A GUIDE FOR ECOLOGICAL MONITORING OF MARINE AND COASTAL HABITATS IN MOZAMBIQUE

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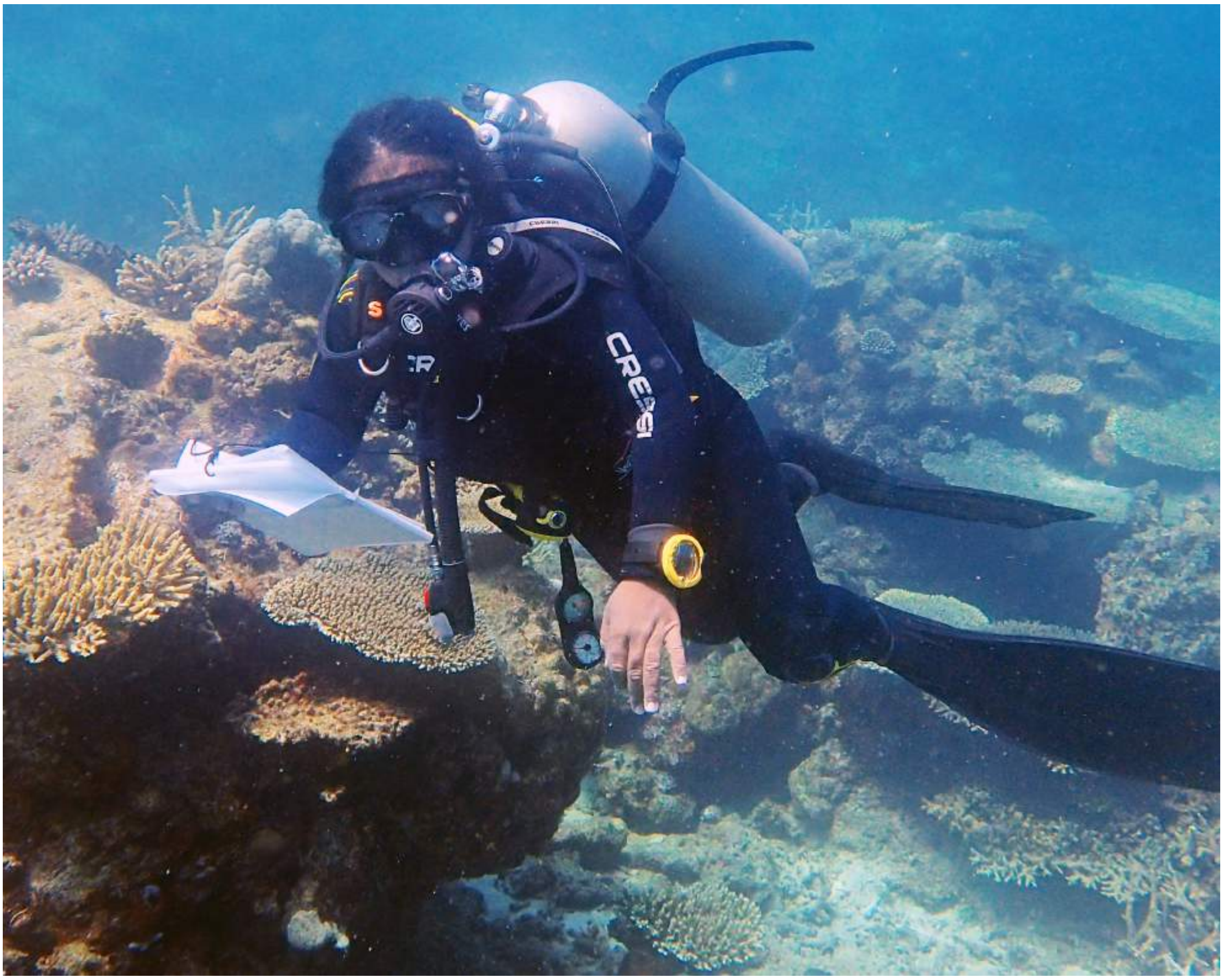
GLOSSARY AND ABBREVIATIONS

Abbreviation / term	Definition
BRUVs	Baited remote underwater video in stereo
Cleaning station	A reef area used by biota, ranging from megafauna such as sharks, manta rays and turtles to reef fish, where smaller fish and crustaceans feed on parasites of larger permissive biota.
CoralNet	CoralNet is a platform used for semi-automated description of points in photo-quadrats, and has close ties to CPCe
CPCe	Coral Point Count with Ms Excel extensions is a software used to define points and identify organisms or substrates at points in photographs. The software is frequently used to gain data from phtoquadrats.
CPUE	Catch per unit effort
DBH	Diameter at breast height
FishBase	FishBase is an online global biodiversity information system on finfishes. The breadth and depth of information in the database, combined with the analytical and graphical tools available in the web, cater to different needs of diverse groups of stakeholders (scientists, researchers, policy makers, fisheries managers, donors, conservationists, teachers and students).
Global FinPrint	Launched in 2015 as the first global survey of its kind, Global FinPrint deploys baited remote underwater video systems (BRUVS) to record sharks, rays and other sea life on coral reefs (https://globalfinprint.org/about/index.html).
GPS	Global Positioning System
IIP	National Institute for Fisheries Research (Instituto Nacional de Investigação Pesqueira)
IPCC	Intergovernmental Panel on Climate Change, an intergovernmental body of the United Nations that is dedicated to providing the world with objective, scientific information relevant to understanding the scientific basis of the risk of human-induced climate change, its natural, political, and economic impacts and risks, and possible response options.
LIT	Line Intercept Transect
LMMA	Locally Managed Marine Areas
Management regimes:	*No-take:* area where no fishing or harvesting is allowed *Open access:* area where there are no restrictions in place with regards to fishing or harvesting *Restricted access:* area where there are restrictions placed on fishing activity. Often in the form of prohibition of types of fishing gear.
Mermaid	Mermaid or data Mermaid is a data entry and data tidying platform currently available for fish belt transects, Point Intercept Transect (PIT) data and rapid bleaching assessments data. It be used offline and online, and facilitates data tidying, data back-up and data sharing as well calculations of fish biomass to speed up the reporting of results.
Monitoring plan	An outline of ecological monitoring activities to describe the state of an ecosystem or community at a particular point in time, the time of survey, and also to detect changes in the state of an ecosystem or community between surveys.
Monitoring program	A coordinated program to undertake ecological monitoring with the collection, analysis and interpretation of data on the natural environment, frequently to identify or describe changes that occur in the ecosystem, which may be associated with management actions or human usage patterns.
R	R is a freely available programming language and environment for statistical computing and graphics. R provides a wide variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, …) and graphical techniques, and is highly extensible. https://www.r-project.org/about.html
RCP	Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by IPCC (2013). Four pathways were used for climate models and research reported in the IPCC fifth Assessment Report (IPCC 2013). The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in the years to come. The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, respectively).
Reef channel	A channel between two reefs or through a reef structure where water drains from the reef at low tide or through which tidal movements force water circulation
Reef types	*Barrier:* a reef structure that develops parallel to a current or ancient coastline and which is usually a combination of numerous individual reefs. *Fringing:* a reef that develops along a coastline, either of an island or continental coast. *Pinnacle:* a reef structure that resembles an isolated not directly associated with a land mass *Point:* a section of reef that protrudes from a reef structure and which is often associated with intensified currents.
Reef zones	Coral reefs can be separated into distinct zones such as the back reef, reef crest, reef flat and fore-reef. Reef zones result from the variability of abiotic factors such as depth, wave energy, light intensity, temperature, and water chemistry associated with location. These factors influence the distribution the diversity and growth nature of reef communities. The *fore reef* is the outer edge of a reef, often also referred to as a reef slope because of the sloping nature of many fore reefs. This reef zone is more likely to be exposed to clearer water and greater light penetration to depth. The *reef crest*, is the shallowest zone or top of the leading edge of a reef and is likely to be exposed to high light intensity and the air during extreme low tides. Reef crests are also where waves are most likely to break on a reef,

Abbreviation / term	Definition
	which causes physical stresses that limit coral diversity to the species and morphologies that can persist in this high-energy zone. The *reef flat* is the shallow area at the top of a reef structure sheltered behind the reef crest. Temperatures and currents can be high because of the shallow nature, and the zone may also be partially exposed during low tides. Physical stress from wave s and storms can also be high here. The *back reef* is the trailing edge of a reef usually on the protected side of a reef, sometimes bordering a lagoon. Wave energy is usually low here permitting more delicate branching and table coral morphologies to develop and there are often large colonies in back reef areas. Turbidity can be relatively high if water exchange is restricted in a lagoon and limited water exchange can also result in relatively warmer temperatures than outer reef environments.
REICIM	"Regulamento de Investigação e Pesquisa Científica Marinha"; in translation the "Regulations for Marine Investigation and Scientific Research" of Mozambique
SAS-JMP	Interactive and visual data analysis software. SAS (previously "Statistical Analysis System")[1] is a statistical software suite developed by SAS Institute for data management, advanced analytics, multivariate analysis, business intelligence, criminal investigation,[2] and predictive analytics
Seagrass Watch	A standardised global protocol for the training or participants and coordination of seagrass monitoring
SLR camera	Single-lens reflex camera
SPSS	Statistical Product and Service Solutions, is a software package used for interactive, or batched, statistical analysis produced by SPSS Inc., which was acquired by IBM in 2009. Current versions (post 2015) have the brand name: IBM SPSS Statistics.
UVC	Underwater visual census
WCS	The Wildlife Conservation Society



1. INTRODUCTION

This guide for the development of a monitoring plan has been prepared by the Wildlife Conservation Society (WCS) Mozambique to promote the discussions and practical applications necessary for ecological monitoring of marine and coastal areas in Mozambique, particularly those co-managed by local communities (AKA Locally Managed Marine Areas) or subject to any other form of management. The ecological monitoring is intended to assess the state of local marine and coastal habitats, communities of marine organisms (e.g. coral communities), and populations of key organisms (e.g. manta rays), as well as to assess the impacts of human activities and the success of environmental management. The foreseen activities should engage local stakeholders, such as community fishing councils, local community members, and dive tourism operators in the monitoring. This requires monitoring appropriate to a range of skills, experiences and means.

