distribution and complexity over time.

Other outputs (if applicable)

- A GIS database of data on the location and extent of habitat types and zones, their biotic and abiotic composition, their structure, and their quantity and quality.
- A collection of digital maps generated by GIS with varying levels of overlaid indicator data and analysis.

B3

should identify, biologically and structurally characterize, and spatially delineate the position of all known habitat types occurring within and outside the MPA area. The report should also document any observed changes to the distribution and complexity of habitats through time, and discuss and interpret the analytical findings generated from measurement of this indicator. Review and discuss the results generated from this indicator and summarized in this report with a community ecologist familiar with the ecosystem and habitats involved prior to disseminating or using them for adaptive decision-making.

Strengths and limitations

This indicator requires a significant investment of time, effort and financial resources, particularly within large MPAs hosting entire ecosystems and highly complex habitat structures. Data collection and analysis done at a high spatial resolution and scale can be expensive and tedious. In addition, both GIS analysis and the collection and use of remote sensing data are expensive and time consuming activities that require suitable staff experience, sophisticated equipment, and maintenance in order to be of use to the evaluation team. As a result of the combined technical (both survey and analysis), financial and human resource requirements, this indicator is one of the most cumbersome and resource-intensive ones offered in this guidebook, and may be out of the reach of many MPA operations.

Data must be collected at a geographic resolution that is precise enough to observe changes that occur at a fine scale. If the scale of analysis at which surveys are done is not sensitive to disturbance and biological change, the results of the indicator may be false in that they miss detecting actual changes that are underway. Also, even if adequate resolution and coverage in the survey are provided, there may be insufficient power to explain observed changes.

Despite these challenges, understanding the status and trends in the distribution and complexity of habitats within and around the MPA remains a priority information need and prerequisite to a well designed and adapted ecosystem management effort.

Useful references and Internet links

CSIRO (1998). *Reef Resource Survey and Habitat Mapping of Shallow Reefs in Milne Bay Province, Papua New Guinea*. ACIAR Phase 1 Proposal. Submission by the CSIRO Marine Research to the ACIAR, Canberra, Australia.

Done, T.J. (1982). "Patterns in the distribution of coral communities across the central Great Barrier Reef". *Coral Reefs* 1: 95–107.

Done, T.J. (1995). "Ecological criteria for evaluating coral reefs and their implications for managers and researchers." *Coral Reefs* 14: 183–92.

Fonseca, M.S., Kenworthy, W.J. and Thayer, G.W. (1998). *Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters*. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, MD, USA.

Mapstone, B.D., Ayling, A.M. and Choat, J.H. (1998). *Habitat, Cross Shelf, and Regional Patterns in the Distributions and Abundances of Some Coral Reef Organisms on the Northern Great Barrier Reef, with Comment on the Implications for Future Monitoring*. Research Publication No. 48. Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia.

NOAA and Analytic Laboratories of Hawaii (2000). *Benthic Habitat Mapping Program Partnership*. [Online URL: cramp.wcc.hawaii.edu/Overview/5._Cooperative_Programs/NOAAALH_Benthic_Habitat_Mapping_Program/Default.asp]

Tupper, M. and Boutilier, R.G. (1997). "Effects of habitat on settlement, growth, predation risk, and post-settlement mortality of a temperate reef fish". *Marine Ecology Progress Series* 151: 225–236.

Index of biotic integrity

Karr, J.R. (1981). "Assessment of biotic integrity using fish communities". *Fisheries* 6(6): 21–27.

Karr J.R., Fausch, K.D., Angermeirer, P.L., Yant, P.R. and Schlosser, I.J. (1986). "Assessment of biological integrity in running waters: A –menthol and it's rationale". *Illinois Nat. Hist. Surv. Spec. Publ.* 5.

United States Environmental Protection Agency (2002). "A brief history of the Index of Biotic Integrity". [Online URL: www.epa.gov/bioindicators/html/ibi-hist.html]

GIS introduction

Convis, C.L. (ed.) (2001). *Conservation Geography: Case Studies in GIS, Computer Mapping, and Activism*. Environmental Systems Research Institute (ESRI) Press. Redlands, CA, USA.

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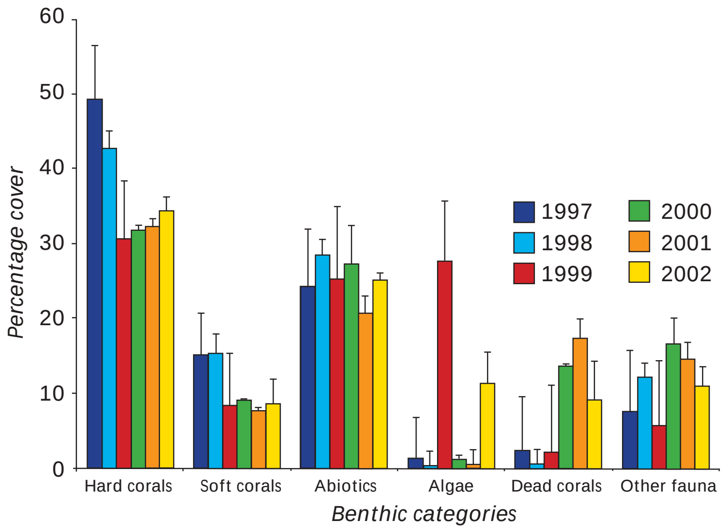
▲ ***A diver takes vital measurements at the Tubbataha Reef National Marine Park, Philippines.***

Box B4

EXAMPLE FROM THE FIELD

Between the mid- and late-1990s, sharp declines were observed in the percentage of live hard coral cover located within the Tubbataha Reef National Marine Park. In part, this is thought to be due to the massive bleaching experienced throughout much of the world during 1998, contributing to an upsurge in algal cover observed in 1999. Since then, habitat surveys completed up to 2002 indicate that live reef cover appears to be gradually recovering. The protection of Tubbataha from fishing pressures is believed to have contributed to this positive trend, and some are suggesting that the habitat is exhibiting resilience to the disturbances experienced during the 1990s. The ability of the Tubbataha management team to clearly convey this story with target audiences is helping to ensure the area's future support.



▲ ***The observed percentage of live cover from 1997 to 2002 of six major benthic habitat types found within Tubbataha Reef National Marine Park.***

Ripple, W. (ed.) (1994). *The GIS Applications Book: Examples in Natural Resources. A Compendium.* American Society for Photogrammetry and Remote Sensing, Bethesda, MD, USA.

USGS (2002). Geographic Information Systems. [Online URL: www.usgs.gov/research/gis/title.html]

Remote sensing

Green, E.P., Mumby, P.J., Edwards, A.J. and Clark, C.D. (2000). *Remote Sensing Handbook for Tropical Coastal Management.* Coastal Management Sourcebooks 3. UNESCO, Paris, France. [Online URL : http://www.unesco.org/csi/pub/source/rs.htm]

Green, E.P., Mumby, P.J., Edwards, A.J. and Clark, C.D. (1996). "A review of remote sensing for the assessment and management of tropical coastal resources". *Coastal Management* 24: 1–40.

Relates to goals and objectives

GOAL 1
1B 1C
1D

GOAL 2
2A 2C
2E 2G

GOAL 3
3B 3D

GOAL 4
4A 4B
4C 4D

GOAL 5
5B 5C
5D 5E

Difficulty Rating 4 1–5

B4

What is 'composition and structure of the community'?

A **community** is a collection of different and interacting populations of organisms (biota) found living together in a defined geographic area, including indigenous and exotic organisms. Some MPAs will host multiple communities of organisms. This indicator is concerned with the species that both comprise habitat types and the organisms residing in them to form the community – i.e. what is in the community.

> *Note this indicator is primarily used to collect information on multiple populations of species (focal and otherwise) within a community sampled. It is not expected that the evaluation team would realistically be able to measure all populations of organisms that occur within the community.*

Community composition is the diversity and makeup of all species present within a community and their relative abundance (respective to one another). Species richness, dominance, diversity, and relative abundance are all characteristics of community composition.

Community structure is a summary description of how the numbers and relative abundance of species occur within a community and are found spatially across the physical environment (form) and habitats in or upon which the members (composition) of the community live. Community structure can therefore be described as the numbers and relative abundances of all species within the community and how they are organized into zones, or strata, of living space. For example, at a basic level the community structure of a coastal ecosystem could be considered within **intertidal**, **neritic** and **benthic zones**. Habitat diversity and relative habitat abundance are both important determinants of community structure. **Abiotic** characteristics (e.g. geology and light) also largely influence community structure.

Why measure it?

This is one of the most commonly identified biophysical indicators of high importance. The maintenance or restoration of the naturally occurring composition and structure of a resident community is often desired to encourage the 'integrity' of an ecosystem, including its health, functioning, and resistance to disturbance. Understanding changes – and the extent and sources (both natural and anthropogenic perturbations) of such changes – occurring within the composition and structure of each community found within and adjacent to the MPA are therefore prerequisites for diagnosing and treating ailing ecosystems. Measurement of community composition and structure through time allows managers to evaluate whether or not their management efforts (in this case, the use of an MPA) are having the desired effects on the target ecosystems.

Additionally, understanding what species comprise a community or organisms and how these organisms are structured within the natural setting allows managers to prioritize and monitor coastal areas requiring management action. For example, by improving the understanding of which near shore areas host the highest levels of species richness and diversity, managers can begin to adaptively prioritize their management efforts and allocate resources accordingly as conditions change. This increases the investment value of management efforts through time and reduces risk.

Requirements

- Similar requirements as listed under indicators B1, B2 and B3.
- A representative sample of survey sites inside and outside the MPA, stratified across known habitat types and zones.
- An adequate number of staff and/or volunteers (respective to the size of the area needing to be surveyed) are needed who are: a) trained in underwater census, b) can accurately identify the species being surveyed *in situ*, and c) willing and committed to undertake the necessary survey work. A minimum team of four people is recommended.
- The necessary survey equipment (e.g. a boat with safety equipment, survey gear and snorkel, hookah or SCUBA equipment) needed to observe the various species and habitats observed within the sampled area (both inside and outside the MPA).
- The ecological knowledge and experience necessary to interpret changes in community composition and structure. This may require consulting the services and/or advice of a professional ecologist familiar with the study area. This caveat comes from recognition that there are rarely simple, universal benchmarks that will describe such changes everywhere they are encountered.

How to collect the data

Where the area to be surveyed under this indicator hosts multiple communities, it may be necessary for the evaluation team to work with management staff to select a set of priority (e.g. two or three) communities that warrant an evaluation of composition and structure based on their ecological role and importance within the overall ecosystem; for example, communities hosting focal species, rare or fragile communities, or communities subjected to strong human impact, such as dive tourism sites or trawling locations.

The methods of data collection for this indicator are described under the *in situ* observation methods for indicators B1, B2 and B3. Data collection for this indicator should be executed simultaneously with indicators B1 and/or B2 in order to maximize the return on the team's investment in monitoring resources. However, unlike B1 or B2 this indicator requires observation of ***all*** (or the visible and vast majority of) living organisms found within the designated community and particular location sampled, as opposed to only a few selected focal species. Therefore the survey is likely to require significantly more energy, time, and capital resources than B1 or B2.

This indicator is associated with the methods and data collected under indicators B1 and B2. In particular, collection of data on the relative abundance of selected focal species found within a sampled community will be useful under this indicator.

As a first step, it will be important to identify for each community (or selected priority communities) occurring in and around the MPA, the various habitat types and/or zones found within the areas being managed and contained within the MPA. Next, within each zone/habitat type, a complete inventory should be done of all the types (species) and abundances (frequency) of organisms observed within each community. The precise survey technique used for observing and inventorying the organisms present will depend on the habitat and characteristics of where the survey is being conducted (see indicators B1 and B3 for specifics). Ideally, the evaluation team would have a measure of the area surveyed. Generally speaking, however, randomized timed swims and stationary point counts across the habitat types surveyed will suffice in lieu of visual censuses along transects or within quadrats. These methods are feasible and well documented in detail elsewhere in the literature (see Useful references, below).

Data collected from within the area sampled should reflect the following:

- ❑ A record of each organism (species) observed;
- ❑ A note of which organisms observed are endangered, exotic and rare;

▼ ***In the Philippines, local government managers sometimes train coastal residents in the use of simple assessment techniques to monitor changes in the composition and structure of mangrove forest, seagrass and coral reef communities over time.***

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- ❑ The number (frequency) and size (where relevant and feasible) of each individual observed within each species;
- ❑ The relative position/depth in the water column where the individual is observed; and
- ❑ The habitat type(s) within which they are sampled, including the species that they comprise.

Where possible, the composition and structure of habitats should also be documented through estimation of the percentage of cover and other appropriate measures of abundance. In particular, biotic structural components of habitats (e.g. kelp beds, soft-bottom communities, rocky and coral reefs, seagrasses, mangroves) should be adequately sampled to estimate coverage. Techniques to do this include *in situ* snorkel and SCUBA survey approaches (e.g. manta tow, line intercept transect, quadrats) as well as remote sensing (e.g. aerial photography, satellite imagery, videoed transects) technologies (see indicator B3). The choice of a technique depends largely upon the abilities and resources of the team undertaking the habitat composition study and the type of habitat being inventoried. This may require separate surveys to be conducted from the species inventory described above. Where possible, it is encouraged that the habitat composition surveys be conducted concurrently with other surveys designed to collect other indicator information. For example, during a transect survey across an area of coral reefs sampled, one group of divers may collect species abundance and size data (indicators B1 and B2) concurrently with a second group conducting a line intercept along the transect to provide a profile of the community composition of the coral reef habitat.

Survey of deepwater and pelagic communities will require considerably more time and effort to undertake. In such cases, *ex situ* survey methods (as described under B3) may be useful. Species inventory for deepwater communities is often done through examination of trawl or seine net catches. As such techniques are destructive and not likely to be suitable for regular use within the MPA or under a sustainable monitoring protocol, such destructive survey methods are not recommended.

Data collection for this indicator can be linked to data collection under indicator B6. Additionally, as this indicator is tied to better understanding the effects of human extraction and other activities on the marine environment, it has links to indicator B10 and several socio-economic indicators.

Species inventories and habitat cover surveys for each community sampled should be conducted at least every two or three years or ideally annually, particularly if impacts or changes in the community composition are evident. A sufficient number of replicate surveys must be sampled across communities and study sites in order to have confidence in results generated in terms of what is and is not there and in what relative quantities. The timing of inventories undertaken during the year should be repeated consistently and take into account known life history events such as spawning, recruitment, seasonal migration, etc.

Note that there are more advanced and some highly technical methods available to the evaluation team to measure community composition. The team will need to have the skills and time necessary to conduct such advanced study, or have access to external expertise and resources to do so.

How to analyse and interpret results

Collate, enter and manage data gathered within the MPA effectiveness-monitoring database.

There are several simple analyses that can be undertaken by calculating species composition (i.e. diversity in terms of richness and evenness) and structure (i.e. relative abundance and physical distribution) using the data that have been collected. In particular, a minimum of two attributes must be calculated in order to measure this indicator:

- ❑ species richness, and
- ❑ relative species abundance.

Two additional attributes can be optionally calculated:

- ❑ species evenness (using the Shannon and Simpson's indices), and
- ❑ habitat diversity.

Species richness is measured as the total number of species present within the community. To determine this, generate a list of all species observed within the managed area and categorize each by habitat type/zone surveyed. Generating a profile (matrix/diagram and description) of the habitat composition and structure of species found within and outside the MPA will also be useful. The total number of species present from this list can be monitored through time to keep track of changes/trends. Note that it will be necessary to keep abreast of any relevant taxonomic changes or new understandings related to speciation, particularly with marine organisms where new informa-

▲ ***An example of a vertically structured community from the Red Sea, Egypt.***

tion is continually updating taxonomic relationships such as with coral reef fishes.

Next create a graph showing the relative species abundance (or create a relative abundance index) by plotting the commonness (grouped from most to least on the x-axis, and listed by name) of species present in the community against the frequency with which they were observed (y-axis) relative to one another. This can further be analysed at a habitat-specific level. Highlight/identify exotic, rare, endangered and commonly found organisms within this description. Characterize the community structure by determining and describing the relative abundance of various species present within the community.

Also, from this point species evenness can be measured as the proportion of individuals among species based on relative abundance respective to the degree that a species dominates a community (dominance ranking). Calculate a measure of dominance (that is those that biologically control a community by most influencing the surrounding environment) using the Simpson's Index of concentration (see Useful references, below). Using this index, determine which species most dominate the community. Species evenness can be calculated using a Shannon Diversity Index, a relatively simple calculation well documented in the literature (see Useful references, below). Comparisons between indices can be analysed using a modified t-test method to compare Shannon indices (see Magurran, 1988). The Morisita-Horn Index allows for comparisons between baseline and time series results (see Magurran, 1988).

In addition, a habitat profile can be developed through a Habitat Diversity Index using Shannon calculations for the area surveyed. A map characterizing habitat types, diversity and coverage across the managed area and within the MPA can be built from the results of this analysis. Changes in habitat composition through time can be monitored using these results, and results can be compared against previous spatial data (if possible, overlaid using geographic information systems) to determine the location, extent and degree of observed habitat change underway.

In terms of fish assemblages, a common test for comparing composition observations of fish communities through time is the Czekanowski's Proportional Similarity measure (see Schoener, 1968, for methods).

Characterization of the relative abundance of species within the community can optionally be identified as either **log-normal**, **broken stick**, or ecological dominance. Distribution of these patterns of relative abundance can be plotted and analysed. These analytical methods are well documented in the literature (see Useful references, below).

Based on the community structure (relative abundance, dominance shifts, and physical distribution) data collected for each community surveyed within and outside the MPA and the resulting evidence generated, is the community studied within the MPA experiencing a notable shift (large shifts away from normal structure in relative abundance or dominance) in terms of its structure? Do data suggest that the community studied within the MPA is experiencing a notable increase (presence of more than three species previously absent and/or increase in the relative abundance of a several species) in terms of its diversity?

Discuss results between indices across and between habitats and communities sampled. What patterns in local and regional diversity can be elucidated? How do communities compare relative to the species that are found in them and their abundances? Are there any changes observed through time regarding the relative abundance of native versus invasive species, and if so, what correlated changes in species richness and abundance are observed with the presence of these invasive organisms?

If changes are observed in community composition and structure (such as a reduction in the diversity of species present or shifts in dominance of certain species), or if the presence of new or exotic species is detected, these changes may necessitate

Outputs

- List of the species and habitats composing the community.
- Description of how these species and habitats are structured within the community.
- Profile of the relative abundance of selected species present within the community.
- Profile of species dominance.
- Profile of species diversity (richness and evenness).
- Profile of habitat diversity.
- Habitat composition/type map.

increased effort to monitor these specific observations more regularly (annually or twice a year).

Note that confident interpretation of changes observed in community and diversity require sufficient time and an adequate dataset. Drawing credible conclusions within the short-term may be a challenging task, and should not be underestimated. Short-term changes observed in biodiversity can lead to misinterpretation of results; for example, the number of species in a community may rise with or shortly after the onset of a disturbance, not dropping until a later time period. Finally, ecological attributes can suggest or contribute toward observed changes in community composition shifts, such as with interactions between populations of organisms or in patterns and gradients of community-habitat utilization.

Strengths and limitations

The basic methodological strengths and limitations of the *in situ* survey techniques identified here are described under indicators B1 and B2. Additionally, not all the habitat types need to receive the same survey effort. For example, coral reef monitoring may be prioritized over seagrasses or other soft-bottom communities based on threat, value and risk assessment.

An adequate understanding of changes in community composition and structure is critical to achieve optimal management and fully understand the extent of impacts that management interventions have on the environment concerned. Establishing empirical causality between community composition changes and/or stability and implementation of an MPA is notably challenging, but nevertheless critical to improving MPA use and replication should such causality be established.

This indicator is one of the more challenging biophysical indicators to measure. The actual survey methods involved are relatively straightforward and approachable with a modest level of training and experience. However, due to the indicator's scope of data collection, a thorough and comprehensive understanding of community composition and structure will require considerably increased staff time, effort and financial resources beyond what is required for simply monitoring the abundance and structure of populations of selected focal species. Beyond data collection, this indicator also requires substantially increased analytical and interpretive complexity. With this complexity there is also a higher degree of uncertainty involved in accurately interpreting results and drawing valid conclusions. Given these increased requirements, there is the risk that this indicator may be seen as a secondary priority in terms of

Box B5

Example from the Field

To characterize the composition and structure of the extensive (110km long) coral reef community of Mexico's Sian Ka'an Coastal Biosphere Reserve, the species diversity of fish, algae and scleractinian corals was assessed across several monitoring stations. In comparing data collected over the past several years, fluctuations observed in species richness within the community appear to be occurring in a cyclical manner. Moreover, these changes to the community have not appeared to be overtly influenced or exacerbated by natural disturbances, such as hurricanes. Instead, recreational use, such as boat traffic, fishing and diving are increasingly attributed as the cause of change to the community structure.

Toni Parras

B4

management effectiveness data collection when in actuality it is of primary importance given the priority goals and objectives of the MPA.

It should also be noted that the comparability of community composition results between a managed area (i.e. within the MPA) against adjacent, unmanaged areas undergoing both natural and man-made change may be difficult to interpret accurately due to “shifting baseline” effects. This effect is where the extent of changes in the community structure and composition that would naturally occur within the MPA if it were not experiencing human management intervention are not detected or are confused as “reductions” in changes observed in adjacent, unmanaged areas. The consequences of this effect can lead to errors in interpretation and conclusions when comparing reference and treatment (MPA) data. Given these potential problems, it would be wise to collect 5–10 years of data, rather than two or three, before attempting to interpret the results.

Box B5 (cont.)

Changes observed within the composition of coral reef fish communities in Sian Ka’an over the past ten years

	Pedro Paila		Yuyum
	back reef	reef crest edge	inner fore reef
SPECIES RICHNESS			
1991	33	23	31
1996	24	30	26
1997	15	41	29
1998	11	20	28
1999	20	27	18
2000	–	19	15
2001	–	15	16
2002	14	15	10
DENSITY (individuals/m^2)			
1991	0.90	0.39	0.60
1996	2.78	7.95	1.75
1997	0.80	2.85	5.43
1998	1.18	1.08	14.13
1999	0.38	1.13	0.60
2000	–	0.60	1.13
2001	–	0.93	0.98
2002	1.80	0.65	2.23
DIVERSITY (H)			
1991			
1996	2.2836	1.3274	2.7996
1997	2.3257	2.9356	2.1094
1998	1.3143	2.1973	0.5419
1999	1.7670	2.1341	0.8862
2000	–	2.4166	2.4585
2001	–	2.1214	2.3013
2002	1.7489	1.9241	0.8390
EVENNESS (J)			
1991			
1996	0.8060	0.4592	0.9196
1997	0.9699	0.8810	0.6474
1998	0.5708	0.8326	0.2181
1999	0.9081	0.8320	0.9071
2000	–	0.9422	0.9079
2001	–	0.7834	0.9261
2002	0.6627	0.8757	0.3644

Useful references and Internet links

Done, T.J., Ogden, J.C., Wiebe, W.J., Rosen, B.R. (1996). “Diversity and ecosystem function of coral reefs”. *In* H.A.Mooney, J.H. Cushman, E. Medina, O.E. Sala, E.D. Schulze (eds.), *Functional Roles of Biodiversity: A Global Perspective*. SCOPE 55. John Wiley & Sons, Chichester, UK. pp. 393–423.

Green, D.G., Bradbury, R.H. and Reichelt, R.E. (1987). “Patterns of predictability in coral reef community structure”. *Coral Reefs* 6: 27–34.

Schoener, T.W. 1968. “Sizes of feeding territories among birds”. *Ecology* 49: 123–141.

Methods

English, S., Wilkinson, C. and Baker, V. (eds) (1997). *Survey Manual for Tropical Marine Resources. 2nd Edition*. Australian Institute for Marine Science, Townsville, Queensland, Australia.

Samoilys, M. (ed.) (1997). *Manual for Assessing Fish Stocks on Pacific Coral Reefs*. Training Series QE9700. Department of Primary Industries, Queensland, Australia.

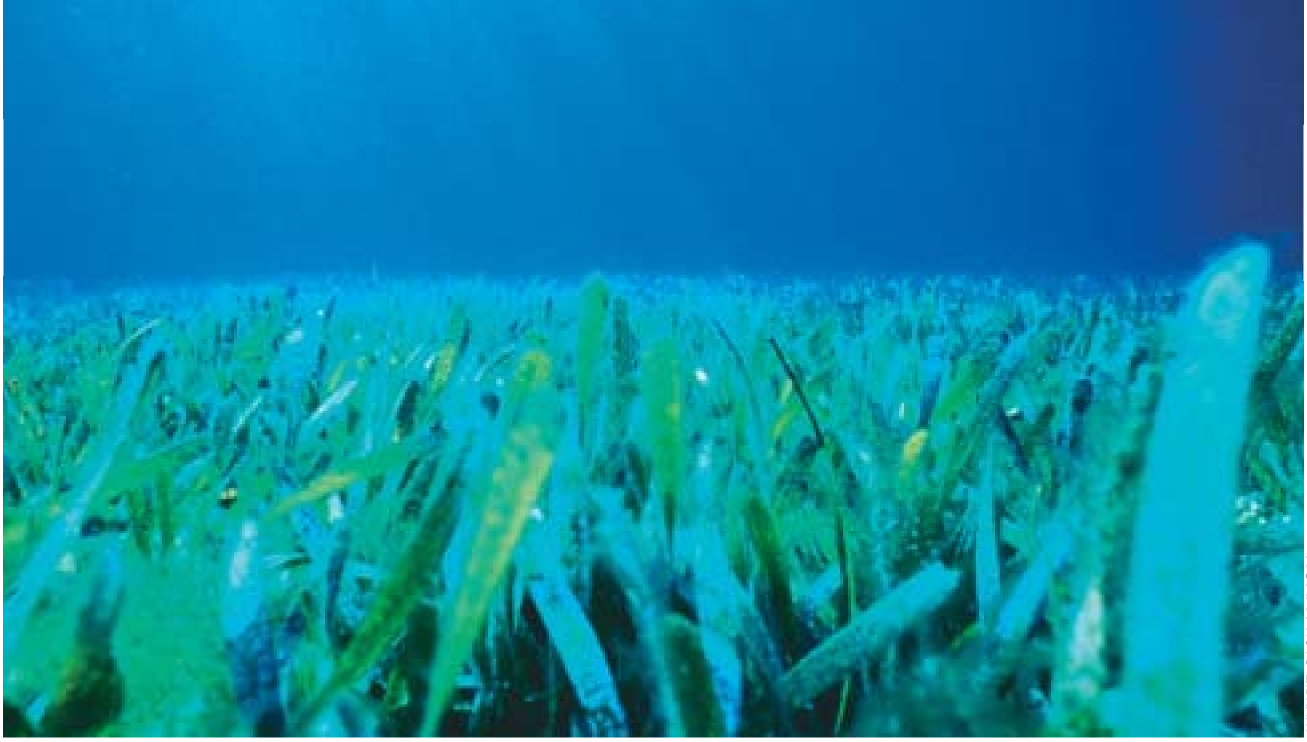
Fish community composition

Helfman, G.S. (1978). “Patterns of community structure in fishes: summary and overview”. *Env. Biol. Fish*. 3: 129–148.

Sale, P.F. and Douglas, W.A. (1981). “Precision and accuracy of visual census technique for fish assemblages on coral patch reefs”. *Environmental Biology of Fishes* 6:333–339.

Sale, P.F. and Douglas, W.A. (1984). “Temporal variability in the community structure of fish on coral patch reefs, and the relation of community structure to reef structure”. *Ecology* 65:409–422.

Sale, P.F. (ed.) (1991). *The ecology of fishes on coral reefs*. Academic Press, San Diego, CA, USA.



NOAA Photo Library

B4

Diversity

Connell, J.H. (1978). "Diversity in tropical rain forests and coral reefs". *Science* 199: 1302–1310.

Dallmeier, F. (1996). "Biodiversity inventories and monitoring: essential elements for integrating conservation principles with resource development projects". *In* R.B. Szaro and D.W. Johnston (eds.), *Biodiversity in Managed Landscapes: Theory and Practice*. Oxford University Press, New York, NY, USA. pp 221–236.

Magurran, A.E. (1988). *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, NJ, USA.

Reid, W.V., McNeely, J.A., Tunstall, D.B., Bryant, D.A. and Winograd, M. (1993). *Biodiversity Indicators for Policy-Makers*. The World Resources Institute and IUCN. The World Resources Institute, Washington, DC, USA.

Monitoring and Assessment of Biodiversity Program (2002). Conservation and Research Center of the National Zoo's of the Smithsonian Institution. [Online URL: www.si.edu/simab/]

Saunders, D., Margules, C. and Hill, B. (1998). *Environmental Indicators: Biodiversity*. Australia State of the Environment Indicator Report. Environment Australia, Canberra, Australia.

Simpson, E.H. (1949). "Measurement of diversity". *Nature* 163: 688.

Szaro, R.B. and Johnston, D.W. (eds.) (1996). *Biodiversity in Managed Landscapes: Theory and Practice*. Oxford University Press, New York, NY.

World Bank (1998). *Guidelines for Monitoring and Evaluation for Biodiversity Projects*. Environment Department Paper No. 65. Global Environment Coordination, The World Bank, Washington, DC, USA.

What is 'recruitment success within the community'?