It is fundamental for a monitoring plan to 1) identify the objective(s) of monitoring; 2) assess the options and resources available for monitoring; 3) decide upon the spatial and temporal scales of monitoring (e.g. few or many sites in a smaller or larger area, frequently or occasionally); 4) choose standard protocols and training and keep this consistent; 5) repeat and replicate observations and measurements consistently so that comparisons of data are meaningful; 6) communicate results promptly to enable decisions that allow management to adapt to circumstances. It is also important that a monitoring plan defines procedures for quality control, storage and analysis of the data collected. Time and resources must also be allocated to reporting and communication of results.

A monitoring plan should address specific questions, and it is the intention that this document provides an outline of a recommended monitoring plan, as well as sufficient information to enable discussions different stakeholders to define specific monitoring questions. For example, "did coral cover decline by 10 % or more from one year to another?" or "did fisheries management regimes result in an increase in the size of targeted fish species in specific areas?" Answering the monitoring questions will require reference to quantitative measurements of features of the ecological community, such as the biomass of fish per hectare, the number of fish from each taxa observed, or the percentage cover of corals on a reef substrate. Some quantitative measurements are more informative for desired interpretations of the state of a community or ecosystem, such as the level of resilience, and these are referred to as indicators. This monitoring plan identifies indicators and outlines approaches to assess impacts of human activity and impacts of environmental factors or extreme events such as seawater temperature anomalies.

1.1. Objectives and desired outcomes of this guide

The primary objectives of this guide are to outline procedures for baseline and on-going assessments that describe the ecological status of marine and coastal ecosystems and communities, in particular coral reefs, seagrass, and mangroves. The guide is particularly focused on supporting the development of monitoring plans for fishing areas co-managed by local communities and for marine protected areas. Monitoring in its simplest form should compare management regimes of no-take, open access fisheries and control sites outside of any area with a management regime, to assess the impacts of human activities and environmental changes on ecological communities. The monitoring guide explores the skills and expertise required for monitoring and suggests avenues for community participation where possible in monitoring, to stimulate a sense of ownership as well as participation in the conservation of marine ecosystems. It is also a desired outcome that community associations, schools, research institutions, NGOs, private enterprise, tourisms ventures (e.g dive resorts) participate in monitoring and conservation activities.

2. CHOICE OF LOCATION & THE NUMBER OF SAMPLING SITES

2.1. Marine and coastal habitats to be monitored

Based on the existing types of marine and coastal habitats in Mozambique this guide considers that monitoring is likely to be undertaken for at least coral reefs and rocky substrate reefs. It may also be desirable to monitor habitats that are interconnected with reefs, such as seagrass meadows, mangroves, mudflats and coastal sand dunes, and for this reason these are also addressed to a limited degree in this guide.

2.2. Survey design considerations

Monitoring should include sites from at least three management regimes so that the impact of these regimes on biota and the ecosystem state can be compared and interpreted to guide adaptive management decisions or interventions. Ideally these management regimes are surveyed consistently through time, and the survey design minimises the influence of factors that cannot be easily understood on the interpretation of how management impacts biota or the ecosystem.

The suggested management regimes to consider in the study area are:

- "***Open Access***" areas where fishing or other harvesting is allowed
- "***No-take***" areas where fishing or other harvesting is prohibited (temporarily or permanently) and this is enforced.
- "***Control***" areas outside of managed areas. These are sites where no management is applied and which can provide insight into background fluctuations in the environment. Control areas can be compared to managed areas to assess the effectiveness of management. The choice of control sites determines the comparisons that can be made and requires consideration in the context of the specific monitoring interests.
- ***Additional areas*** with specific management regimes may be included. For example areas where fishing of specified taxa is limited, or fishing is only permitted with specified fishing gears, or fishing is limited to a specified group of fishers.

It is important to group or choose monitoring sites that have comparable characteristics, so that any un-described features of a site have less impact on interpreting the influence of the main factors of interest, such as the management regime. Defining the primary interests of a monitoring program is important to identify the habitat or site characteristics that should be consistently grouped or replicated in surveys (Table 1). For example, comparing the abundance of corals between a habitat with solid substrate that favours corals and a habitat that is dominated by unstable sand, which is unsuitable for corals, is unlikely to identify impacts of management on coral abundance. It is also important to consider how human activities vary, for example artisanal fishing may be minimal in wave exposed reef crest and slope environments, but intense in sheltered reef lagoons. Therefore, no-take management may have greater benefits for the conservation of fish communities in reef lagoons than in wave exposed environments where fishing pressure may be restricted by access and lower.

Once the characteristics of sites that are likely to affect the observations and measurements of a monitoring program have been identified, the survey design should include replicate observations of sites with these factors. This is exemplified in the following survey design (Figure 1). The design includes three regions of interest. Within each region there are habitat types of interest for monitoring: coral reef, rocky reef, seagrass, mangrove, mudflat. These can be considered as parallel monitoring programs to some extent, and it may be that not all of the habitats are monitored or represented in each or any of the regions.

Each habitat type should be separated into distinct habitats. For example coral reefs can be differentiated based on reef morphology into fringing coral reefs, patch coral reefs, or reef pinnacles, which are all likely to have different values for the variable of monitoring interest (e.g. percentage coral cover). Ideally monitoring activities will be replicated for each distinct habitat surveyed or sites chosen should represent of distinct habitats of primary interest. This same consideration extends to habitat zonation. For example, on any coral reef, zones with differing abiotic features, such as wave energy, depth or light intensity, can be identified such as reef slopes, reef crests, reef flats, and back reefs.

The method chosen to make observations of a variable is likely to differ for each monitoring question, but should always be replicated consistently. For example, point intercept transects, quadrats or photo-quadrats may all be used to assess the diversity and cover of benthic organisms such as corals. We should replicate surveys with any of these methods at a site. However, replication may also be at the level of measurements made on individual coral colonies if the interest is to assess the frequency of disease, the intensity of coral bleaching or the size class distribution of corals.

A more simple and well replicated survey design will better answer the questions it was intended for, be easier to undertake, and be more useful to guide management and conservation decisions. The factors included in a survey should be kept minimal (or within limits of what can be suitably replicated) and should be chosen to address the primary interest(s) of the survey. It is important to replicate data collection of each of the factors included, and ignoring replication to favour including more factors will make the information gathered less useful. Therefore, it is important to replicate observations without introducing additional variation that would be best addressed by another factor in the survey. The time and the resources available will often determine the complexity of a survey design.

Table 1. Table of example habitat feature to consider for choice of consistently comparable monitoring sites.

Habitat	Habitat features
Coral reefs (and rocky reefs)	• Depth • Reef zones: slope, crest, flat, back reef, lagoon, patch reef • Reef types: points, pinnacles, reef channels, cleaning stations • Turbidity and sediment loads, distance offshore or from source of sediment. • Reef substrate orientation • Distance from human centre or fishing port as proxy for fishing intensity • Tidal currents and water movement speeds • Exposure to waves and wind
Seagrass	• Depth • Distance from shore • Distance from human centre or fishing port as proxy for fishing intensity • Turbidity and sediment loads, distance offshore or from source of sediment. • Tidal currents and water movement speeds
Mangroves	• Distance from the shoreline/waterline • Substrate type (e.g. coarse sand versus silt) • Proximity to human centres