Recruitment success within the community is the degree of larval input, settlement, and juvenile recruitment and **survivorship** experienced across populations of organisms that exist within a community. The degree of recruitment success is thought to serve as a proxy for the ability of the community to persist through time and be viable (i.e. the likelihood of continued persistence). Through the observation of changes in recruitment success, this may assist in describing how the relationships between populations in the community are or may be changing. This indicator therefore aims to provide some reflection on assessing the probability of a community of organisms being able to maintain itself through time.

This indicator is used to measure changes in the recruitment levels of multiple populations in a community so as to better understand how the community is doing overall. It is not expected that recruitment success can be monitored for all populations of species occurring within the community. It is hoped that from data collection on this indicator, MPA managers and other practitioners may improve their ability to predict whether or not the diversity and amount of surviving recruits observed in the community indicate recovery of the community toward what it was prior to threat exposure, or whether or not the recruits indicate that the community is merely being maintained or perhaps being degraded. In this sense it is intended to be a dynamic indicator, serving as a forecasting indicator of trends occurring in the community rather than simply a 'snapshot' of how the community is composed and structured (indicator B4). However, recognising the natural fluctuations in recruitment and seasonal population variability, the indicator must be considered from a long-term perspective.

As the composition and relative abundance of species within a community is in part a function of a community's ability to replenish its constituent populations, this indicator is closely related to and associated with indicator B4.

This indicator is sometimes used as a proxy for ecosystem health (B3, B4) and food web integrity (B6). It therefore has important meaning for managers who are concerned with maintaining ecosystems function and resiliency through MPA use.

This indicator aims to enable rapid collection of information on multiple populations of species (including focal species) within the community across the relevant habitat types or zones, it is not realistically expected to measure every population occurring within the community. This indicator focuses on measuring the regularity (periodicity) and extent of general species larval settlement and recruitment as well as rates of juvenile survivorship within multiple populations in the community. It does not measure true reproductive capacity and viability.

Why measure it?

While a community's composition and structure serve to provide a periodic or static understanding of the overall health and status of the community and its ecology, this indicator attempts to serve as a dynamic measure or proxy of a community's potential and ecological resiliency. For example, it is not enough to argue that a community is healthy and will be resilient based only on a stable and balanced community composition. Managers must also have some understanding of the potential for this community to persist, based on the regularity of spawning and recruitment events, an adequate abundance of recruits across populations to the community, and survivorship of an adequate number of these recruits to adult sizes. In this regard, this indicator is a community-level corollary to indicator B2.

Relates to goals and objectives

GOAL 1: 1B 1E

GOAL 2: 2A

GOAL 4: 4A 4B 4C

Difficulty Rating 5 (1–5)

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Requirements

- Same requirements and equipment as listed under indicators B2 and B4.
- The necessary equipment to conduct non-specific collection of juveniles and recruits, including trawls, seines and gill nets.
- A list of all of the species within the community needing to be studied (from B4).
- Knowledge of the larval settlement stages for the species concerned.
- Knowledge of how to visually identify larval stages and juveniles for the species concerned.
- Knowledge of the reproductive biology and recruitment process for the species concerned.
- Knowledge of larval settlement patterns within the community.
- Knowledge of known recruitment areas located within the community.
- Knowledge of larval settlement stages and recruitment areas for juvenile representatives of the community.
- Knowledge of the breeding event seasons (timing) and spawning locations.
- An understanding of basic oceanographic patterns and processes as they relate to physical effects on larval import and export distribution and patterns.
- Dyes or simple drogues (for monitoring oceanographic patterns).

How to collect the data

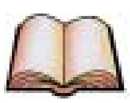
This is one of the most complex and advanced management effectiveness indicators offered in this guidebook. In addition, there is much debate over the use and reliability of recruitment data to interpret ecological health due to the high spatial and temporal variability associated with recruitment. As such, measurement of this indicator should only be conducted by highly qualified individuals and within unique biological communities that host numerous focal species, represent rare or threatened communities, and/or face an acute level of human stressors.

While highly challenging and somewhat controversial to attempt, recruitment success can be examined through the following parameters: a) the presence and relative abundance of relevant size classes (recruits/juveniles and reproductive adults) of populations within the community, b) the breeding or spawning potential and event regularity, and c) the settlement and recruitment potential and event regularity. Due to the fact that recruitment success is also a function of larval input and dispersal, this attribute may also need to be taken into account for a full understanding of recruitment potential.

Should it be decided to attempt this indicator, the recommended minimum data collection is the capture of size class information of focal species within the community surveyed, with a particular focus on juveniles and recruits. The survey methods used to sample species (relative abundance and size classes) across the community are the same as those described for *in situ* survey under indicator B2. The collection of age structure data across all species within the community is not mandatory under this indicator, although such information could be collected concurrently under indicator B2.

Ideally, the size class and age structure of many species within the community should be studied. Sampling the community is previously discussed under B4. The relative abundance and sizes of all species' individuals (juveniles) captured in the recruitment survey should be recorded. Assuming some basic reproductive biology is known for members within the community, size class structure results may also serve to calculate the abundance of juvenile versus adult individuals across species within the community and begin to build a profile through time of survivorship rates of recruits and juveniles to adult stages.

Monitoring the regularity and extent of known spawning and recruitment events should also be conducted under this indicator. Visits to known spawning locations and estimation surveys of spawning biomass should be attempted for focal species within the community. In addition, validation of the occurrence of these events should be demonstrated through:



The data collection of size information on observed focal species recruits and juveniles under this indicator can be collected concurrently with indicator B2.

- *in situ* collection of spawn (eggs and sperm) during and following known spawning events at aggregation sites, and
- *in situ*, low-impact collection (e.g. light traps, collection plates/tiles, water column stations) of settling larvae and established recruits within known recruitment/settlement centres (e.g. mangroves and seagrass communities).

Recruitment via asexual reproduction (e.g. fissure of soft-bodied invertebrates or coral reef fragmentation and grow out) is not measured under this indicator.

Placement of small floats and drogues can assist in tracking water movement during and directly after spawning events to provide a sense of where the eggs and larvae are going. Current meters deployed in relation to tidal activity can be useful to make predictions about the timing of spawning daily or seasonally.

Fixed visual census stations or timed swims (using either snorkel or SCUBA) can be used to account for post-settlement juveniles when collecting other indicator (one through three) data, depending on the species and their life history. The specific steps in undertaking a juvenile/recruit capture survey and spawning collection techniques are documented elsewhere in the literature (see English *et al.*, 1997, for a good starting point). References for the identification of larvae and post-larval stages of many species are also available in the literature. While more sophisticated larval settlement and recruitment studies are possible, they are quite time and labour intensive and are therefore not considered minimum requirements for data collection under this indicator.

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Note that the use of trawl, seine and gill nets to collect recruits/juveniles will likely lead to indiscriminate (non-specific) mortality and may be considered destructive. Therefore, such sampling techniques may not be permitted and/or suitable for regular use under a sustainable monitoring protocol.

Note that fish aggregation and spawning sites often occur at discrete locations that may or may not be included within the area delineated by the MPA. If a known site is located adjacent to the MPA or in the general area, it will be important to monitor it as fishes within the MPA may likely migrate to the aggregation site at certain times during the year to spawn there and then return back to their home range territory within the MPA.

Data should be captured at least annually, and ideally timed to coincide with the completion of survey work for indicators B2 and B4. Timing of data collection will depend largely on the known timing and frequency of spawning and recruitment events.

More advanced biological studies of breeding (reproductive biology) or spawning (reproductive behavioural) potential are also possible to gauge with this indicator. Such methods will require significantly more labour, finances and time than discrete studies of size classes and juvenile settlement and recruitment patterns in selected focal species within the community.

How to analyse and interpret results

Collate, enter and manage the data gathered in the MPA effectiveness-monitoring database. Create a community profile of the relative abundance of each population of species observed within the community and what proportion of observed individuals of each species are juveniles versus adults. Plot the relative abundance (y-axis) of juveniles versus adults (x-axis); using size class data to distinguish between species observed and sampled within the community. Are there more or less juveniles and reproductive adults present across the represented populations than observed previously. Cross-reference these findings with the results of indicator B2. Track the age structure (juvenile versus adult) and relative abundance of species observed through time.

Write up results and interpretation for public dissemination. Orally present results using graphs and tables, and discuss with selected stakeholder groups, decision-makers and peers. Encourage independent validation of results by outside parties within the sampled area in order to confirm or reject findings and improve the understanding of the effects of management action on the area. Be sure to include any stories or anecdotes that illustrate the results observed from stakeholders.

Generally speaking and holding all things equal, an adequate and stable number of surviving juveniles and reproductive adults across populations within the community will increase the community's ability to be viable through time. At what level are surviving recruits in populations studied within the MPA experiencing a decline (reductions in the number of recruits across a majority of the populations studied) in the community? How have the timing, frequency and output of observed spawning and recruitment events changed?

Describe qualitatively (low, unpredicted or high) and/or quantitatively (probability based on reproductive potential across species within community) whether or not the community appears to be viable into the future. If not, how can these results inform adaptive management decision-making to address these concerns?

Finally, present the relative abundance (number/density) results of recruits and juvenile sizes resulting from the recruitment survey and discuss how these figures compare to previous observations.

Outputs

- A community profile of the relative abundance of recruits/juveniles to the community following known larval settlement and juvenile recruitment events.
- A summary profile of the contribution of immature (juvenile) versus mature (reproductive adults) size classes to each species observed within the community.
- A confirmation of the frequency of known spawning events and estimate of spawning biomass.
- An estimate of the reproductive potential and resiliency of the community in the near future.
- A profile of the biomass of eggs, sperm and larvae released during such events.

Optional outputs may include

- Age class structure (through otolith analysis) across populations of species present within the community.
- A profile of the reproductive potential (including spawning success and estimate of reproductive output) of species present in the community.
- An improved understanding of the reproductive biology and spawning behaviour of species within the community.

Strengths and limitations

This is a complex indicator to measure. Collection of size class and recruitment data across many species within the community (difficulty rating 5) will require considerably more time, skill, equipment and financial resources to complete than the study of a selected group of focal species within the community (difficulty rating 4). In either case, an appropriately skilled team of evaluators will be necessary. If a suitably qualified team of individuals is not available from within the MPA management team, universities and research centres may be the best positioned to assist in developing a partnership for data collection and training MPA staff in survey techniques. Such specialists will need to fully meet the stated knowledge, equipment and skill requirements.

Moreover, the value of 'snapshot' recruitment studies is highly contested, as the data generated are known to be highly unreliable due to their inability to take into perspective the notorious effects of temporal and spatial variability. Even if they are found to be reliable, results of juvenile recruitment rates and spawning regularity may not be sufficient to confidently provide for a complete or accurate interpretation of the reproductive potential within a community of organisms. Many years of data collection will be required to draw conclusions about recruitment success with confidence.

Recruitment study techniques using nets, seines and trawls can lead to indiscriminate mortality and should therefore be avoided, minimized or conducted very carefully so as not to be highly destructive.

All of this being said, this indicator is sometimes viewed as the closest suggestion of how managers can encourage a more complete understanding of the dynamic nature of community ecology and reproductive potential.

Useful references and Internet links

Introduction, including variability issues

Caley, M.J., Carr, M.H., Hixon, M.A., Hughs, T.P., Jones, G.P. and Menge, B.A. (1996). "Recruitment and the local dynamics of open marine populations". *Annual Review of Ecology and Systematics* 27: 477–500.

Carr, M.H. (1991). "Habitat selection and recruitment of an assemblage of temperate zone reef fishes". *Journal of Experimental Marine Biology and Ecology* 126: 59-76.

Doherty, P.J. (1991). "Spatial and temporal patterns in the recruitment of a coral reef fish". *In* P.F. Sale (ed.), *The Ecology of Fishes on Coral Reefs*. Academic Press, San Diego, CA, USA. pp. 261-293.

Sale, P.F. (1999). "Recruitment in space and time". *Nature* 397: 25–26.

Sale, P.F., Doherty, P.J., Eckert, G.J., Douglas, W.A. and Ferrell, D.J. (1984). "Large scale spatial and temporal variation in recruitment to fish populations on coral reefs". *Oecologia* (Berlin) 64: 191–198.

Victor, B.C. (1983). "Recruitment and population dynamics of a coral reef fish". *Science* 219: 419–420.

Walters, C.J. and Collie, J.S. (1989). "Is research on environmental effects on recruitment worth-while?" *Canadian Journal of fisheries and Aquatic Sciences* 45: 1848–1854.

Williams, D. McB., Russ, G. and Doherty, P.J. (1986). "Reef fish: large-scale distribution and recruitment". *Oceanus* 29: 76–82.

Juvenile survey

English, S., Wilkinson, C. and Baker, V. (eds) (1997). *Survey Manual for Tropical Marine Resources. 2nd Edition*. Australian Institute for Marine Science, Townsville, Queensland, Australia.

Larval survey

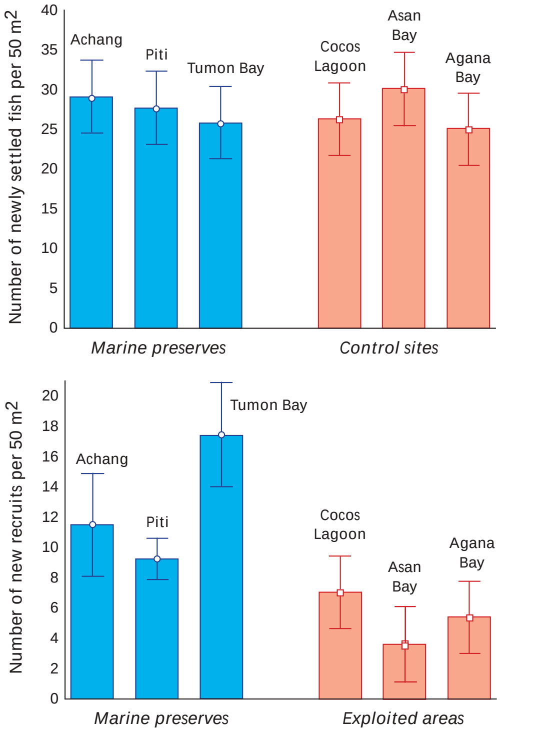
Choat, J.H., Doherty, P.J., Kerrigan, B.A. and Leis, J.M. (1993). "Sampling of larvae and pelagic stages of coral reef fishes: a comparison of towed nets, purse seine and light-aggregation devices". *Fishery Bulletin* 91: 195–201.

Doherty, P.J. (1987). "Light-traps: selective but useful devices for quantifying the distributions and abundances of larval fishes". *Bulletin of Marine Science* 41: 423–431.

Box B6

EXAMPLE FROM THE FIELD

Surveys of newly settled yellowstripe goatfish (*Mulloidichthys flavolineatus*) and other coral reef fish within and outside marine preserves located in Guam were undertaken during 2002. Fish observed were enumerated along four replicate, 25 x 2m transects at each study site (these smaller 50m^2 transects were used because newly settled fish are small and often cryptic, requiring additional time to obtain an accurate count). Three months later, the evaluation team revisited the transects and performed repeat counts of surviving recruits known to fall within a specific range of sizes after three months of grow-out time. Results indicate that despite settlement rates for *M. flavolineatus* between sample sites being indistinguishable (nested ANOVA, $F = .04$, $p = 0.840$; see Figure, left), three months later recruitment success was significantly lower within harvested areas ($F = 9.5$, $p = 0.004$; see Figure, right). This difference can be partially explained by the fact that newly settled goatfish are a prized catch by local fishers, who prefer eating juveniles. Therefore, lower rates of recruitment success outside the preserves are due in part to fishing pressure.



The observed settlement rate (top) and recruitment success (bottom) of yellowstripe goatfish experienced over several months in protected (blue) versus non-protected (red) sites sampled in Guam.

BIOPHYSICAL INDICATOR 6

Food web integrity

B6

Relates to goals and objectives

GOAL 1
1B 1C
1D

GOAL 2
2B

GOAL 3
3A 3B

GOAL 5
5A

Difficulty Rating
5
1–5

What is 'food web integrity'?

A **food web** is a representation of the energy flow through populations in a community. The 'web' of relationships within this representation illustrates the many distinct but interconnected food chains, or linear sequences of organisms that indicate prey items and predatory relationships among them. A small proportion of the energy stored by the biomass within a position in the food chain is passed on to the next **trophic level** (position in the food chain) when this biomass is consumed.

Food web integrity is a measure of how supportive (for the members of the community) and reliable the trophic relationships are within the interconnected food chains of a community. When a food web loses its integrity, it indicates that the relationships between trophic levels have been disturbed or lost. This may occur, for example, if a species within the food web is eradicated through over-harvesting, thereby changing or eliminating the feeding relationships that were dependent on its position in the food web – that is, elimination of its influence on prey items and removal of its biomass for those predators which relied on feeding on it. It is important to note that even if a food web is stable, it does not necessarily mean that it is supportive of the overall community or is a desirable state of predator-prey relationships.

Trophic position in a food chain is a functional classification and is not determined by taxonomy (although phylogeny can be used to make predictions about trophic function). The trophic relationship concept allows a hierarchical perspective to emerge within community ecology. At the most basic level, individuals hold positions within food webs either as producers (photosynthetic organisms) or consumers. Consumers can be further categorized as herbivores (feed on producers), carnivores (feed on herbivores and/or other carnivores), or detritivores (feed on decomposed or decomposing organic matter). In turn, groups of individuals within the same trophic position form functional 'guilds' within the community (e.g. herbivorous fishes or apex predators). Finally, the network or 'web' of functional guilds and food chains culminates in a mass balance of energy exchange and biomass that comprises an ecosystem. It is this highest level, where the energy exchange and biomass contained within the ecosystem is manifested within a food web, that this indicator seeks to assess and monitor.

Why measure it?

MPAs are hosts to single or multiple ecosystems, including their constituent communities of organisms and food webs. A healthy and stable ecosystem is one that is able to sustain the energy flow between trophic levels within a food web. Therefore, describing the food relationships between populations of organisms within the community is an essential feature in the effective management of an MPA.

When positions in the food web are eliminated (for example, from over-fishing), trophic relationships are lost or jeopardised and the ecosystem may experience imbalance and negative cascading effects throughout the food web. Measuring, understanding and monitoring such changes through time are important to assess the impacts of effective MPA management in coastal ecosystems. Also, detecting changes in trophic relationships and observing reductions in food web integrity may serve as an 'early warning' signal for managers to predict troubled trophic relationships, remedy deteriorating ecological conditions, and increase management efforts in the area. As such, it can be useful in diagnosing large-scale ecological variations.

One of the most important potential services that MPAs can provide is re-establishment of natural conditions and predator-prey relationships. This indicator can be used to document important and

JURGEN FREUND/NATUREPL.COM

A shark hunter near Bohol, Philippines, in 1997. The systematic extirpation of top-level predators, such as sharks, can result in 'cascading' negative impacts down through the trophic chain of organisms threatening the overall integrity of the food web.

complementary evidence of progress towards the achievement of re-establishing such natural conditions, and can be a powerful tool for demonstrating and characterizing how these natural feeding relationships exist where (as is often the case) such baseline information is not available. Given that we understand only a few food webs in the marine environment, the potential for contributed knowledge is very important. This indicator therefore also aims to collect evidence of restored or strengthened food web relationships, and not merely detect when food relationships are awry.

Detecting changes in food web relationships provides managers with the opportunity to highlight such changes publicly, investigate their source, and determine whether or not they are the result of activities occurring within or outside the MPA. In the case where changes are within the control or political and legislative influence of the MPA manager, this detection may provide an opportunity to reconcile or address the causes of change. In some cases however, food web changes observed within the MPA may be due to exogenous (outside) influences that are well beyond the control of the MPA managers and/or unrelated to the MPA goals and objectives. For example, increased predation on threatened focal sea otter populations in an MPA by orca may be identified as a result of over-fishing using purse seines of orca prey fish populations hundreds of miles away from the MPA. In such instances, the awareness of the changing feeding relationships due to outside factors may:

a) Provide managers with the necessary knowledge and protection against unjustified criticism of MPA performance due to changes observed within the MPA; and

b) Provide an opportunity to lobby for reconciliation beyond the jurisdiction and goals of the MPA.

In this sense, such outside influences on food relationships can help MPA managers illustrate how external, non-MPA related actions have direct effects on MPA management effectiveness. This can help managers identify how to distribute (or re-distribute) human, financial and policy resources toward other external interventions in order to improve the health of the area being protected. This being said, it is important to determine the scale of the evidence collected under this indicator so that it is used to address only questions/issues relevant to the scale at which they are being asked/raised. Therefore, changes in food relationships that are the result of higher scales of ecological change (e.g. global climate change) are beyond the scope of the MPA or its ability to influence such relationships and should be identified as such.

Requirements

- Same requirements listed under indicator B1.
- Set of scales or balances (measurements in grams).
- Knowledge of the species present within the community or ecosystem.
- An understanding of predator-prey relationships between resident species.
- A calculator.
- Mathematical skills.
- Advanced: mathematical and ecological modelling skills; access to an individual who can consult with the evaluation team and is familiar with the measurement and analysis techniques used; access to mathematical trophic modelling software.

Finally, in theory food webs possess characteristics that allow them to be considered excellent ecological descriptors (Winemiller, 1990). As a consequence, food web integrity is considered an important determinant of ecosystem health and functionality, both of which are difficult parameters to concretely demonstrate. Illustrating a functional and resilient food web therefore may serve as a proxy for a healthy ecosystem.

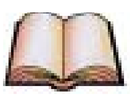
How to collect the data

Data collection to fully measure this indicator is not a discrete or easily approachable task. However, as an approachable starting point (or at a very minimum) a descriptive data collection process can be initiated. To do this, the team should conduct interviews and hold focus group discussions with knowledgeable individuals (e.g. research scientists, fishers, MPA scientific staff) in order to map out and characterize (functionally) the known roles and niches organisms occupy within various trophic levels, including their multiple predator-prey relationships and how or why these may be changing through time. As part of this process, a focused examination can be made into a single 'chain' (discrete thread) of particularly relevant relationships within the overall food web, from single or specific bottom- through top-level trophic occupiers. This relevance may be as a result of a biological attribute (such as the chain hosting relationships between multiple focal species or being of known ecological cornerstone value), or because the food chain has some socio-economic importance (such as providing livelihood opportunities). Information collected should include a discussion on the status of and between occupiers (species) at various trophic levels based on as much empirical evidence as possible (data collected from indicators B1 and B2 may be useful here). For example, the characterization and modelling of the following chain of trophic relationships could be conducted: phytoplankton – krill – fish – seals – polar bears. Under this example, close monitoring of the abundance of krill or seals and their trophic relationship status to fish or polar bears could serve as a proxy for the overall integrity within the food chain. Collecting descriptive and empirical information to characterize a few of these cornerstone chains, including the degree of interconnectedness between them, would act as a surrogate for the complete characterization of the entire web and all of its constituent trophic relationships.

Alternatively, examination of top and bottom points in a single food chain (e.g. apex predators and lowest-level producers) may serve as proxies for the overall chain.

In some cases, MPAs may have the staff, expertise and time necessary to characterize and monitor the full gamut of trophic positions and relationships within a community's food web. In such cases, a more rigorous and in-depth evaluation can be done. First, the various organisms occurring within the system should be identified and aggregated into their trophic positions and guilds within the community's overall food web. This process will result in assigning each species single or multiple roles, between producers, herbivores, first-level carnivores, second-level carnivores, etc. up to top-level carnivores. This should result in the characterization of a completed set of interconnected food chains between all members in the community.

Next, the average weight (g/m^2) and relative biomass of populations or organisms found within the community should be directly measured and recorded using *in situ* capture and release or fish catch surveys. Relative biomass (g/m^2/species) can be determined for each population by collecting the weight and size of individuals observed in addition to calculating the area from which these observations are taken. Average species biomass records should be listed by trophic guild in ascending order. This can be done either from a book of species with trophic guild membership that can be consulted or from a baseline study of digestive tract contents found in the relevant species concerned.



The collection of data for this indicator can build seamlessly from other data collection activities and surveys under indicators B1, B4 and B7.

JOHN PARKS

From here, the relative abundance (number) of organisms found within the area and surveyed using data collected under indicators B1 and B4 should be identified. The relative biomass (g/m^2) of each trophic guild can then be calculated by multiplying the average biomass of individuals in a population by the total number of individuals (abundance) observed within the trophic level. The total biomass of each guild should be listed in ascending order, along with the constituent species that make up the level. Note that in some cases (depending on the objectives of the MPA), managers may only be concerned with understanding food relationships between herbivorous and carnivorous species, and may focus data collection accordingly.

Data collection should ideally occur annually or twice a year. An inter-annual time series data collection approach is recommended. Note that because trophic relationships and structures vary widely by geography and community composition, biomass and abundance data must be collected (and analysed – see below) at site- and/or community-specific levels.

How to analyse and interpret results

First, create an illustration of the assumed food web being represented within the community. Specifically, highlight distinct food chains of species observed and interconnections between these food chains. Also, identify and aggregate the various organisms into trophic positions and guilds within the food web: i.e. producers, herbivores, first-level carnivores, second-level carnivores, etc.

B6

Next, using the total biomass results obtained for each trophic guild observed within the food web, determine the trophic ratios (or proportions) between guild levels and assign rankings. The trophic ratio is the relationship of the biomass values among the different trophic guilds (e.g. the producer:herbivore ratio or the producer:tertiary carnivore ratio (Arias-Gonzalez, 1998).

Then, assign trophic levels as either integer (1, 2, 3…) or fractional (1.3, 2.7, etc. as determined through a weighted average of prey item trophic levels) rankings across specific guilds within the communities present in the ecosystem(s) (see Lindeman, 1942; and Odum and Heald, 1975). A good summary of the specific steps in how to go about trophic level assignment can be found in Christensen and Pauly (1992).

A very simple trophic level index (TLI) can now be calculated weighing both integer and fractional trophic level by the trophic guild biomass. For example, in a system that is characterized as 30% herbivorous (trophic level = 1), 40% first-level carnivorous (trophic level = 2), and 30% second-level carnivorous (trophic level = 3), the TLI will be: 1 (0.30) + 2 (0.40) + 3 (0.30) = 2.

Ecological efficiency is the percentage of biomass produced by one trophic level that is incorporated into the biomass of the next higher trophic level. Generally speaking, this is approximately 10% of the total energy available within any one trophic level. Based on this rule, each trophic level that is assigned for guilds present is weighted 10 times the one below it. Of equal or greater importance may be that it reflects progress towards the stated goal of maintaining abundance and large size among species of high trophic levels. Create a table of the resulting values in order of increasing trophic assignment.

Finally, calculate a trophic structure index using the summary results generated to this point (see Done and Reichelt, 1998; Christensen and Pauly, 1992).

Observe changes and shifts in trophic structure/position and the index through time. Determine (based on index results) whether or not the food web observed is stable, in decline or improving. Use observed results to predict trophic trends and inform management decision-making and priority setting. Do data suggest that food webs within the MPA are undergoing changes? If so, are changes observed indicative of food web deterioration or strengthening, in terms of how close the relationships are from the desired state?

Outputs

- A descriptive profile of the trophic relationships and status between members of at least a single food chain within the overall food web.
- An illustration of the food web and the interconnected food chains.
- A profile of average species and relative biomass, grouped by trophic guild.
- A profile of total biomass within observed trophic guilds.
- A list of trophic ratios between guilds to be monitored through time.
- A trophic structure index.

Rigorous ecological analysis and advanced modelling will be necessary to confirm or reject with confidence the results of this indicator. It should be noted that numerous, more advanced mathematical modelling techniques exist and are available through which to gauge the stability and reliability of trophic relationships found within the target ecosystem. For example, some models enable a prediction of the effects of species exploitation at varying levels of maturity on the overall food web. For the purposes of meeting this indicator such advanced modelling techniques are not required, as it may not be feasible for the MPA project team to undertake them.

Strengths and limitations

This is not an easy indicator to measure. Data collection can be time-consuming, depending on the number of species being considered (i.e. a single chain of species versus an entire food web) and the complexity and overlap between and among individual and clusters of trophic relationships within the area surveyed. Should an evaluation team determine that this indicator must be measured, the team should be aware that it will likely take additional time to secure the necessary human and financial resources to develop the capacity to measure this indicator. Given the difficulties in collecting data for this indicator, evaluation teams need to think carefully about how closely justified data collection for this indicator is against the MPA goals and objectives.

Incrementally, capture of weight data for this indicator may, at first glance, appear relatively simple and straightforward given existing data collection investments made under related indicators (e.g. B1 or B7). However, such incremental time investments will require more than a minor amount of additional time and manpower. Based on real-world experience, even modelling of a single food chain of relationships can become time consuming and labour intensive. Furthermore, incremental data collected (such as weight) are not necessarily always easily and quickly obtained. Finally, a comfort level and familiarity with mathematics is required.

The full potential of this indicator is theoretically achieved through comparison of data collected from food webs within the MPA against those found under 'pristine' ecosystems. As 'pristine' conditions and reference data are difficult to come by, in the absence of such benchmark locations this indicator loses some of its analytical power. For example, since a 'pristine' food web that would be found to occur naturally under no human impacts is not possible to characterize, how can the restoration of food web integrity to such a level be defined? What food webs would be considered 'normal' given current conditions in the world?

This indicator has limited accuracy and poor inference beyond the sites and communities where trophic information is modelled. As the level of analysis of food web relationships grows, its accuracy is decreased significantly. Further, establishing causality between trophic changes observed in the food web and use of management interventions (or the lack thereof) is not possible. The indicator may function as more of an educational and illustrative tool about the state of the community ecology being managed, than as a proven measure of management effectiveness.