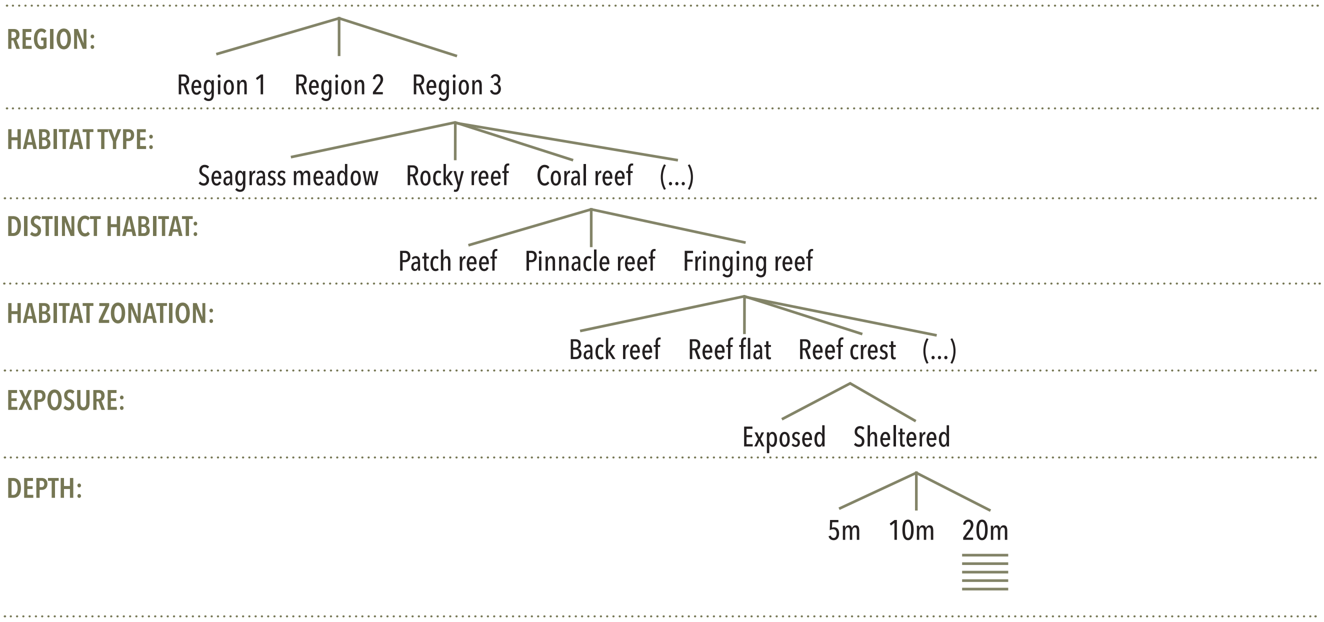


Figure 1. A general survey design for the collection of replicated monitoring data in marine habitats of three regions with diverse habitats exposure and depths. Horizontal lines represent replicates at each of the unique hypothetical sites included in the survey.

2.3. Timing and frequency of monitoring activities

The timing and frequency of surveys is important to determine the effectiveness of monitoring and the cost and effort required. Timing can be a factor in the survey design if it addresses a specific monitoring question such as when are targeted fish aggregated in a habitat in preparation to reproduce. Choosing the most appropriate timing and frequency for monitoring activities is determined by the monitoring questions, and the organisms of interest. Monitoring too frequently may be inefficient in terms of cost and effort, whilst more surveys also generate more work to tidy the data, interpret the results and prepare reports. Therefore it is important to establish a sustainable balance of monitoring effort that translates into timely management decisions. The following are recommendations for the timing for monitoring key organisms and communities in tropical marine habitats.

2.3.1. Corals

- *Time of year:* if only monitored once, choose the hottest months of the year (March, April) to allow for bleaching assessments as well as general coral surveys.
- *Time of day:* ensure sufficient light for observations between approximately 7:30 and 16:30.
- *Time of tide:* snorkelling and diving may be best at high or low tide, because the least water movement is best for diving and observations. Incoming tides often provide clear water, which is best for snorkel, diving and drop camera observations

2.3.2. Macroalgae

- *Time of year:* most practically this should be done at the same time as coral surveys. However, macroalgae biomass and percent cover varies seasonally, and this differs between species. Seasonal surveys 30, 60 or 90 days apart might be chosen to describe macroalgae variation in throughout the year.
- *Time of day:* ensure sufficient light for observations between approximately 7:30 and 16:30.
- *Time of tide:* snorkelling and diving may be best at high or low tide, because the least water movement is best for diving and observations.

2.3.3. Other benthic reef organisms (e.g. soft corals, sponges, anemones)

- *Time of year:* similar to coral surveys.
- *Time of day:* ensure sufficient light for observations between approximately 7:30 and 16:30.
- *Time of tide:* snorkelling and diving may be best at high or low tide, because the least water movement is best for diving and observations. Incoming tides often provide clearer water, which is best for snorkel, diving and drop camera observations.

2.3.4. Reef Fish

- *Time of year:* if only once per year it is preferable to survey reef fish at the same time as corals are surveyed. More frequent seasonal surveys are likely to describe variation in presence and abundance of fish throughout the year (e.g. 60-90 days apart).

- *Time of day:* the middle of the day with good light is best 10:00 – 14:00. Fish activity varies throughout a daily cycle.
- *Time of tide:* high tide; minimal water movement is best. Fish feeding and predator presence varies throughout the tidal cycles and this may influence abundance estimates. It is important to record the time of observations, and ideal to keep this relatively consistent. Incoming tides often provide clear water, which is best for snorkel, diving and drop camera observations
- *Lunar cycle:* moon phase influences fish aggregation behaviour for spawning

2.3.5. Seagrass

- *Time of year:* keep observations consistent each year for example before or after major floods. To describe seasonality observations might be 60-90 days apart.
- *Time of day:* ensure sufficient light for observations between approximately 7:30 and 16:30.
- *Time of tide:* low tide, especially for intertidal areas; incoming tides often provide clearer water, which is best for snorkel, diving and drop camera observations.

2.3.6. Fish in seagrass habitats

- *Time of year:* same time as coral surveys. Seasonal surveys may show variation in presence throughout the year. Water clarity and runoff of sediments from rivers is likely to be a key determinant of when to undertake in water surveys.
- *Time of day:* middle of the day with good light is best (e.g. 10:00 – 14:00)
- *Time of tide:* high tide; minimal water movement is best. Fish are presence is determined by tide, and predator presence is also determined by water depth.

2.3.7. Mangroves or terrestrial vegetation

- *Time of year:* seasonal patterns may impact foliage and presence of associated organisms. If observations are yearly the time of year should be consistent. Seasonality may be described with surveys at 30, 60, 90 or 180 day intervals.
- *Tidal cycles:* can be key to determining access to undertake surveys or presence of biota. For example predatory fish may only be present at high tide.
- *Time of day:* ensure sufficient light for observation and safety

2.3.8. Megafauna – (e.g. manta rays, turtles, dugong, dolphins, whale sharks)

- *Time of year:* large marine organisms may have seasonal patterns in presence, which relate to food availability (e.g. tiger sharks) or reproduction (e.g. turtle nesting, whale aggregations).
- *Tidal cycles:* can be key to determining food availability or activity, for example sharks often forage on reef flats at high tide when there is sufficient water depth.
- *Time of day:* influences feeding activity, vulnerability to predators and activity patterns (e.g. many sharks are more active nocturnally).

2.3.9. Abiotic factors

- *Time of year:* if possible abiotic factors should be measured continuously throughout the year, or at least each time a site is visited
- *Tidal cycles:* it is important to consider how tidal cycle affects the source of water. For example an out going tide is likely to carry heavier sediment loads and may have lower salinity if near a river mouth.
- *Time of day:* time of day influences temperature and visibility, as well as biological activity such phytoplankton and zooplankton abundance. Consistency of the time of observations is best or at least a record of the time of observations should be made.

3. PROPOSED INDICATORS OF ECOLOGICAL STATE

We suggest collecting data for variables that provide insight to an ecological state or processes, or indicator variables, which are also widely used to enable regional comparisons of a marine community. These indicator variables are useful to assess the resilience and status of ecological communities as well as measure the success of management actions. The suggested indicator variables are habitat and community specific and are listed for: coral communities in Table 2, fish communities in Table 3, seagrass communities in Table 4, mangrove communities in Table 5 and megafauna in Table 6. We also propose measurements of physical characteristics of the marine environment known to influence biota in Table 7.

Collecting data for indicator variables can differ in complexity. Data such as the nutrient composition of seagrass blades, or the organic content of mangrove sediments may be desirable to describe aspects of a community state. However, collecting data for these indicator variables would require relatively more training and resources than for example gathering percentage cover data. In this guide we attempt to favour more simple approaches to describe the ecological state of an ecosystem or community. Nonetheless, further sampling guidelines can be found in the references listed herein.

Table 2. Indicators of coral community and population status (* recommended indicator).

Coral indicators	Description	Possible methods	Common units
* Coral percentage cover	The percentage of the substrate occupied by coral; best when detailed to the level of genus or species and complements coral density.	Belt transects, point- or line-intercept transects, timed swims, photo-quadrats, manta tows	%
* Coral diversity	A quantitative measure of how many coral species are present, and which reflects how evenly species are distributed. Approximately 300 species of coral occur in Mozambique (Obura 2012). Suggestions include that the species richness of coral communities is assessed with the Simpson's Index, and that the Species diversity be assessed with the Log Series (α) Index (a parametric method) or the Shannon-Wiener Index (a nonparametric method).	Belt transects, point- or line-intercept transects, timed swims, photo-quadrats	No units (Diversity indices)
* Coral size-class distribution	Size specific abundance of coral taxa; allows demographic interpretation of the state of a coral population and assessment of impacts from disturbances and recovery rates. Measure coral maximum diameter and perpendicular to maximum diameter and later allocate to size classes (e.g. 5 cm bins). Focus on key species.	Belt transects, timed swims, quadrats, point- or line- intercept transects, measurement of coral diameter	Abundance per size class; reproductive versus immature colonies
* Coral abundance	The number of corals per m^2; best when detailed to the level of genus or species and complements coral percentage cover.	Belt transects, point- or line- intercept transects, timed swims, photo-quadrats	n/m^2
Abundance of key coral species	The abundance of key coral species that provide insight to important ecosystem functions and responses. For example species of Acropora with table morphology are important to habitat structure, they are also relatively susceptible to coral bleaching (Marshall and Baird 2000; McClanahan et al. 2004).	Belt transects, quadrats, point- or line- intercept transects, timed swims, photo-quadrats	% cover, n/m^2
Abundance of coral predators	Quantify the abundance of coral predators such crown-of-thorns-starfish. Describe the size class distributions and population dynamics of these predators.	Belt transects, quadrats, timed swims, manta tows.	n/m^2
Abundance and diversity of coral diseases	Proportion of the coral community that is affected by diseases. You may choose to use a 'total prevalence', which combines all diseases and all corals, or a subset of diseases or corals to assess effects from a particular disease or on a particular coral.	Belt transects, quadrats, photo-quadrats, point- or line- intercept transects	% diseased colonies, frequency of diseases, n/m^2
* Coral recruitment rate	Abundance and density of coral recruits from each taxa (< 5 cm diameter). Identification of coral recruits to genus level is recommended. All indicators for corals in general are relevant (e.g. diversity, density).	Quadrats, belt transects	count/m^2
* Macroalgae % cover, density and diversity	Macroalgae can provide an indication of the degradation of a habitat. Attention should be given to turf algae and crustose coralline algae as well. Measurements can be made of percentage cover, diversity, height, levels of sediment trapped.	Belt transects, quadrats, point- or line- intercept transects, timed swims, photo-quadrats	% cover, n/m^2 diversity indices

Table 3. Indicators of fish community status (* recommended indicator).

Fish indicators	Description	Possible methods	Common units
* Fish diversity	Greater diversity is likely to represent greater resilience and better ecosystem state; More diverse fish communities are likely to have greater the functional redundancy. The diversity of fish in Mozambique includes 862 reef-associated species, which is approximately half of the species listed for Mozambique (Froese & Pauly 2020). Suggestions include that fish species richness is assessed with the Simpson's Index, and that the Species diversity be assessed with the Log Series (α) Index (a parametric method) or the Shannon-Wiener Index (a nonparametric method).	Belt transects, timed swims, stationary point counts, non-baited video, manta tow	No units (Diversity indices)
* Fish biomass per area (e.g. hectare)	The biomass of reef fish has been used as a threshold indicator of habitat state (e.g. Graham et al 2017, McClanahan 2018).	Belt transects, timed swims, stationary point counts, non-baited video, manta tow	kg/ha
* Fish size class distribution	The abundance of individual size classes provides insight reproductive potential and to pressures on a fish community. Fish reproductive potential is size dependent. Larger predators are generally absent even at low levels of fishing.	Belt transects, timed swims, stationary point counts, non-baited video	kg/ha
Biomass and diversity of key functional and trophic groups	The diversity and relative biomass or abundance of taxa in key functional and trophic groups can provide insight to how vulnerable an ecosystem function is to disturbances such as fishing. For example if herbivory relies primarily on parrot-fish and these are fished. Can be inclusive of all major herbivore functional groups (scrapers, grazers, excavators, browsers) or can separate these.	Belt transects, timed swims, stationary point counts, non-baited video	kg/ha
Herbivore diversity and biomass	See 'coral diversity' description; same for herbivorous fish and invertebrates. Can also be assessed as the number of key herbivore functional groups present at a minimum abundance (e.g., scrapers, grazers, browsers and excavators).	Timed swims, belt transects, stationary point counts	Diversity indices, relative abundance

Table 4. Indicators of seagrass community and population status (* recommended indicator).

Seagrass indicators	Description	Possible methods	Common units
* Seagrass diversity	Taxonomic diversity, ideally to species level. Shoot morphology diversity might also be assessed. The following seagrass species occur in Mozambique (Bandeira & Gell 2003): *Cymodocea serrulata, Enhalus acoroides, Halodule wrightii, Halophila stipulacea, Halophila minor, Halophila ovalis, Thalassia hemprichii, Thalassodendron ciliatum, Zostera capensis*. Suggestions include that the species richness of a seagrass habitat is assessed with the Simpson's Index, and that the Species diversity be assessed with the Log Series (α) Index (a parametric method) or the Shannon-Wiener Index (a nonparametric method).	Quadrats, belt transects, photo-quadrats	No units (Diversity indices)
Seagrass shoot density	The number of seagrass shoots in a defined area (e.g. m^2).	Quadrats, belt transects, photo-quadrats	n/m^2
* Seagrass percentage cover	The percentage cover of seagrass meadows in a habitat.	Quadrats, belt transects, timed swims, manta tows	%
Seagrass height	The abundance of individual size classes provides insight reproductive potential and to pressures on a fish community. Fish reproductive potential is size dependent. Larger predators are generally absent at low levels of fishing.	Belt transects, timed swims, stationary point counts, non-baited video	kg/ha
Sediment and epiphyte stress	Sediment or epiphyte quantities on seagrass. Accurate assessment can be complicated requiring oven drying and calculations of dry weight. Alternatives could be to photograph individual seagrass blades and later estimate % cover of epiphytes or sediment.	Sample seagrass blades; belt transects, photographs	%, g/blade
* Herbivore diversity and biomass	Similar to surveys of fish and in coral habitats; quantification of herbivore or other functional and trophic groups of fish	Timed swims, belt transects, stationary point counts, non-baited video	divers ity indices, kg/ha, n/m^2
Seagrass recruitment	Provides insight to regenerative potential of a seagrass community; settlement tiles or propagule searches require training and microscope use.	Quadrats, sand/sediment samples	Count/m^2

Table 5. Indicators of mangrove community status (* recommended indicator). Note that indicators such as soil and leaf litter nutrient contents have been included here but the focus is on indicator variables for the mangrove community that are more simple to observe.

Mangrove indicators	Description	Possible methods	Common units
* Plant biodiversity	Greater diversity of habitat building species translates to greater niche diversity and biodiversity within the mangrove ecosystem. The following ten mangrove species may occur in Mozambique (Saenger et al. 1983, FAO 2005, Spalding et al. 2010): *Acrostichum aureum, Avicennia marina, Bruguiera gymnorrhiza, Bruguiera cylindrical, Ceriops tagal, Heritiera littoralis, Lumnitzera racemosa, Rhizophora mucronata, Sonneratia alba, Xylocarpus granatum*. The biodiversity of a mangrove (or other) ecosystem can be assessed with a variety of biodiversity indices (UNU-INWEH 2013). Suggestions include that the species richness of a mangrove habitat is assessed with the Simpson's Index, and that the Species diversity be assessed with the Log Series (α) Index (a parametric method) or the Shannon-Wiener Index (a nonparametric method).	Belt transects, Quadrats or larger permanent plots (e.g. 10 m × 10 m)	No units
* Spatial area covered (e.g. hectare)	The spatial extent of a mangrove ecosystem can be measured and monitored for change through time. Expanding mangroves suggest favorable conditions for growth, while mangrove contraction indicates a stresses resulting in loss of vegetation.	Point intercept transects, aerial photos or satellite images, geo-referenced point observations or quadrats	ha^2
* Canopy transparency	The lower the transparency of a mangrove ecosystem canopy the more likely the ecosystem is stressed or degraded. Lewis et al. (2016) suggest detecting mangrove degradation and observations of stressed mangrove stands can use the benchmarks of 25 % transparency below which the condition is good, and 50 % transparency above which condition is poor.	Quadrats, Point intercept transects, aerial photos, satellite imagery and measurements	%
* Propagule, Seedling, Sapling Presence	Seedlings and saplings are less resistant to stress and can be an earlier indicator of stress to a mangrove ecosystem than mature mangrove trees. The mean density of seedlings and saplings provide insight to the potential to fill gaps in the vegetation, to recover from disturbance, and general suitability of mangroves for the present abiotic conditions.	Quadrats, belt transects, plots (e.g. 5 m × 5m)	n/m^2
* Canopy height	Plant height is often used as a proxy for productivity. Low height development may indicate unfavourable conditions such as hypersalinity or excessive inundation)	Measurement of individual trees	m
* Complexity Index of mangrove structure	Mangrove structural complexity can be quantified by combining measurements of physical features of the mangrove community that are easily measured such as stem density, diameter at breast height (DBH, measured by convention at 1.3 m height above the ground, or the diameter 30 cm above the highest stilt root for the genus Rhizophora), and tree height. Greater structural complexity indicates better ecosystem condition (Cintrón and Novelli 1984, Lewis et al 2016). CI = (number of species of mangroves) (number of stems) (basal area) (maximum height of mangroves) / 100	Fixed study plots (e.g. 10 m × 10 m), point-centered quarter method, measurements of individual trees	No unit
Importance Value (IV)	The importance value of a mangrove species is a product of the relative measures of species density, frequency and dominance (FAO 2005) which are each calculated as follows: Relative Density = (Number of individuals of a species/total number of individuals) × 100 Relative Dominance =.(Total basal area of a species/Basal area of all species) × 100 Relative Frequency = Frequency of a species/sum frequency of all species) × 100 Basal Area (g)= the proportion on the ground occupied by the vertical projection of the tree trunk to the ground and it is calculated as g=(DBH/2)2 Stand density = Number of individuals in a unit area and its calculated as Density per hectare = (No. of stems in plots x 10,000)/ Area of the plot IV = (Relative density + Relative dominance + Relative frequency)	Direct measurement of parameters such as basal area of trees and tree density to estimate parameters	No unit
Above ground biomass: live and dead	A relationship can be established between the biomass of whole trees (or their components) and parameters such as diameter at breast height, species, wood density and tree height using published allometric equations to calculate mangrove biomass specific to geographic regions (Kauffman and Donato 2012 and references therein). The calculation of dead tree biomass is corrected for the	Measurement of tree parameters (species, diameter at breast height, tree height) and use of alometric equations	kg