Despite the limitations and uncertainties, food webs and their role in ecosystem resilience are now widely recognised as critical components of successfully managed marine areas. While the methods for measuring this indicator are still being tested, refined and expanded, the topic of food web integrity was widely accepted by contributors to and reviewers of this guidebook to be of critical enough a nature for inclusion. This is particularly relevant given that the indicator is accepted as a potential macro-descriptor of changes occurring within an ecosystem and of its overall health.

Useful references and Internet links

Botsford, L.W, Castilla, J.C. and Petersen, C.H. (1997). "The management of fisheries and marine ecosystems". *Science* 277(5325): 509–515.

Christensen, V. (2003). "Using Ecopath with Ecosim for ecosystem based management of fisheries". *In* H. Jákupsstovu (ed.), *Workshop on Ecosystem Modelling of Faroese Waters, Tórshavn, September 2002*, FRS 2003: 73–75.

Christensen, V. and Pauly, D. (1992). "ECOPATH II - A software for balancing steady-state models and calculating network characteristics". *Ecological Modelling* 61: 169–185.

Christensen, V. and Pauly, D. (eds.) (1993). *Trophic Models of Aquatic Ecosystems.* ICLARM Conference Proceedings 26. International Center for Aquatic Living Resources Management, Manila, Philippines.

Done, T.J. and R.E. Reichelt (1998). "Integrated coastal zone and fisheries ecosystem management: generic goals and performance indices." *Ecological Applications* 8 (suppl.): 110–118.

Hutchings, J.A. (2000). "Collapse and recovery of marine fishes". *Nature* 406(6798): 882–885.

Jackson, J.B.C., Kirby, M.X. *et al.* (2001). "Historical overfishing and the recent collapse of coastal ecosystems". *Science* 293(5530): 629–638.

Jennings, S., Kaiser, M.J. and Reynolds, J.D. (2001). *Marine Fisheries Ecology*. Blackwell Science, London, UK.

Lindeman, R.L. (1942). "The trophic-dynamic aspect of ecology". *Ecology* 23: 399–418.

Myers, R. A. and Worm, B. (2003). "Rapid worldwide depletion of predatory fish communities". *Nature* 423: 280–283.

Odum, W.E. and Heald, E.J. (1975). "The detritus-based food web of an estuarine mangrove community". *In* L.E. Cronin (ed.), *Estuarine research, Vol. 1.* Academic Press, New York. pp. 265–286.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. and Zeller, D. (2002). "Towards sustainability in world fisheries". *Nature* 418: 689–695.

Pauly, D., Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D. and Wallace, S. (2001). "Fishing down Canadian aquatic food webs". *Canadian Journal of Fisheries and Aquatic Sciences* 58: 51–62.

Sainsbury, K. and Sumaila, U.R. (2003). "Incorporating ecosystem objectives into management of sustainable marine fisheries, including 'best practice' reference points and use of Marine Protected Areas". *In* M. Sinclair and G. Valdimarson (eds.), *Responsible Fisheries in the Marine Ecosystem*. CAB International, UK. pp. 343–361.

Winemiller, K.O. (1990). "Spatial and temporal variation in tropical fish trophic networks". *Ecological Monographs* 60(3): 331–367.

Box B7

EXAMPLE FROM THE FIELD

Because Canadian legislation clearly states that the preservation of ecological integrity is a marine management priority, food web integrity is recognised as a prerequisite for management effectiveness at Québec's Saguenay–St. Lawrence Marine Park. Despite the Marine Park being too large and complex to monitor the area's overall food web integrity, the evaluation team has been innovative. They have chosen to measure the indicator along one of the most critical trophic chains in the overall web: from phytoplankton as producers, to krill as herbivores, to pelagic fish such as smelt (family Osmeridae) and capelin (*Mallotus villosus*) as intermediate-level carnivores, up to beluga whales (*Delphinapterus leucas*) as top-level carnivores.

PARKS CANADA

◀ ***The endangered Beluga whale (*****Delphinapterus leucas*****) is the flagship species of Saguenay-St. Lawrence Marine Park. The St. Lawrence population numbers less than 500 individuals.***

Relates to goals and objectives

GOAL 1
1A 1C
1D 1E
1F

GOAL 2
2A 2D

GOAL 3
3A 3B
3C

GOAL 5
5A

Difficulty Rating
3
1–5

What is 'type, level, and return on fishing effort'?

The type of fishing effort is a description of the kind and degree of extractive power used during fishing activities, both in terms of technology and skilled labour.

The level of fishing effort is a measure of the amount of total labour (number of people) and time (number of hours/days) used during a fishing activity.

The return on fishing effort is a measurement of the efficiency with which the harvesting activity is undertaken. Efficiency in fishing effort is measured as the number (of individuals) or weight (biomass) of a species caught per unit effort (day or hour per person or team of people) of harvest invested across each fishing method and technology used. The catch per unit effort (CPUE) is a profile of the relative efficiency of a particular fishing technology. CPUE can be measured in harvest areas outside the MPA, in areas immediately adjacent to its boundaries (to measure 'spill-over' effects), and/or in areas within it (where zoned relevantly, or for catch-and-release comparison data). CPUE data are typically collected either *in situ* during fishing operations, or during a creel survey of catch landings when brought ashore (see below).

Why measure it?

Often MPAs are established explicitly because of the high importance that fisheries extraction has in sustaining human societies. Increased fishery yields (via spill-over of biomass from no-take zones and MPAs) and improved livelihoods (via improved income and food availability from increased fisheries yields) are therefore common and important objectives of MPA use throughout much of the world. This indicator is a direct attempt to quantify and track trends in fisheries yield, technological uses, and livelihood opportunities through time.

Despite the importance of measuring the impacts of MPA use on fishing catches, it is important to note that only in relatively few cases has this type and level of analysis been done in the literature on MPAs.

This indicator is indirectly linked to measuring the spill-over effects from areas of no or reduced human activity (indicator B10). In addition, catch levels can also strongly influence community structure (indicator B5) and trophic relationships (indicator B6); for example, through the collateral effects of by-catch volume that are associated with some overly-efficient fishing technologies or the systematic extirpation of high-level predators, such as grouper.

Note that within MPAs whose aims may be to reduce or eliminate fishing effort in and around the MPA, reduction of fishing effort will not be sought for the purpose of maximizing yields to fishers but rather as evidence of strengthened focal species populations.

This indicator relates thematically (human use) to several of the socio-economic and governance considerations, and so data collected here may be useful for consideration under some of these indicators (e.g. S1 and G1).

TONY ECKERSLEY

The word 'fishing' is broadly defined here as including any activity involving the extraction of living marine resources, either for commercial or non-commercial (e.g. subsistence) use. As such, it includes:

- Harvesting of skipjack tuna by commercial fleet purse seine vessels.
- Shallow-water harvesting of charismatic gastropods and echinoderms for curio sale to tourists.
- Gleaning of cockles, seaweed and other edible marine invertebrates by hand at low tide for home consumption (below, right).
- Hunting of seabirds and seals for sale as meat at a local market.

Requirements

- Clipboard and paper.
- Pencil or pen.
- Creel (landing) survey forms.
- CPUE observation data sheets.
- General knowledge of the number of resource harvesters and their fishing activities.
- Knowledge of locations of relevant marinas, boat ramps and public access points.
- Knowledge of locations.
- The amount of time (hours/days) each person spends harvesting resources.
- How efficient the technology is at catching the desired species.
- The physical impact (if any) of the fishing technology on the habitat.
- List of survey locations including: points of entry and landing, key fishing areas, and (where relevant) multiple-use zones for each gear type allowed in and around the MPA.

How to collect the data

At a minimum, the following information about the type and level of fishing effort should be collected through creel (landing) surveys and interviews with randomly sampled boats and fishers (or other resource users) at known landing locations:

a) What species is/are being targeted for catch,

b) Which species are actually being caught (full catch composition),

c) Where the catch was taken, either outside and adjacent to the MPA or within it (where applicable),

d) A general description of the harvest method(s) used,

e) The type(s) and number of fishing gears used,

f) The support technology available (e.g. a hydraulic winch),

g) The number, type(s), and size(s) of the boats used to land the catch,

h) The number of people (fishers) involved in landing the catch, including boat crew, and their individual roles,

i) The number, type, and size (horsepower) of engines involved in landing the catch,

j) The amount of time (hours/days) required to land the catch, including transit time,

k) The size of individuals landed per species,

l) The total weight of the catch (in kg, estimated if necessary), and

m) The total monetary value of the catch (in local currency) needed to be captured and recorded.

Random sampling is done by randomly selecting a specified number of individual boats or fishers within a known population of currently active vessels or harvesters.

Beyond simple landing surveys, a more advanced level of data collection requires the capture of detailed CPUE observations made *in situ* (on board

Measurement of this indicator is closely linked to that of indicator B1 (for 'target' focal species), and is likewise one of the most commonly used indicators. Increased CPUE is often observed as being correlated to increased focal species abundance.

TONY ECKERSLEY

B7

While the principal focus of this indicator is to assess fishing effort related to income generation and dietary consumption, the indicator can also be easily adapted to assess the non-commercial, non-food effort related to:

- recreation fishing, and
- catch-and-release sport fishing.

In addition, data can be collected under this for non-extractive commercial uses of living marine resources, such as:

- dive tourism,
- whale watching, and
- aquaculture.

In all such cases, the rate of 'return on effort' from these activities can be measured in terms of income.

or in the water) by the evaluator in real time during fishing activities. Precise times (hours, minutes) and locations (ideally using GPS coordinates and a geo-referenced basemap of the harvest area) of observed fishing effort and landings are recorded as they occur. Such CPUE data must be accompanied by completion of a comprehensive frame survey that details the power (e.g. boats, engines, fishers and gears) employed across spatial (total fishing area, in km^2) and temporal (time expended, in days, hours and minutes) effort. Such frame surveys must be regularly updated.

The specific process and forms used in performing creel and CPUE surveys are well documented elsewhere in the literature and are not repeated here (see Useful references, below). It is not recommended that the evaluation team request harvesters to record their own CPUE data *in situ*. However, if appropriately trained and willing, harvesters may be in a position to record simple fields of catch data into a log book for specific target species; e.g. catch volume and individual sizes, the total time spent fishing, the number of boats and people involved, etc.

Fishing effort is employed differently depending on the target species. Likewise, fishing effort affects each species differently. Therefore, measures of fishing effort must be species-specific, even within an ecosystem-level monitoring framework. Each species must be individually parsed out and measured separately from the others, with data collected on it specifically and analysed as such.

JOHN PARKS/WWF

▲ ***Catch surveys can take a lot of time, particularly when the catch of an individual fisher is large. For example, data collection for this one person's catch of mixed reef fish caught outside a small MPA in West Papua, Indonesia, took one hour.***

For example, if multiple species of deepwater fish caught are simply grouped together and recorded as "a mixed catch of 150 fish" within a single day's catch survey, this may mask the fact that one of the species included in the catch is an increasingly uncommon species. This could lead to the inadvertent and systematic extirpation of rare species whose decreasing frequency in catch (and decreased CPUE) has been masked by the presence of other, commonly (or increasingly) occurring species of fish. The rationale and logic behind this argument is well documented in the literature (Polunin and Roberts, 1995; Russ, 1991).

Supplementary catch and effort information may be available for review via national or regional fisheries statistics. Governmental agencies and/or non-governmental organizations may be a source of such information, providing the evaluation team with data from which to triangulate direct observations and completed interview surveys.

Tangential but related information that may also be useful includes:

Where possible, supplemental interview data on catch effort can also be collected from fishers during household surveys conducted under relevant socio-economic indicators (e.g. approximately how often they go to harvest target species, how long they need to go out to secure an adequate catch, and what their typical catch composition and sizes are like).

a) licensing records held by a government bureau about registered industrial or medium- to small-scale commercial fishing operations, and

b) a description of the trade and market attributes of the fisheries in question, including the market value and annual tonnage/value of catches using government bureau statistics.

These data should be triangulated with relevant socio-economic indicators presented after the biophysical category.

Information should be collected on the types and numbers of destructive fishing gears operating, the prevalence (frequency or popularity) of such use, and the amount of destructive fishing effort (people, time) being employed. This information can be collected (or estimated) through direct observation (patrols, number of recorded incidents) or through talking with key informants (including users, management staff and enforcement officials). Because many destructive fishing techniques are illegal, note that it may be difficult to collect reliable information. Therefore key informants should be carefully selected, and evaluators should be aware of any potential biases (see IMA, 2000).

Data should be collected on a regular basis throughout the year (weekly, monthly) or during seasonal harvest or reproductive event periods. Creel surveys should ideally be randomly sampled or uniformly stratified across all relevant landing sites with respect to the day of the week and time of month (moon phase) when harvest is active.

To measure precisely the return on fishing effort expended for each target species would require a highly sophisticated and deep level of fisheries-independent data collected through advanced measurement and analysis techniques than is feasible and practical for MPAs under this indicator.

How to analyse and interpret results

It is possible to begin to develop an understanding of the trends in fisheries extraction effort and methods by monitoring changes over time in:

- ❏ the type and popularity of fishing gears used,
- ❏ the power of gears,
- ❏ the level of and return on fishing effort in and around the MPA,
- ❏ the incidence in destructive fishing technology use,
- ❏ changes in the size and species composition of catch,
- ❏ changes in the number and volume/weight of target species caught.

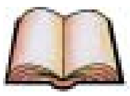
With data on the level of effort collected, calculate the catch per unit effort using the weight of key species caught per day per person spent harvesting for each fishing method/technology: CPUE = total weight (kg) of target species catch per unit time (day).

Examine the relative efficiency between fishing methods in terms of their competitive returns on effort, total labour investments (number of fishers, hours or days fished), and total volume of catch. Which technologies are the most efficient? Which are clearly overly efficient relative to the others? What are the trends with respect to the prevalence in use of different gears available? Are some increasingly being used over others, and how does this relate to their catch efficiency ratings? If data are available, is the incidence of destructive technology use (such as cyanide fishing, dynamite fishing and fine mesh nets) declining, unchanged or on the rise? How do observed changes or trends in fishing gear types being used and efficiency relate to management actions in the MPA? Based on results, do data suggest that the level of fishing effort around the MPA has changed (declined/improved)? If so, to what degree?

For each target species and gear type, calculate the following figures over a specified interval of time (e.g. three months, a fortnight, or a year) for the following:

- ❏ the total amount of catch (by weight, volume, and/or number individuals),
- ❏ the total species richness (diversity) of the catch,
- ❏ the total effort (# of boats, # of fishers, # hours/days),
- ❏ the average catch,
- ❏ the average size of individuals caught, and
- ❏ the average CPUE.