Mangrove indicators	Description	Possible methods	Common units
	absence of leaves and branches with additional alometric equations (Kauffman and Donato 2012). Knowledge of biomass is useful for calculating carbon sequestration in mangroves.		
Below ground tree biomass	Similar to above ground biomass published allometric equations are used to calculate below ground mangrove biomass, However, fewer equations have been well calibrated (Kauffman and Donato 2012). Knowledge of biomass is useful for calculating carbon sequestration in mangroves.	Measurement of tree parameters (species, diameter at breast height, tree height) and use of alometric equations	kg
Soil bulk density	The soil bulk density is determined from samples that are oven dried at 60 °C using the following formula (UNU-INWEH et al 2013, Kauffman and Donato 2012): Soil bulk density (gm^{-3}) = Oven-dry sample mass (g) / Sample volume (m^3)	Soil cores	gm^{-3}
Soil organic matter content	The organic content of mangrove soil can be estimated by drying soil for 8 hours at 450 °C in a muffle furnace to then calibrate the following formula (UNU-INWEH 2013, Kauffman and Donato 2012): Organic Matter Content = [[Initial weight (g) – Final weight (g)] / Initial weight (g)] × 100	Soil cores	%
Soil organic carbon concentration (%OC)	Soil organic carbon concentration (%OC) can be estimated from change in sample weights after drying and a conversion factor of 1.724 when we assume that soil contains 58% organic matter (UNU-INWEH 2013). Whilst, direct determination of soil organic carbon concentration is possible with colorimetric quantitation or dry combustion (UNU-INWEH 2013). The soil carbon mass per sampled depth interval is calculated as: Organic Matter Content = [[Initial weight (g) – Final weight (g)] / Initial weight (g)] × 100 Where %OC is expressed as a whole number. Total soil carbon is determined by summing the carbon mass of each sampled soil depth.	Soil cores	%
* Fish diversity	The fish diversity, in particular of juvenile fish, provides insight to the value of a mangrove as a nursery for other ecosystems (e.g. coral reefs and seagrass meadows) and fisheries. The density of species recognised as important to fisheries is also an indicator of ecosystem state and importance	Video sampling, fish traps or cast, pull or drop net sampling.	Diversity indices

Table 6. Indicators of the status of megafauna populations and communities.

Megafauna indicators	Description	Possible methods	Common units
Taxonomic richness and diversity	Suggestions include that the species richness of megafauna be assessed with the Simpson's Index, and that the Species diversity be assessed with the Log Series (α) Index (a parametric method) or the Shannon-Wiener Index (a nonparametric method).	BRUVs and non-baited video, large scale aerial transects	No units (diversity indices)
Abundance (and biomass)	Knowledge of the abundance (and biomass) is useful for monitoring populations of megafauna, but presents challenges because of the relatively large spatial ranges that megafauna may use. Animals that are frequently at the water surface (e.g. whale sharks, dugongs, turtles) may be easier to monitor.	Large scale aerial transects, acoustic monitoring, local and opportunistic sightings from boats, vantage points and at dive sites, feeding scars (e.g. dugong), mark recapture in collaboration with local fishers.	n/ha
Number of known individuals	Identification of individual animals from markings and distinct features provides insight into the territoriality and residence of megafauna at key locations (e.g. manta rays, sharks).	BRUVs and non-baited video, opportunistic observations and photos	n
Sex ratio	Identifying the sex of individuals is useful to understand sex rations can help describe the population structure, but may also help identify reproductive seasons and key habitats for mating.	BRUVs and non-baited video, opportunistic observations and photos	No unit
Population size class structure / Juvenile to adult ratio	Descriptions of the size class structure of a population may provide useful insight into the age structure of a population. Understanding the relative abundance of juveniles to reproductive animals provides insight to the reproductive success of a population.	BRUVs and non-baited video	n or % per size class
Beach nests/ nesting tracks	Provides insight into the abundance of reproductive female sea turtles and identifies key beach areas and timing of reproduction	Transects, haphazard searches	Number per, transect, beach or length of coastline
Hatchling beach nest tracks	Provides insight into the nest success for sea turtle reproduction	Transects, haphazard searches	Number per, transect, beach or length of coastline
Movement tracking	Acoustic tracking and satellite tracking can enable the identification of key habitats and range areas of a variety of megafauna.	Satellite tags, Acoustic tags and receivers	km (distances travelled), ha or km^2 (range area)

Table 7. Indicators of abiotic variables and the physical state of the marine ecosystem (* recommended indicator).

Environmental indicators	Description	Possible methods	Common units
* Temperature and temperature variability	Variability of temperatures during the warm season. Higher variability has been associated with bleaching resistance.	Remote sensing (e.g. NOAA), Temperature loggers on site	°C, Unitless
* Habitat complexity or structural complexity	Three-dimensionality complexity of the substrate; abundance and diversity of habitat niches and shelter for organisms. More diverse habitats are associated with greater biodiversity (Wilson et al 2007).	Chain rugosity measurements, visual qualitative description. Belt transects, PIT	Ratio, qualitative categories
Light (stress)	Amount of light per square meter arriving at the substrate; particularly relevant to bleaching events during warm months or seawater temperature anomalies.	Light loggers	watts/m^2
Turbidity and sediment stress	The amount of suspended sediment in marine environment; influences light and sediment deposition stress onto benthic organisms	Sechi disk measurements; Remote sensing (e.g. NOAA), sediment traps	m (secchi disk)

4. DESCRIPTION OF MONITORING METHODS

4.1. Point-intercept Transect (PIT)

The biota or abiotic substrates is identified at points spaced by regular intervals along a transect, often defined by a 50 m survey measuring tape. The interval for observation points commonly ranges between 25 cm and 1 m, generating between 200 and 50 observations per 50 m transect. The ideal observation interval is a function of the statistical power desired when interpreting the data, the number of replicate transects at a site, and the time required to survey a transect, all of which are ideally assessed during pilot or baseline surveys (Facon et al. 2016). The benthic biota or abiotic substrate at each point should at a minimum be described to the level of life form categories (Table 8). It is preferable to record greater detail for organism central to the monitoring objectives such as corals and macroalgae, which may be identified to the level of genera or species. For each coral observed information regarding growth form can also be recorded (Table 8). The hard coral genus *Acropora* has a relatively large variety of growth forms and it can be useful to identify the specific growth forms of colonies in this genus (Table 9). The state of each coral, for example with regards to bleaching or disease, can also be described using categories (Table 10).

Advantages of surveys using the PIT method include they are relatively quick to undertake, with a site normally surveyed during a single dive, and the data is available for analysis as soon as it is entered after each dive. This can facilitate a quick translation of monitoring data to management decisions. Data entry platforms such as Mermaid currently support PIT format data, which reduces data entry errors and the need to tidy data, thus allowing for a faster interpretation and communication of the results. PIT surveys do not require costly equipment beyond SCUBA equipment, survey tapes, dive slates and planned datasheets. We provide an example of a PIT data sheet widely used by WCS scientists in appendix 1.

Training in the identification of corals and other marine organisms is required and surveys are best undertaken by persons with experience in identification of organisms as well as SCUBA or snorkelling. However, identification skills can be incorporated into training for other monitoring activities such as photo-quadrats.

Underwater cameras are valuable tools to aid with the identification of organisms. Photographs allow taxonomic references to be consulted after a dive and specific features of corals or other biota that may not have been noted can be checked. This is important to ensure accurate identifications and consistency of identifications between observers.

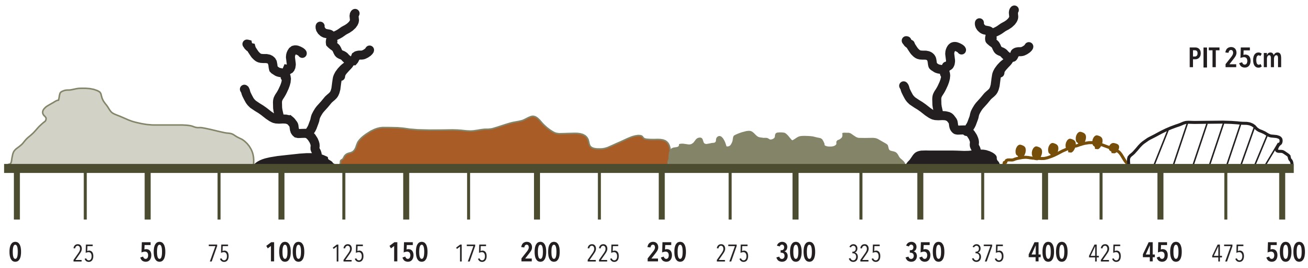


Figure 2. Example illustration of points spaced 25 cm apart, along a Point Intercept Transect (PIT).

Table 8. Life form categories and morphologies used to distinguish observations during PIT surveys

Life form	Category	Code
Hard Coral	coral branching	CB
	coral corymbose	CC
	coral encrusting	CE
	coral foliose	CF
	coral massive	CM
	coral submassive	CS
	coral mushroom	CMR
Algae	algal assemblage	AA
	coralline algae	CA
	Halimeda (malgroalgal genus)	HA
	macroalgae (general)	MA
	turf algae	TA
	dead coral with fleshy algae	DA
Soft coral	Soft coral	SC
Sponge	Sponge	SP
Zoanthid	Zoanthid	ZO
Other biota	Other biota	OT
Abiotic	Rock (non carbonate)	RC
	Rubble	RB
	Sand	SD
	Silt	SI
	Reef matrix	RM

Table 9. Specific life form categories for the hard coral genus *Acropora*.

Life form	Category	Code
Hard Coral	*Acropora* branching	ACB
	Acropora corymbose	ACC
	Acropora digitate	ACD
	Acropora table	ACT
	Acropora submassive	ACS
	Acropora encrusting	ACE

Table 10. Descriptive categories for the status of corals observed in PIT surveys

Coral status (live/dead)	Code
Live	L
Bioeroded	E
Partially bleached	B1
Bleached/White	B2
Bleached and partly dead	B3
Partly dead	PD

4.2. Line Intercept Transect (LIT)

Line intercept transects use a transect line to estimate the percent cover of organisms or categories of substrate type in an area by recording the lengths of the transect line that intercept those organisms or substrate categories (Figure 1). The larger the organism or substratum patch the more likely it will be recorded in an LIT survey, and organisms smaller than 9 cm in diameter are often not intercepted (Bakus 2007). The method is most appropriate when the size of organisms or substrate categories is small relative to the length of the transect, and the length of the transect is small relative to the area of interest (English et al. 1997). Besides the percent cover of organisms, or categories, LIT surveys also provide insight into the frequency of interactions, by recording adjacent organisms or categories (Bakus 2007).

LIT are frequently used for coral reef surveys because they provide considerable information for the benthic organisms and substrate types present for relatively low effort (Marsh et al. 1984, Bakus 2007), such as:

1) The dominance or percent cover of organisms and substrate types expressed as a proportion or percentage of the LIT
2) Insight to associations, dependencies or frequent interactions between adjacent categories
3) The complexity, rugosity or heterogeneity of a coral reef habitat
4) The density, or abundance per area of selected organisms or categories, by using one of:
    a) Strong method, also known as the modified Eberhardt method, which can be applied to individual categories of organisms (e.g. coral colonies)
    b) Weinberg method, which works well for circular organisms larger than 1.0 m in diameter
    c) Nishiyama method, developed to account for oval shaped organisms that are not perpendicular in their orientation to the LIT, which is overlooked by the previous two methods.
5) The size frequency distribution of corals or other organisms, provided additional measurements are made of the size of organisms. Using the LIT

intercept measurements is likely to under-record the size of organisms if the survey tape is taught, and may over-record the size of organisms if the survey tape is fitted to the contours of the substratum. Note there will also be a bias towards observing larger organisms (Bakus 2007, Zvuloni et al. 2008)

6) Incidence of coral bleaching, carallivory or coral disease when additional observations and records are made.

Common practice for LIT is to use a graduated fiberglass survey tape of 10 m to 50 m length, placed on the reef substratum parallel to the reef crest (English et al. 1997, Hill and Wilkinson 2004). Other authors have used lengths of chains, which fit to the contours of the reef crest (Hughes and Jackson 1985), which provides a simultaneous option for recording coral reef rugosity, or reef heterogeneity, if the linear distance from the start to finish of the chain is measured (McCormick 1994, Bakus 2007). It is important to recognize that the way the LIT is fitted to the reef substratum will impact the results obtained which is reported to vary by up to 27 % of estimated percent cover between a taught or straight line between the start and end of the LIT, a slack line laying on the reef substratum, and a line or chain that is closely fitted to the contours of the reef substratum (Bakus 2007). It is also suggested that a taught or straight line approach is less useful for later estimating species richness from a site, because it does not capture the correlation of greater species richness with greater habitat complexity (Bakus 2007).

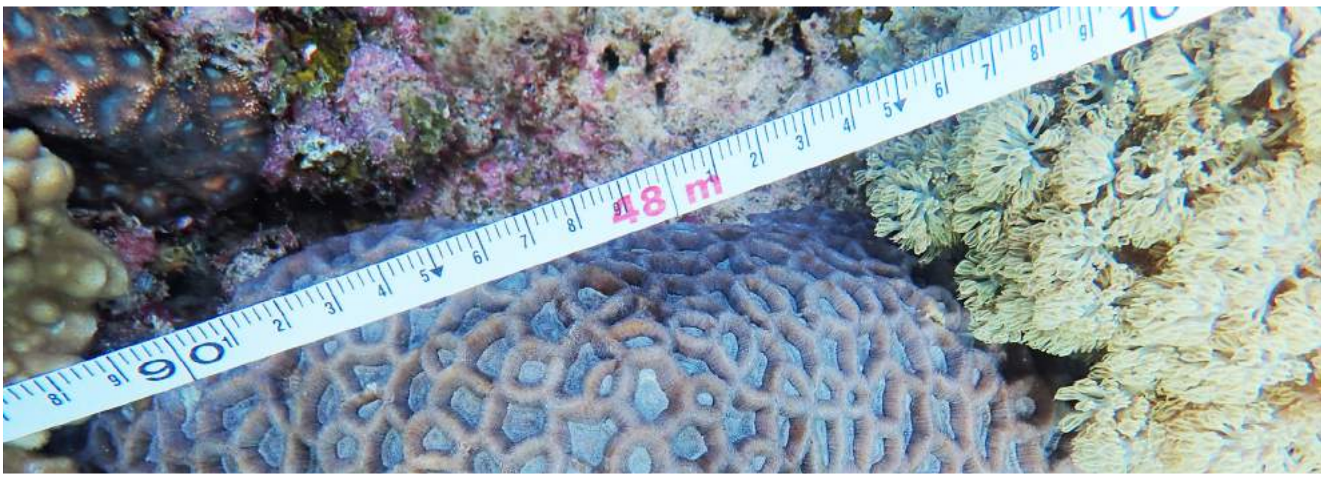
The tape or chain should be firmly attached at the start. A straight line may be easiest to use if transects are relatively short (e.g. 10 m), and the start and end of categories can be more accurately recorded using a plumb line (line with a weight) held to intercept the transect and organism boundaries (Bakus 2007). A slack LIT should be laid as close as possible to the substratum in a consistent direction although following the depth contour of the reef substratum, and should remain with 0-15 cm from the substratum to which it can be anchored at intervals to prevent movement (English et al. 1997). A large rubber band or piece of tire inner tube can be used as a loop attached to the start of a transect as well as at intervals along the transect tape to attach this to the substrate. Alternatively a transect tape may be looped around small objects, or metal rods that are permanently placed to locate a repeatedly surveyed transect. Bear in mind that the larger the object the tape is wrapped around the more this will shorten the total length of the transect, and this error should be accounted for at the end of the transect or when calculating the percent coverage of categories.

The percent cover of an organism or substratum category is calculated as follows:

Equation 1. Calculation of percent cover from LIT data

Percent cover = total length of category / length of transect × 100

For simplicity many studies identify organisms or categories in generalized groupings such as life forms such as live coral, sand, rubble, dead coral, seagrass, sponge, algal turf, fleshy macroalgae, soft corals, other organisms (English et al. 1997, Hill and Wilkinson 2004, Bakus 2007). If the observers are suitably skilled it is possible to identify organisms in greater detail, such as to the level of coral growth morphology, genera or species.