Enter these data into a table, where the columns are the categories of calculations and the rows the time intervals. Next, plot these attributes through time (across specified intervals) for each target species, and then overlay the various results. Are there observable trends or inverse relationships



This indicator is closely associated with other socio-economic (S1, S5, S10) and governance (G1, G4, G15) indicators, in addition to being linked to B1 and B6.

between any of these attributes? If so, what does this mean? Do increased catch sizes and effort inversely relate to the average size of individuals caught?

One caveat is that differential interpretation of results may arise based on the life history of the population being fished and the timing of the catch survey done. For example, data may be skewed (false positive) to look as if a tremendous increase in CPUE is observed when in reality this is simply due to undertaking the landing survey at a time when fish migration, aggregation or recruitment is underway.

Strengths and limitations

Data in this indicator are relatively straightforward to collect, although it may appear simpler than it really is and can often be time consuming and labour intensive. Measurement of this indicator is not as simple as it may appear, and it is important to be aware that accurate catch data collection for the predominant species (those caught most often) and for focal species (those of interest to the MPA and its goals and objectives) will require notable additional time and man-power. CPUE surveys also require relatively well-trained staff and must be done consistently for at least a full year in order to acquire an accurate idea of what catch rates are. Furthermore, scientific consultants and staff (who may need to be hired out and are expensive) will be necessary to develop catch-effort databases and analyse baseline data.

With sufficient training, CPUE and creel surveys can be undertaken by project staff and community volunteers for relatively little cost or logistical investment. However, technical oversight and scientific review of results by qualified and experienced fisheries biologists is important, and so the collection of CPUE data may not be appropriate or feasible in every MPA site. Visual or creel/vessel based surveys are fairly accurate in terms of estimating return on fishing effort invested.

Changes in the type of fishing gears being used and the number of boats and fishers may be both more easily measured and more useful in terms of identifying fishing pressure issues and increases. Likewise, changes in the size and composition of catch are as or more important as how many fish are being caught.

CPUE is not necessarily a good indicator of ecological change and therefore alone is not sufficient to identify and prevent imminent collapses for all fishery stocks. Also, the long-term, consistent monitoring perspective required for CPUE data makes it very difficult to correlate CPUE with environmental change.

The evaluation team should check for accuracy in fishing effort and CPUE reporting submitted from volunteer fishers and, if possible, check for and factor in the falsification or misreporting of data. Data accuracy related to submitted catch reports from all fishers should not be assumed.

Outputs

- A record of the gear types being used.
- A record of the power being invested.
- A record of the size and composition of catches.
- A record of catch-effort efficiency and CPUE calculations for target resources removed by local stakeholders across all gears and technologies used.
- Time series graphs of total catch size, total effort, average sizes of individuals landed, and the CPUE for each species.
- A map of key representative fishing sites across habitat types in and outside the MPA and locations of key points of entry (parks, boat ramps) to the MPA.

Useful references and Internet links

Dulvy, N.K., Metcalfe, J.D., Glanville, J., Pawson, M.G. and Reynolds, J.D. (2000). "Fisheries stability, local extinctions and shifts in community structure of skates". *Conservation Biology* 14: 283–293.

Gulland, J.A. (1975). *Manual of Methods for Fisheries Resources Survey and Appraisal: Part 5 - Objectives and Basic Methods.* FAO Fisheries Technical Paper No. 145. United Nations Food and Agriculture Organization, Rome, Italy.

Gulland, J.A. (1983). *Fish Stock Assessment: A Manual of Basic Methods.* Wiley Interscience, Chichester, UK.

Gunderson, D.R. (1993). *Surveys of Fishery Resources.* John Wiley and Sons, Inc., New York, NY, USA.

Hilborn, R. and Walters, C.J. (1992). *Quantitative Fisheries Stock Assessment: Choice, dynamics, and uncertainty.* Chapman and Hall, New York, NY, USA.

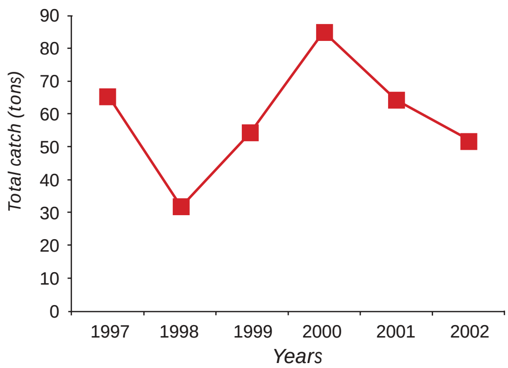
Box B8

Example from the Field

In the Galapagos Islands Marine Reserve, there are two dominant commercial lobster fisheries in operation: blue or green lobster (*Panulirus gracilis*) and red lobster (*P. penicillatus*). Fishing for these species is permitted only during a specified 4-month season. Data collected over the past six years illustrate an interesting story for the MPA. During the late 1990s, total catches rose to new highs (see Figure, below). This prompted the entry of many new fishers into the fishery during 2000 and 2001, thereby leading to a decline in the stocks and reduced harvests in 2001 and 2002. In 2002, fewer active fishers were reported (due to lowered catches the year before), leading to reduced effort. Some speculate that this may lead to increased catches in the coming years, likely followed by another influx of fishing effort. Such high-and-low cycles in commercial fisheries are not uncommon, and have prompted managers and stakeholders in similar situations to discuss the need for further limitations on fisheries in order to set a scientifically-sustainable level of catch by a limited level of effort.

Total lobster fishery catches (T) per annum from the Galapagos 1997–2001

Year	*Commercialized Catch (tons)*
1997	65.3
1998	31
1999	54.4
2000	85
2001	64.1
2002	51.4
Average	***58.55***



Jennings, S., Kaiser, M.J. and Reynolds, J.D. (2001) *Marine Fisheries Ecology*. Blackwell Science, London, UK.

Munro, J.L. and Pauly, D. (1983). "A simple method for comparing the growth of fishes and invertebrates". *ICLARM Fishbyte* 1(1): 5–6.

Pauly, D. (1978). "Fish population dynamics in tropical waters: a manual for use with programmable calculators". *ICLARM Stud. Rev.* (8): 325p.

Pauly, D. (1983). "Some simple methods for the assessment of tropical fish stocks". *FAO Fish. Tech. Pap.* (234): 52 p.

Polunin, N.V.C. and Roberts, C.M. (eds.) (1996). *Reef Fisheries*. Chapman and Hall, London, UK.

Russ, G.R. (1991). "Coral reef fisheries: Effects and yields." *In* P.F. Sale (ed.), *The Ecology of Fishes on Coral Reefs*. Academic Press, New York, NY. pp. 600–635.

Schnute, J.T. (1985). "A general theory for analysis of catch and effort data." *Can. J. Fish. Aquat. Sci.* 42: 414–429.

Sparre, P. and Venema, S.C. (1992). *Introduction to Tropical Fish Stock Assessment. Part 1 – Manual*. FAO Fisheries Technical Paper No. 306, Rev. 1. United Nations Food and Agriculture Organization, Rome, Italy.

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Water quality

Relates to goals and objectives

GOAL 1
1B

GOAL 2
2B 2D
2E

GOAL 3
3B 3C

GOAL 4
4A 4B
4C 3D

GOAL 5
5B 5C
5D

Difficulty Rating 3 1–5

What is 'water quality'?

Water quality is an abiotic and biotic (in the case of bacterial pollution) measure of the ambient environmental parameters present within the water column. Parameters of water quality include temperature, salinity, oxygen content, turbidity, sedimentation rate, nutrient loading, and presence (suspension) and density of toxins, bacteria and other particulate matter.

Why measure it?

Water quality is a limiting factor to biological processes within the organisms, populations of organisms, and habitats present within the project site and MPA. Water quality is therefore a key determinant of overall community health and viability. As such, it is an important indicator to measure, one which will be necessary to maintain a respectable level of scientific credibility.

Water quality can be easily and negatively influenced through multiple sources of human activities in or near the coastal zone, particularly in the case of marine pollution. Some examples of human activities that negatively influence water quality include point and non-point discharge of human and other solid and liquid wastes, dumping of trash and refuse into the sea, oil and toxic spills within coastal waters, storm water run-off from urban areas, upland erosion of sediments and their transport and deposition/siltation on downstream coastal environments, fertilizer presence from agricultural run-off, and bilge water discharge.

Requirements

- Adequately trained staff.
- Knowledge of physical oceanography.
- An understanding of local currents, tides, and water dynamics.
- Thermometer.
- Refractometer.
- Collection bottles for water samples.
- Secchi disc.
- Light meter.
- Other standard hand-held and laboratory water quality monitoring equipment.
- Advanced: specialized equipment, such as instrumentation for analysis of phenol, heavy metals and other toxics; partnerships with universities, environmental quality government agencies, and/or other research institutions; assistance to analyse complex parameters of water quality; programmatic links to and support from baseline national environmental quality assessments or long-term monitoring protocols; remote sensing technologies.

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TONI PARRAS

◀ *Sediments washed out to sea as a result of deforestation and erosion in the Philippines can endanger marine ecosystems like coral (inset).*

One objective of MPA use is to protect coastal waters from or minimize the impacts of marine pollution and activities that are known to reduce water quality. This is particularly true for MPAs which contain habitat types that serve as land-sea interface areas, such as wetlands and mangrove swamps that act as important filters in mitigating marine pollution and maintaining an adequate level of water quality for the wider community and coastal ecosystems present within the surrounding areas.

This indicator should particularly be measured in MPAs with goals and objectives tied to tourism, diving and other economic activities requiring high water quality. Further, MPAs with goals and objectives linked to improvement of water quality and water or waste management practices should prioritize data collection for this indicator.

It should be noted that the link between effective MPA management and improved water quality may not necessarily be causal. However, it is assumed that through the designation and management of the MPA, in many cases this will include a reduction in known *in situ* activities that pollute the marine environment and/or changes in land-based activities that have downstream impacts on the marine environment. In such cases, an improvement in (or maintenance of) water quality over the long-term could be reasonably expected from effective MPA management.

Understanding the effects of land-based activities and water quality on the nearshore marine environment, focal species therein, and even human health can also provide important public educational opportunities for redirecting social behaviour related to marine pollution and waste disposal.

How to collect the data

Much has been written about how to undertake water quality surveys within the coastal water column (at varying depths), and so these techniques are not repeated here (see references listed at the end of this section). However, the following parameters and measurements are recommended for collection under this indicator on a regular basis (weekly, monthly, or quarter-annually, depending on the parameter) across sampling locations:

- ❑ *Sedimentation rate*: downstream sediment traps can be used to measure particulate presence, composition, and suspension density (parts per thousand) from water samples taken; measure loads and changes in densities and attempt to identify sources.
- ❑ *Temperature:* a marine-rated mercury thermometer in protective casing or inexpensive electronic probes can be used; for longer-term deployment (particularly in known areas at risk to sea surface temperature warming), submersible, retrievable temperature loggers whose data readings can be downloaded after a fixed period of time and then re-deployed can be used.
- ❑ *Salinity and freshwater input* (particularly useful in sensitive estuarine habitat): a durable refractometer should be used.
- ❑ *Oxygen content:* a number of hand-held electronic devices exist to measure dissolved oxygen content and monitor eutrophication areas.
- ❑ *Turbidity:* a secchi disk at various sampling locations can be used.
- ❑ *Standard water analysis*: presence of known pathogens such as *E coli* (biological indicator) should be checked, and presence and loading rates (amount) of oil, petroleum, nutrients (especially nitrogen, phosphorous) and fertilizers, pesticides and other toxins, and heavy metals should be screened and measured.
- ❑ *pH levels.*
- ❑ *Biological agents:* such as chlorophyll and phytoplankton levels.

Some water quality parameters (particularly those that are land-driven) may not necessarily be realistically influenced by the management actions be taken at the MPA. In such cases, measurement of such non-linked parameters – while perhaps interesting – should not be conducted as an indicator of the MPA's management effectiveness. Instead, the evaluation team should be encouraged to focus on these abiotic conditions, which arguably are effected through the effectiveness of the MPA being managed.

Scientific validation of findings and study trends (literature) that demonstrate relationship(s) between environmental (in this case, water quality) parameters and species and habitat abundance and viability is also needed over the long term to provide a firm understanding of causality. Therefore, the evaluation team will likely need baseline data on the history and trends of various environmental factors within the area.

Also, accounting for natural perturbations (particularly those related to water temperature and salinity changes) will be important to accurately gauge impacts related to management (inside the MPA) or unmanaged human use (outside the MPA). This may necessitate undertaking broader, long-term monitoring programmes of study with project partners in the government and academic institutions. For example, monitoring upland agricultural development impacts including pesticide/fertilizer and nutrient loading in the watershed, estimating runoff volume and sedimentation rates may be necessary to fully understand and predict upper and lower limits of water quality parameters during certain times of the year (e.g. during the rainy versus dry seasons).

> *Note that in MPAs where water movement is highly dynamic and variable (such as within highly fluctuating tidal areas or areas exposed to river currents), the simple water sampling methods offered here may be insufficient to accurately characterize the effects of the MPA and its management on water quality levels.*

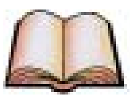
The seasonality of water quality (e.g. rainy seasons and frequency of river basin flooding) must be accounted for when considering an appropriate timeframe within which to collect such information.

More advanced evaluation of water quality and its links to the biotic system may also be useful to evaluation teams that have the necessary skills, time, and resources to undertake them. For example, remote-sensing technologies may be available to profile relevant abiotic parameters and how they relate to biological events. Or perhaps sampling for the presence and degree of bioaccumulation (amount) of heavy metals or contamination of persistent organic pollutants within the tissues of focal species (such as molluscs or dead sea mammals) may be an important activity to undertake in an MPA located downstream of upland agricultural activities given its goals and objectives. Or perhaps tracing the path and monitoring the levels of heavy metal bioaccumulation through various trophic levels of the resident food web are important to people living near an urban MPA who rely on local fishery spill-over from a no-take area for food and income.

How to analyse and interpret results

Summarize and disseminate results with resource users and stakeholders. Analyse the results generated in terms of two components:

- ❑ identification of the water quality issues and specific parameters needing to be addressed, and
- ❑ assessment of what is causing/sourcing these changes.



Collection of data for this indicator can be linked to the collection of information related to assessment of indicator B10.

In this regard, the scale-dependency of the parameters investigated becomes more evident.

Monitor observed changes and trends in the environmental parameters measured for water quality and disseminate findings. Correlate these findings against the results of B1 and B4 to see if any relationships or patterns emerge.

Encourage a community-organized water quality monitoring system to take responsibility for regular monitoring and analysis activities. Simple computer software packages (e.g. PRIMER ecological statistics) and the use of friendly, specific procedures to interpret water quality (e.g. the BIOENV procedure) could also be useful for community interpretation of results.

> *The seasonality of water quality (e.g. rainy seasons and frequency of river basin flooding) must be accounted for when analysing and interpreting results.*

A water and environmental quality specialist should review results, and ideally, the specialist should carry out independent spot-checking to confirm or reject measurements taken.

Do data suggest that the water quality within the MPA is changing? If so, to what degree have parameters shifted away from the desired water quality state across the majority of parameters measured?

Strengths and limitations

Equipment and training costs for the full suite of measures (outlined below) will require moderate to significant financial resources. More technical equipment and measurements do exist for evaluating water quality, but are in all probability not necessary to sufficiently profile this indicator.

Outputs

- An index of water quality parameters.
- Graphs of parameter results plotted across time.
- Advanced: scatterplots of parameter measures correlated against natural phenomena and biological data.

For most of the measures outlined above, relatively simple methods of water quality testing can be undertaken with some labour investment (two to three persons) and an adequate commitment of staff time. The data collected under this indicator are easily collected and can involve trained community volunteers to complete them. The frequency with which these measures are taken necessitates a relatively high turn over in monitoring equipment, which can add up through time. However, because of the relative ease and importance that this indicator carries as it relates to the biophysical environment (particularly in terms of abiotic factors), this indicator should be easily undertaken.

Water quality is a highly complex issue to address and control with many sources of influence that often arise from outside the jurisdiction and mandate of the MPA and its managers. In this situation, MPA water quality may be strongly influenced by on- and upland development and environmental management practices that lie well outside the influence of the MPA team. For example, an MPA objective to improve water quality may be unfeasible based on poor upland agricultural practices that lead to downstream sedimentation and the introduction of fertilizers into the marine environment of the MPA. In such cases, the indicator can be used to highlight the extent and persistence of such problems by MPA managers to the public and decision-makers. Also, MPA managers can use such opportunities to raise issues about the appropriate siting and design of the MPA.

Because it may be difficult to accurately or definitively link the water quality status in an MPA to the success or failure of the MPA to achieve the stated goals and objectives, in some cases it may be dangerous to claim a direct correlation between this indicator and 'proof' of effective MPA management. Despite this shortcoming, the measurement of water quality against stated MPA goals and objectives will be an important indicator to measure in many MPAs, and thus is being included in this guidebook.

Also note that hydrophobic compounds are difficult to measure in water.

Useful references and Internet links

Sheehan, P.J. (1984). "Effects on community and ecosystem structure and dynamics". *In* P.J. Sheehan, D.R. Miller, G.C. Butler, and P. Boudreau (eds.), *Effects of pollutants at the ecosystem level*. John Wiley and Sons, New York, NY, USA.

Box B9

EXAMPLE FROM THE FIELD

This indicator is the only biophysical indicator focusing on 'environmental' conditions and basic monitoring of micro-scale and abiotic factors. This being said, in many MPAs it is increasingly being recognised that red tide events, heavy metal and toxin bioaccumulation, eutrophication, and fish kills are all prevalent phenomena linked to the types of abiotic parameters being assessed under this indicator. During the process of developing the original set of indicators, several separate abiotic indicators were generated and then collapsed under this single, 'umbrella' environmental indicator by participating experts and managers. Despite this, some pilot sites expressed that given the nature of some MPAs created to address highly abiotic goals and objectives, it may be useful for evaluation teams to split out the multiple measures collapsed under this single indicator into several discrete indicators; for example: chemical and biological compound presence (water composition); rates of sedimentation and siltation; toxin presence; or temperature and turbidity.

Standard survey methods

Strickland, J.D. and Parsons, T.R. (1972). "A practical handbook of seawater analysis". *Bull. Fish. Res. Board Can.* 167: 310.

United States Geological Survey (1999). *National Field Manual for the Collection of Water-Quality Data: U.S. Geological Survey Techniques of Water-Resources Investigations*. USGS Information Services, Washington, DC, USA. [Online URL: water.usgs.gov/owq/FieldManual]

United States Virgin Islands Coastal Zone Management Program (2001). *Coastal Water Quality Monitoring Manual: Parameters and Techniques*. Department of Planning and Natural Resources, Division of Coastal Zone Management. National Oceanic Atmospheric Administration, Washington, DC, USA. [Download online URL: www.ocrm.nos.noaa.gov/PDF/USVI_Monitoring_Manual.pdf]

BIOPHYSICAL INDICATOR 9 *Area showing signs of recovery*

Relates to goals and objectives

GOAL 1
1C 1E 1F

GOAL 2
2A 2B

GOAL 3
3A 3B

GOAL 4
4A 4B

GOAL 5
5A 5B 5C 5D 5E

Difficulty Rating 3 (1–5)

What is 'recovery'?

Recovery is measured as the proportion of the total MPA area (km^2, or % of total area) or focal species population (abundance, biomass, or % of total population) that has experienced or 'been restored' to assumed 'original' (target) levels of either:

- ❑ Community composition or habitat distribution deemed representative of 'ideal' (i.e. relatively undisturbed by human activity) or 'natural' conditions (i.e. non-human influenced); or
- ❑ Viable population levels and stock integrity, such as the return of 60% or more of the original standing spawning stock that is assumed would occur in the absence of human impact.

Whether the recovery target requires that the MPA return biotic characteristics 'back' to some state of 'natural condition', or if it is simply to achieve some identified level below this state, is dependent on the definition of what 'recovery' is. This 'recovery' target may be defined previously within the MPA's recovery-related goals and objectives, in which case it requires them merely to be adopted. But in some cases, a measurable target for 'recovery' has not been specified under the aims of the MPA. In this situation, the MPA management team may need to think carefully about setting measurable aerial restoration targets annually and incrementally through time. From such clearly defined aerial targets, this indicator can be more easily measured. For example, an MPA goal whereby "focal species populations are restored to levels where they can replenish themselves through time within 40% of state waters" is a more measurable definition than one that simply states that "focal species are to be restored back to naturally occurring levels".

It should be noted that in some MPA locations that frequently experience natural disturbances (e.g. cyclones) which limit/prevent the restorative capacity of the project, this indicator may not easily be applicable. In such cases, the 'natural conditions' restoration target may not be realistic and instead may need to give way to a compromise restoration level that is sub-natural conditions.

> *There is room for much subjectivity and bias in creating definitions for 'natural' conditions or 'restored' levels. What is more important than the words used is the ability for these words to be measurably defined, even at the expense of substantial debate. If it is not possible for the evaluation team to agree on a measurable definition of what the state of 'recovery' or 'natural condition' is, then this indicator cannot be measured, nor likely will progress made toward the associated MPA objectives be able to be evaluated.*

Finally, this indicator may not be relevant at all MPA sites, depending on the extent (or even presence) of restoration targets within the MPA goals and objectives.

Why measure it?

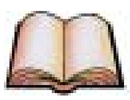
This indicator is a discrete measure of the amount of area (with constituent biotic and abiotic attributes) that has been returned to target operational conditions, that is, has been fully restored to natural conditions from some defined level below this. As such, it attempts to act as a concrete success measurement of MPA performance against the stated restoration target. It is a universally understood indicator of interest to stakeholders, decision-makers, donors and researchers.

Note that this indicator should not be measured by MPAs where the goals and objectives of the area do not include 'restoration' (either back to natural state or sustainable fishing levels). However, if 'restoration' is a clearly defined management objective in an MPA, this indicator is a direct measurement of the extent to which this aim is being achieved.

The indicator is used to determine and highlight whether or not a 'restoration' objective for an MPA has been fully achieved. Partial achievement of a

Requirements

- Same requirements as those listed under B1 to B6, particularly B4 and B5.
- An accurate basemap of the project area, MPA delineation, and habitat types.
- A hand-held GPS unit is needed to delineate areas.
- Clearly defined, measurable definition of 'recovery'.



Note that while both aerial indicators (B9 and B10) may be collecting similar types of information as those data collected under the enforcement-related governance indicators (G13 to G16), the distinction is that here the data collected are used to address questions relating to biophysical aims, as opposed to compliance ones.

defined and measurable restoration objective may be laudable progress overall, but this incomplete success will be reflected clearly within the indictor's measurement.

How to collect the data

To document the recovery of fish or mobile invertebrate focal populations, a visual census should be used to estimate and document the threshold level of population recovery (as a percentage change in population size and structure). Such recovery thresholds may likely have little grounding in scientific literature or fisheries biology, but for the purposes of the indicator they must serve as a 'best guess' that can be adjusted and refined. For areas (km^2) that are closed and fully-protected to allow recovery of focal fish and invertebrate populations, their recovery in the closed area can be sensibly expressed as the proportion of the overall population in which the local sub-populations have exceeded the assumed (designated) recovery thresholds.

On the other hand, within an area not fully closed but under restoration, it is the proportion of that area, or the proportion of sample stations in the area, that have exceeded a 'recovery milestone'. The 'recovery milestone' is defined as the exceeding of a known reference point for:

- ❑ focal species abundance and population structure (B1 and B2),
- ❑ community composition and structure (B4),
- ❑ habitat distribution and complexity (B3),
- ❑ food web integrity (B6), and
- ❑ recruitment success (B5).

These indicators could be derived based on a frequency analysis of areas exceeding the recovery milestone or threshold at a large enough number of samples in the designated area (within and outside the MPA). A stratified or randomized sample of observation stations would be made throughout the designated area at which ratings or estimates of these indicators would be captured through time. Therefore, the extent of area restored could be expressed not only in terms of area (km^2), but also as the proportion (%) of stations at which the observed index exceeds a pre-defined level (e.g. recovery milestone).

In some respects, this indicator can be thought of as an embodiment or filter of other relevant biophysical indicators, most notably B1 to B6. As such, data collected under these other indicators may be useful in making a 'case' toward an articulated level of 'recovery'.

Samples for this indicator could be measured between every two to five years throughout observation stations across the project area. In order to sample an adequate number of stations within larger MPAs, this may require investment of more time.

How to analyse and interpret results

Disseminate results of the proportion or 'recovery milestone' frequency within the total project area and quantify the total area restored (km^2). Keep in mind that such discrete measurements (number of recoveries, total area) are effective and popular communication tools with stakeholder, public, decision-making, and donor audiences.

Outputs

- Total project area (km^2) restored fully (100%) versus partially (as % of change in structure, biomass, density/ abundance, or total cover).
- Estimated proportion (% change in population density, structure, or biomass) of recovery within focal species population against specified target.
- Estimated frequency with which 'recovery milestones' are met across focal species populations within the community.

Strengths and limitations

With a clearly defined 'restoration' target and supporting data (from B1 through B6) available for use, this indicator can be a relatively simple measure to attempt and done with low incremental investment in terms of time and labour.

However, the setting of 'recovery milestones' and sustainable population levels is challenging scientifically, and often poorly understood or documented. As a result, the reliability of results generated from this indicator may be questionable in terms of measuring population recovery thresholds.

Box B10

EXAMPLE FROM THE FIELD

During the expert group development and pilot site testing of this indicator, there was much discussion and controversy expressed over the illogical definition of what 'restoration' or 'recovery' is in the absence of sufficient evidence to indicate what 'naturally'-occurring levels for the biological attributes involved would be. Several people felt that this indicator suggests the nearly impossible task of attempting to aim for, characterize, and measure true 'recovery'. Given the global reach and multiple levels of human impacts on the Earth's ecosystems, even as far back as several hundred years ago, people saw the use of the term 'restoration' as disingenuous and dangerous. As such, the term 'recovery' was allowed (providing it was used in the content of uncertainty) and 'restoration' discarded as a value-laden and impractical term that presupposes that the evaluation team actually knows what a population, community, or ecosystem looks like in it's 'natural' state. As a result of this stigma, this was one of only two biophysical indicators not tested by the pilot sites.

Useful references and Internet links

Sousa, W.P. (1984). "The role of disturbance in natural communities". *Annual Review of Ecology and Systematics* 15: 53–391.

▼ ***Mangrove swamps, vital for replenishment of fish stocks, can be good areas to restore in an MPA.***

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Area under no or reduced human impact

What is 'human impact'?

Human impact is defined as the cumulative environmental effect of all extractive and non-extractive uses of living and non-living marine resources located within a specified area (in this case, within and outside the MPA). Examples of extractive and non-extractive human uses within coastal waters include fishing, tourism, aquaculture, coastal development, seabed drilling and mining, transportation, and trade. Varying levels of human use of marine resources can result in varying levels of impact. For example, the type and number of certain fishing gears (such as bottom trawls, purse seines, and gill nets) are known to have significantly higher impacts on ecosystems than others (such as pole and line and cast nets). Some extractive uses (such as dynamite fishing) are well documented as having highly destructive impacts associated with them.

An area under no impact is defined as one that is completely free of all extractive or non-extractive human uses that contribute impact. Not all MPAs include such areas. These areas are commonly referred to as 'reserves' or 'fully-protected areas', and are often delineated as distinct, 'no-take' zones within a larger MPA. Some 'no-take' zones are time bound; for example, the seasonal prohibition of access within known spawning grounds of a focal species. One frequent exception to the prohibition of all human activity within 'no-take' zones is the allowance of MPA monitoring and scientific research activities.

> *Note that areas under 'no' human impact are assumed to experience broadcast impacts of human activities that occur outside the MPA, such as a rise in sea surface temperature contributed by global warming effects. The focus on 'no' impact under this indicator is specific to human activities within the MPA.*

Why measure it?

Reducing the level of human impact experienced in an area of waters is a common aim of MPAs. It is assumed that if an MPA experiences reduced or no human impact, the focal species, habitats, and communities therein have a greater probability of being able to replenish and maintain themselves through time than ones outside the MPA that are experiencing a higher level of human impact. It is also assumed that the greater the level of restriction on extractive uses within an MPA, the less total human impact will occur.

Measuring the scale and pattern of human uses through time and their cumulative effect is therefore needed to test and legitimise these assumptions. Understanding the level of and changes to human use within and outside the MPA can also help managers to identify and proactively address **threats** (i.e. natural or human activities that do or could negatively contribute to the overall impact experienced in the area).

> *Note that simply having an area declared free from human use does not necessarily mean that the area is effectively free from such activity.*

How to collect the data

This indicator is measured by: a) characterizing the presence, level, and impact of various human activities and threats through time; and b) quantifying the total area under no or reduced human impact, as the result of the degree of compliance with prohibitions or restrictions on user activity.

At the simplest level, a qualitative characterization of the presence, level, and impact of human activ-

Requirements

- Clipboard, paper, and pencil.
- A map of the delineated MPA boundaries (and fully-protected zones, if applicable) and the surrounding waters/area.
- The desired degree to which human activities and threats are to be reduced or eliminated within the MPA. Such a target may be able to be derived based on the MPA's goals and objectives. In other cases it may require careful thought by the management team with regard to setting measurable impact reduction targets annually and incrementally through time.
- Knowledge of the types of extractive and non-extractive activities and technologies being used within and around the MPA, including threats.
- Stakeholders who are willing to openly share their observations, experiences, and beliefs about human activities and threats.
- Literature and other data sources on the scale and impacts of human activities and threats.
- Advanced: a handheld GPS unit; a boat and engine.