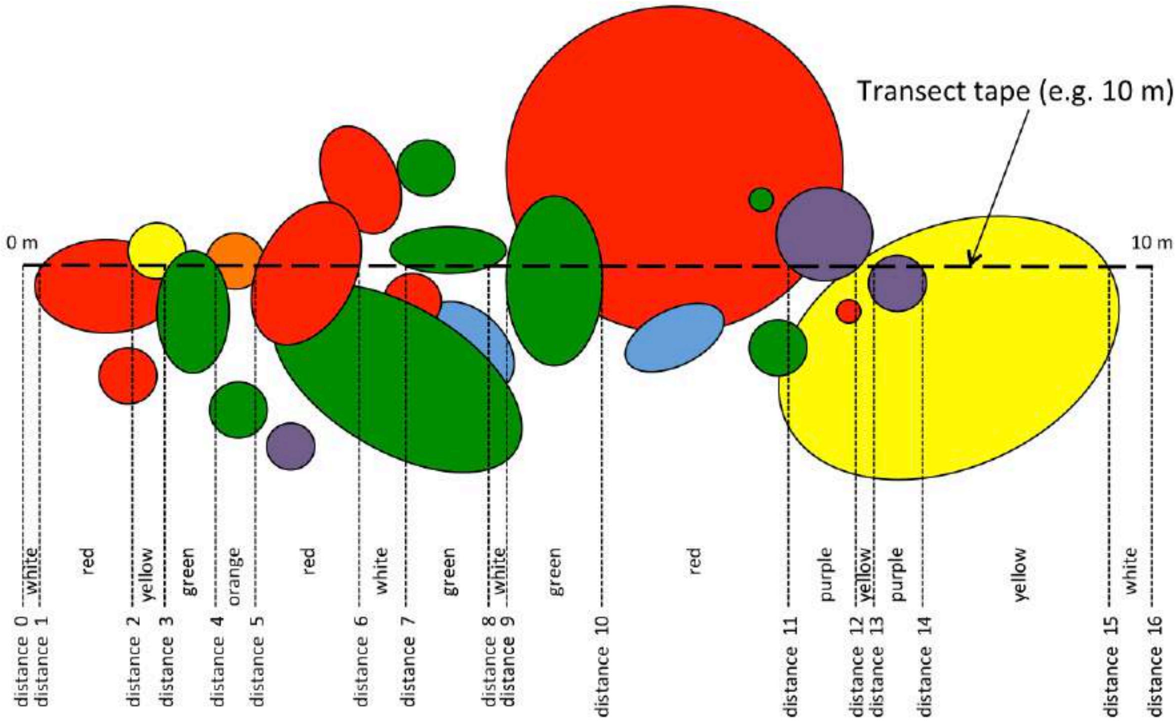


Figure 3. Visual representation of a LIT that is 10 m in length, surveyed from left to right. A bold dashed line is used to represent the LIT transect placement. Colours are used to differentiate organisms, groupings or categories. White represents the substrate in this example. Distances along the transect are recorded where the LIT intercepts the start or end of an organisms or substratum category. In this example to estimate the proportion of the substrate occupied by yellow the difference between distances 2 and 3, between distances 12 and 13 and between distances 14 and 15 are summed and used to calculate a percentage of the 10 m distance occupied by yellow.

4.3. Quadrats surveys of benthic organisms

Quadrats are essentially counts of organisms in an area, that require the area counted is known so that density can be determined directly, and that the organisms are relatively immobile during the counting period so they are not missed or counted repeatedly (Krebs 2014). Quadrats are frequently used to assess diversity, abundance and the percentage cover of organisms such as corals within a quantified unit of area that is easily replicated. Quadrats are usually a square in shape, although sometimes a rectangle is chosen (similar to a camera frame of view), that can be placed on most substrates to survey biota from marine organisms to terrestrial vegetation. The observations made are specific to the interests of the monitoring efforts, and may include for example the percentage of the substrate covered by organisms, the number and taxa of individual corals or plants, the size of individuals or the number of individuals with a disease or epiphytes.

There is not one universal "best" quadrat size even for studies of the same organisms, and we suggest consulting Krebs (2014) for a detailed discussion of quadrats. The size of the quadrat chosen usually differs according to size of the target organisms and the time required to find and describe them. Initial choice can be guided by previous studies, for example a 25 cm × 25 cm or a 50 cm × 50 cm quadrat might be appropriate to search for coral recruits, whilst a 1.0 m × 1.0 m may be suitable for describing the abundance and percentage cover of adult hard corals, soft corals or macroalgae. Larger or rare corals, for example colonies of the genus *Porites* with a massive morphology, may require even larger quadrats (e.g. 10 m × 10 m), or it may be more appropriate to use a belt transect as described below. We advise using a pilot study to identify the appropriate size and number of quadrats for a study.

Special considerations are necessary for including corals (or other benthic organisms) that are only partly inside a belt transect or quadrat to avoid biases in spatial sampling. A detailed discussion is provided by Zvuloni et al. (2008), who recommend including the organisms that have their two-dimensional geometric center inside the belt transect or quadrat to avoid size related biases associated with the inclusion of organisms (Figure 3). Larger corals are more likely to have a portion of the colony inside a belt transect or quadrat, and would therefore be over sampled if selected based solely on being partly inside the belt transect or quadrat.

The number of quadrats surveyed is often an outcome of the time available (e.g. during a dive) and the time required to survey each quadrat. The most appropriate number of quadrats may be determined relative to the variation in the collected data and the statistical power desired to detect an amount of change in a particular quantitative variable (Krebs 2014). Generally the statistical power increases with the number of replicates, however we advise this is checked against a pilot study, previous data or expert knowledge of the likely variation in observations (e.g. range of expected coral diameters).

A key feature is that a quadrat defines an area, but there are variations of how observations are made in a quadrat. Quadrats can be used to search for and make observations on all organisms found within the quadrat. The quadrat can be subdivided, for example with strings, to aid an observer to estimate the proportion of the quadrat area covered by specific biota. The quadrat can also have predefined points, such as where perpendicular strings cross, at which the substrate or biota directly below the point is described. The choice of approach is determined by the monitoring question, for example the first approach described is appropriate for counting coral colonies or recruits and the latter two are more appropriate for describing percentage cover of biota.

4.4. Belt transect surveys of benthic organisms

A belt transect is an area of defined length and width (e.g. 10.0 m × 1.0 m), similar in nature to a quadrat, but elongated. Similar to quadrats belt transects are used to define a search area within which to make quantitative observations of organisms. We find the distinction in nomenclature useful, however some ecologist consider a belt transect to be a quadrat (Krebs 2014). An advantage of the elongated shape of a belt transect is that it includes greater habitat heterogeneity and reduces the variation in data from observations (Krebs 2014). Some authors recommend belt transects when surveying the densities of several species or types of organisms simultaneously (Bakus 2007).

An example application of belt transects is to assess the size class frequency of coral colonies in a community, for which all corals in a belt transect are counted, identified taxonomically, and their maximum diameter is measured. Belt transects may be particularly useful to search for organisms that are less likely to be intercepted by a point intercept transect, such as coral recruits which are relatively small (e.g. less than 5 cm maximum diameter). Similar to quadrats, there is no universal size for belt transects and the dimensions are likely to vary according to the effort required to observe the specific target organism(s).

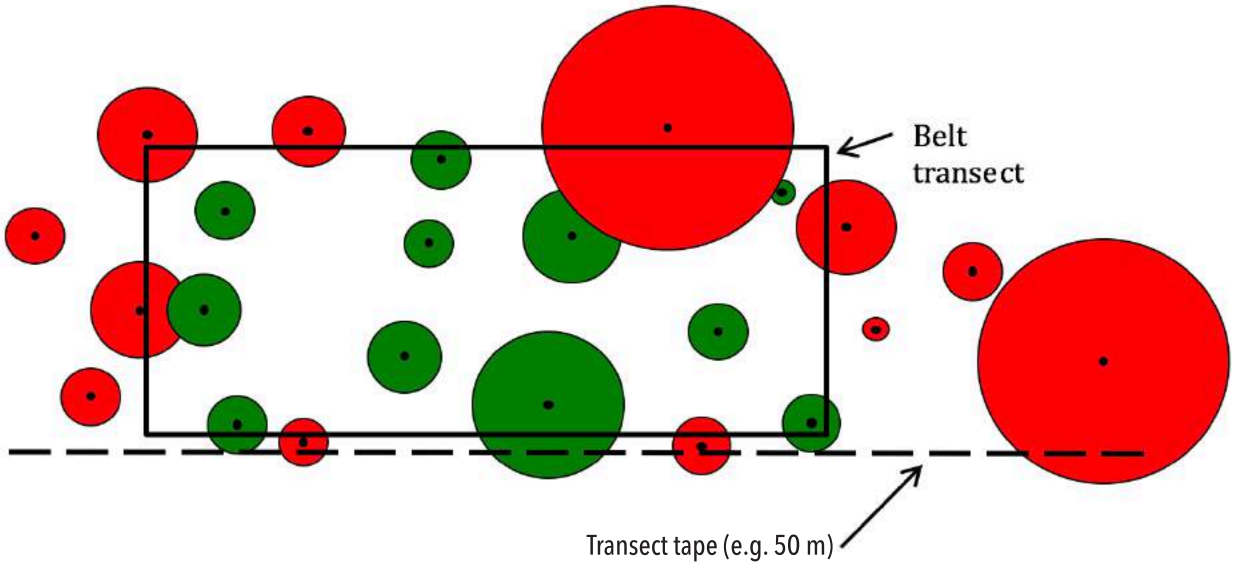


Figure 4. Representation of which coral colonies (or benthic organisms) to include in a belt transect survey based on their geometric centre (black point) adapted from Zvuloni et al. (2008). The green corals have their geometric centre within the belt transect and should be included in the survey. The red corals have their geometric centre outside of the belt transect and should not be recorded. The position of a belt transect would normally be along a transect tape used for other observations

4.5. Photo-quadrats

Photo-quadrats are a variation of quadrats, and potentially belt transects, as described above, but observations are made from photographs after field work instead of making observation in the field. Photo-quadrats can be undertaken by a SCUBA diver, a snorkeler, a reef walker, or from a boat using a drop camera. The method takes a permanent record of a quadrat in the form of a photograph and the collection of data is very similar to visual quadrats. The method alleviates the restrictions placed upon time in the water by SCUBA dive profiles or participant fitness, allows multiple observer to confirm identifications, and can be used to complement other survey methods such as PIT and fish belt transects. Photos may also allow organisms that are mobile to be counted (e.g. sea urchins), but the ability to detect and identify organisms may be lower than from direct observations.