Relates to goals and objectives

GOAL 1: 1C 1D 1E

GOAL 2: 2A 2D 2E

GOAL 3: 3C

GOAL 4: 4C

GOAL 5: 5D

Difficulty Rating 3 (1–5)

ities and threats (both upland and coastal) should be done through manager interview (with supporting evidence regarding enforcement and compliance) and stakeholder triangulation. Key informant interviews with MPA staff and across stakeholder groups can help to initially identify and characterize the presence and number of human uses (both extractive and non-extractive), and which of these are or should be considered threats to the MPA (i.e. activities that are leading or could lead to increased negative impacts within the area).

The next step is to assess and describe all threats found to be operating in and around the MPA. Specifically, for each threat identified, the level of its impact using the following three parameters needs to be described: a) the intensity of the threat (i.e. level of operation and degree of overall human effort involved), b) the extent of the threat (i.e. the total area across which the threat is distributed and active), and c) the urgency of the threat (i.e. the frequency, timing, and acuteness of the threat). These three threat parameters should be quantitatively assessed along with their descriptions; for example, the number of users or boats per threat per harvest unit, the frequency of activities, and the spatial extent (expressed in km^2) of the total area in which threats are observed. Data for these parameters can be collected through structured and semi-structured interviews and focus group discussions of MPA management staff and stakeholder groups. Supplemental information can be taken from secondary data sources and/or direct observation of user activities, levels, and impacts. For example, the intensity (number of fishers), area (in km^2), and urgency (trends in frequency of activity) of a particularly threatening extractive activity (such as dynamite fishing) could be collected through harvester interview, and supplemented with existing studies and survey results from direct observations (such as the number of times blasts are heard in a day).

Characterization of human activities and trends can also be described in terms of: a) the types and numbers of extractive gears and technologies that are used, particularly with regard to the extractive efficiency of such technologies and their destructive effects, and b) changes in the power of extractive and non-extractive effort, particularly in terms of the number of fishers, number of boats, number of gears, etc.

During the baseline characterization inside and outside the MPA, the nature and level of physical, chemical, biological, and other environmental effects that are known to occur as a result of extractive and non-extractive uses should be documented. The uses that are known to have deleterious impacts on species, habitats, and community ecology should be highlighted. The threats (both human induced and natural) may already be identified and previously prioritized for management action (such as with the designation of the MPA) with the aim of eliminating or minimizing these threats over time.

An estimation of the physical location (placement) and extent (area) of threats and other human activities observed within and around the MPA should also be made as part of the characterization.

In terms of collection of data on the extent of destructive fishing methods used within the managed area, it is important to estimate the total area known where such technologies are used. Additionally, the percentage of area (km^2) within the MPA where destructive fishing technologies and other fishing techniques are prohibited should be calculated. Destructive technologies include the use of poisons (e.g. potassium and sodium cyanide, bleach, plant toxins), dynamite, bottom trawling, physical destruction with tools etc., and fine mesh nets for extraction.

A much more in-depth, time consuming, and accurate method of characterizing the presence, level, and impact of human activities is to directly observe all human activities operating in the area in and around the MPA, measuring the three parameters of user behaviour and impacts mentioned above through *in situ* survey. In addition to this, additional impact data about threats and other human activities can be further characterized through the measurement of other biophysical indicators, particularly B1 to B7. In addition to a qualitative discussion of impacts, the results of these indicators can provide supporting evidence as to the nature and extent of environmental impacts associated with the human uses operating within the area surveyed.

> *B10 is not a 'true' biophysical indicator in that it does not assess biotic or abiotic states, trends, or outputs. Rather it is a contextual indicator that assesses activities known to impact biophysical conditions. However, results collected from the measurement of indicators B1 to B7 can be used to provide supplementary evidence to data collected on B10.*

Quantification of the total area under no or reduced human impact requires six steps. First, the total area (in km^2) bounded by the MPA through the use of previously delineated boundaries on a basemap or the *in situ* collection of GPS data from which to quantify the total area should be calculated. Second, the total area (in km^2) of all locations within the MPA that have been designated as 'no-take' or 'fully-protected' zones (i.e. areas free from all human activity) must be gauged. If the entire area within an MPA is fully protected, the totals will be the same. If an MPA does not contain any areas zoned for no human activity, the total will be zero. Note that both of these areas may already have been delineated and calculated within existing documentation, such as in the MPA management plan and/or accompanying legislation. In this case, it still may be useful to validate these totals through *in situ* GPS delineation.

Third, it is necessary to subtract the area designated to be free from human activity from the total MPA area to determine the area within the MPA that has *not* been designated to be free from human activity. These totals should then be converted into percentages, and the three areas and percentages should be recorded in an annotated table. Fourth, the results of the human activity characterization and the spatial estimates of the extent (km^2) of threats operating in the MPA (taken from the threat reduction assessment – TRA) should be revisited. Using these results, it should be possible to estimate the total area in the MPA that is not actually free from human activity. If the characterization results and TRA suggest that human activities may be underway in areas designated as 'fully protected' or 'no-take', an attempt should be made to estimate how much of this designated area is actually being violated versus that being respected (in km^2 and as a percentage).

Fifth, for *each* human use occurring in the MPA, the total area (km^2) of the MPA that was designated for reduction should be estimated, defined by how each human use (or groups of uses) are to be measurably reduced within the MPA. In some cases, a human use will have been designated to be reduced throughout the entire area of the MPA. In other cases, this reduction will have been designated to occur only in a specific habitat type or zone. Finally, for each human use, the results of the human activity characterization and TRA index should be reviewed and an estimate carried out of how much (in km^2 and as a percentage) of the area is actually under reduction compared to how it was originally designated for reduction.

Answering the following questions about the designated versus actual area under no or reduced human impact may be of interest to the evaluation team during its investigation: 1) how was the specific delineation of the no-take area defined? Was it demarcated on the basis of biological parameters or political convenience? 2) How effective is fisher compliance with the no-take area? Are there any reported/confirmed (or unreported/unconfirmed) violations of extractive activities taking place in the area? 3) What forms of surveillance and enforcement are being conducted in the area? How certain are those who police/enforce the area that the area truly is being observed as 'no-take' zone? Manager and stakeholder responses to such questions will assist the evaluation team in determining the degree to which the designated areas under no or reduced human impact are being effectively managed, and the degree to which violations (if any) are occurring in the area (see relevant governance indicators).

Data on human activities as well as natural and man-made threats should be collected twice a year or annually, including all information needed to demarcate the area(s) where they are operating, depending on how active and changing they are. Threat reduction data should be collected twice a year. Calculations of the total area under no or reduced human impact should be made every year, unless needed sooner (for example, if new threats arise or if changes to the existing boundaries are made during the year).

> *Note that the synergistic and dynamic effects among and between threats are not captured under the methods outlined here. As a result, observed feedback loops and synergistic impacts resulting from threats operating on one another should be documented qualitatively.*

How to analyse and interpret results

Theoretically (and ideally in practice), if an MPA is successful in reducing human threats – or prohibiting them altogether – then the actual area under no or reduced human impact should equal the area designated as such. In viewing the calculated area results, how closely do designated (on paper) areas of no and reduced human use compare to actual (in reality) areas of no or reduced human use? Do real-world observations reflect the reduction or prohibition of human activities that, on paper, are supposed to be occurring? How are extractive technology and power (effort) changing through time? Have all human activities halted within fully protected areas? To what degree have human activities and impact been reduced in designated areas, across each activity?

One way to analyse an estimated degree and area of human impact reduction using data collected for this indictor is through the threat reduction assessment (TRA) index (reference guides on how to use the TRA index are listed at the end of this

Data collected under this indicator are closely associated with several other socio-economic (local use patterns and occupational structure) and governance (user conflicts, understanding of rules and regulations, and enforcement) indicators, and should be conducted accordingly. The distinction on B10 is that data collected are used to evaluate biophysical aims of the MPA.

indicator description). Working with management team and stakeholder representatives, the relative progress to date made in abating each threat identified can be estimated as the percentage of total threat reduction in comparison to total threat potential. While subjective, the TRA is undertaken so that meaningful comparisons can be made across different areas as to the degree with which human use impacts have been mitigated over a period of time. The logic behind the TRA is that if the management team can identify the threats facing their MPA and its surrounding waters, then they can also assess their progress through time in achieving no or reduced human impact through measuring the degree to which each of these threats is reduced. Threats can also be visually diagrammed and discussion can take place as to how they conceptually relate to one another through causal relationships. Compare threat reduction scores across all identified threats annually or every two years. Based on the spatial extent of how human activities and threats are operating within and outside the MPA, are there any observable trends (increases or decreases) in the area with respect to the level and scale of these activities and threats? Are key threats and destructive human activities being halted successfully through time within the MPA? Are rates of threat reduction of specific activities steady or changing?

> *As there is increasing international attention and promotion in using fully-protected MPAs (reserves), results generated from such areas will be of interest to many managers and stakeholders beyond your MPA site.*

Results from this indicator will be of most relevance and use when linked with other biophysical assessment results, and when describing the history and contextual background of threats operating at the MPA site. Pair results of other biophysical indicators with results in human impact reduction, do any relationships appear? Are results within areas free from all human activity significantly different from results in other reduced but multiple human use areas of the MPA? For example, are changes observed in the same focal species' abundance in the MPA and within relatively adjacent areas significantly different between reserve and non-reserve waters within the MPA? Through time, is a greater or reduced percentage of total MPA area found under full protection? Finally, is there an optimum percentage (20%, 50%) of reserve versus non-reserve waters found within multiple-zone MPAs being achieved through time? If so, on what grounds (why) can this be argued?

Disseminate summary results of threats profiled and changes observed in threats with various stakeholders, managers, and decision-makers. As data collected on this indicator can be conducted in tandem with governance indicators (e.g. surveillance and enforcement, number of violations), interpretation of how effectively the area of no or reduced human impact is being policed by enforcers and complied with by fishers may also be of interest to target audiences of results.

Outputs

- A descriptive and quantitative characterization of the human activities and threats (both natural and human) present in and around the MPA.
- Total area of the MPA.
- Total area (and percentage) of the MPA designated as being under no human activity.
- Total area (and percentage) of the MPA actually under no human activity.
- Total area (and percentage) of the MPA designated as under reduced human activity.
- Total area (and percentage) of the MPA actually under reduced human activity.
- GPS coordinates for these areas.
- Threat assessment profile and prioritization.
- Threat reduction index (score of 1–100%).
- Map of threat activity within and outside the MPA; areas of destructive fishing technology use.
- Map of the boundaries of the MPA at the site and the reserve area(s) within or overlapping with it.

Strengths and limitations

This indicator may prove to be useful as a rapid, qualitative assessment tool to guage how the biophysical environment, or specific attributes, within and outside the MPA may be being impacted by human activity and experiencing change. However, due to the highly subjective nature of the methods involved (being based in large part on manager and stakeholder perceptions), this indicator should only be measured in conjunction with other biophysical indicators, as the results generated from this indicator cannot be considered accurate on their own or viewed as stand-alone evidence of MPA management effectiveness. Results from this indicator should be considered only as signposts and proxies, and may be of most use when linked contextually with other biological indicator results and when describing the background to the threats operating.

While the indicator may appear conceptually simple, data are not always simply or easily collected. Because of the complexity that occurs where multiple human uses occur in and/or around the MPA, an accurate and repeatable measure becomes difficult to construct. Even the most basic level of data collection on human activities and threats requires adequate time and staff to interview the necessary number of managers and stakeholders, conduct focus group discussions, and source secondary data. The nature of TRA methods may also be difficult to approach and measure with many stakeholders, even at a highly subjective level.

Useful references and Internet links

Schmitt, R.J. and Osenburg, C.W. (1995). "Detecting ecological impacts caused by human activities." *In* R.J. Schmitt and C.W. Osenburg (eds.), *The Design of Ecological Impact Assessment Studies: Conceptual Issues and Application in Coastal Marine Habitats*. Academic Press, San Diego, USA. pp. 3–16.

Underwood, A.J. (1995). "On beyond BACI: sampling designs that might reliably detect environmental disturbances". *In* R.J. Schmitt and C.W. Osenburg, *Design of Ecological Impact Assessment Studies: Conceptual Issues and Application in Coastal Marine Habitats*. Academic Press, San Diego, USA. pp. 151–178.

Warwick, R.M. (1993). "Environmental impact studies on marine communities: pragmatical considerations". *Australian Journal of Ecology* 18: 63–80.

TRA Methodology

Margolius, R. and Salafsky, N. (2001). *Is Our Project Succeeding? Using the Threat Reduction Assessment Approach to Determine Conservation Impact*. Biodiversity Support Program, World Wildlife Fund, Washington, DC, USA. [Download online URL: www.BSPonline.org]

Salafsky, N. and Margolius, R. (1999). "Threat reduction assessment: A practical and cost-effective approach to evaluating conservation and development projects". *Conservation Biology* 13: 830–841.

No-take areas

Roberts, C. and Hawkings, J. (2000). *A Manual for Fully-Protected Areas*. World Wide Fund for Nature, Gland, Switzerland.

Tupper, M. (2001). "Putting no-take marine reserves in perspective". *MPA News* 26: 2.

Promotion of no-take areas

National Center for Ecological Analysis and Synthesis (2001). *Scientific Consensus Statement on Marine Reserves and Marine Protected Areas*. Annual Meeting of the American Association for the Advancement of the Sciences, February 2001.

Box B11

Example from the Field

How easy is it to track human impacts, you might ask? In Tanzania's Mafia Island Marine Park, measuring all human impact throughout the MPA was determined to be "very demanding, verging on impossible". To overcome this, the evaluation team decided to modify and limit the measurement of this indicator to focus on a single human activity (fishing, vis-à-vis total effort) and within only a fraction of the total MPA area (30 of 822 km^2, defined by a regulated fishing zone). The evaluators found that even this restricted measurement of human impact was still labour intensive, requiring 6 people and 3 boats working 10–12 hours per day for 9 days per month over a 4 month period. Even with this level of significant investment in data collection, the issue of the evaluation team's inability to adequately monitor and sample illegal and night fishing activity was quickly identified. To overcome this, the team partnered with innocuous-looking dive tourism boats, who volunteered to record observed incidences of illegal fishing in the zone sampled while they passed through the zone on a daily basis to and from dive sites. While this helped, the team then found that the tourism personnel were not reliable in filling out their data forms. With a bit of training, they have begun to improve with time. The Mafia team are still creatively seeking means to adequately sample night diving.

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▶ ***MIMP wardens George Msumi and WWF Project Community Officer Hisluck Mambosho at Park HQ, Mafia Island.***

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In and around most MPAs, locally caught fish find a ready market with buyers and so provide valuable income to local people – the focus of the socio-economic indicators presented in this book.