A photograph can provide most information when standardised to include a defined area of the substrate, usually defined by a quadrat frame of known dimensions, so that the exact area sampled can be known. Alternative approaches include measuring a distance from a point on the substrate with a rod or weighted string of known length in an effort to standardise the camera distance and focus. However, these alternatives are likely to introduce errors in the estimation of the area sampled and the size of benthic organisms, because the photo will not always be taken perpendicularly to the substrate, and the photograph will not include scales along the x-axis and y-axis of a photo that can be used to account for the parallax effect, which distorts the dimensions of objects close to the edge of an image. On the other hand if the interest is only to estimate the percentage cover of organisms these methods are suitable. It is important to check the camera and quadrat are set-up to include all of the quadrat in photographs, and that this is aligned with the photograph edges. Remember also that objects appear closer in water so a margin must be left around a photo-quadrat set-up when it is tested in an air environment. It is also wise to check photos at regular intervals during sampling to ensure the camera and quadrat frame remain aligned. Sometimes photo-quadrats are rectangular in shape to accommodate the field of view of a camera.

It is also important to pay attention to image quality and image focus. Particular attention should be given to camera settings such as depth of field, and a higher f-number will ensure more of the image is in focus. Alternatively, modern digital cameras may have an integrated photo-stacking option with can be used to combine images with different depths of field.

It is necessary to standardise the collection of photo-quadrats with a survey design, and this is often done taking the photo-quadrats along transects. Transects should be replicated at a site (e.g. 3 to 5 transects of 50 m). Photographs can be taken at each 1 m mark along a transect. These photos can be subsampled randomly later, which also builds in redundancy for any un-useable photographs (e.g. poor focus or partially obstructed images). It is common for each photograph to be analysed by defining a consistent number of points to identify in the photograph in the same way that an observer would use a visual point quadrat in the field. Points can be allocated randomly using software made free for research and conservation purposes such as Coral Point Counts with Ms Excel Extensions (CPCe) or CoralNet. Nonetheless any approach to using a quadrat in situ can also be used with a photo-quadrat (count coral colonies, measure coral sizes).

There are many advantages to photo-quadrats. These allow a quantitative assessment of abundance and density (e.g. number of coral colonies per m^2). Because photo-quadrats are permanent records that can be analysed with more time or revisited. This can allow bias from different observers to be reduced or assessed and can also make it possible to revisit survey times with questions that arise with hindsight and were not an original focus (e.g. what is the level of epiphytes on seagrass, % cover of soft corals, abundance of sea cucumbers in seagrass). Measurement of coral diameter and 2 dimensional area from images can allow for basic size class description's, although this will exclude larger corals that are not completely included in images. Measurements and basic area calculations of corals are possible in freely available software such as CPCe (Kohler and Gill 2006) or ImageJ (Ferreira and Rasband 2012).

Photo-quadrats can also be coupled with GPS tracks or positions that allow each photograph to be geo-referenced. Geo-referenced photographs, can be used in habitat mapping exercises providing valuable information for spatial management of habitats (Roelfsema et al. 2010, 2015).

Photo-quadrats can enable people with basic training in how to use a camera, how to use a GPS and how to lay a transect and follow a survey design to take the photographs that are later analysed to extract data by persons with higher level expertise (e.g. coral identification). However, it is important for people taking photographs to also participate somewhat in their analysis so that they develop identification skills and an appreciation for the what makes a good photograph and what can interfere with its analysis (e.g. camera angle, camera focus and depth of field, lighting and shadows, distance from substrate).

The photographs can be used as training resources to develop these same skills in capacity building exercises. Permanent records also come with the benefit that they can improve confidence in the quality of data by allowing multiple observers to verify each others work and to standardise identification categories and accuracy allowing a level of quality control to be built into a monitoring program.

The number of points identified in photo-quadrats can be assessed in the initial analysis phase, or can be increased to increase the statistical power of analysis if it is found this was insufficient with hindsight. It is also possible for images to be analysed remotely, which increases the possibilities for intern participation or collaborations. Establishing permanent photo-quadrat sites, that are repeatedly photographed year after year, can provide insight to the specific dynamics of interactions between benthic organisms, for example corals and macroalgae.

The disadvantages of photo-quadrats include that they increase the cost of monitoring by requiring digital storage space, cameras, computers for image analysis and also require time after the fieldwork to analyse the images. It is important to train staff to the care for equipment. There is a lag in obtaining results after fieldwork because of the time taken to analyse images. However, overall it is felt the disadvantages are outweighed by the benefits.

Modern imagery techniques also allow for the stitching of multiple photographs and use of stereo photography to create three-dimensional photo-mosaic images of larger areas (e.g. 100 m^2) that can be searched with greater precision than standard photos of quadrats (Edwards et al. 2017). Photo-mosaics are created from multiple raw images using image processing and numerical optimization modules that reduce the required user intervention to produce an orthorectified photo-mosaic by fusing images together. These techniques provide a number of benefits, for example community analysis of plots. However, the techniques are also more time consuming and may require additional or higher cost equipment (e.g. digital SLR cameras) and software. The post field survey processing is also more work intensive, as mosaics may be composed of several thousand images.

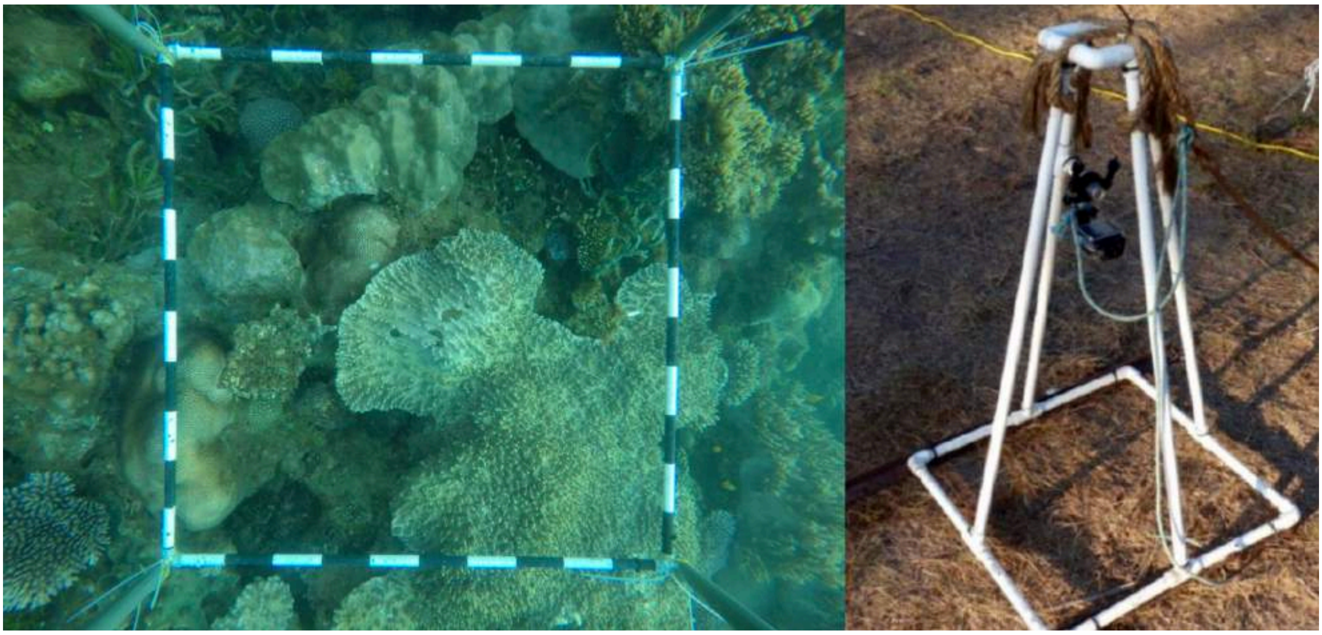


Figure 5 a) Example of a photo-quadrat image and b) example of a frame to standardise the focus, area and distance of camera for a photograph taken

4.6. Observations of tagged colonies

For a monitoring question specific to the state of individual coral colonies we may choose to tag individuals so that we can repeatedly make observations over time on the same colonies. An example may be to assess the impact of sediment released by nearby dredging activity on the health and survival of massive *Porites* colonies. Another example may be access the survival and recovery of *Acropora* corals following a bleaching event. In such a study the individual corals become the replicates and should be replicated evenly (e.g. 20 colonies per site), and it is important maintain consistency in the corals selected. For example corals of different size are likely to have different likelihoods of survival (Hughes & Connell 1987), corals of different taxa (Marshall & Baird 2000) or at different depths are likely to be stressed to different extents by light during a bleaching event (Baird et al. 2018), and corals of different genera are likely to respond differently to smothering by sediments (Jones et al. 2020).

Photographs of colonies from a consistent distance and angle can be a useful method to monitor individual coral colonies (Jones et al. 2020). Similar to photo-quadrats, these provide a permanent record and enable the estimation of the area of a coral affected, for example by partial mortality, bleaching or disease. The images can also be analysed using software made freely available for research and conservation purposes such as CPCe or CoralNet.

4.7. Underwater visual census (UVC) of fish

Visual belt transect surveys are a widely accepted and standardised method for assessing the abundance and diversity of fish communities. In this method a snorkeler or SCUBA diver team lays a transect, or replicate transects, usually of 50 m length and makes observations along these within a defined width of 5 m either side, to survey 500 m^2 (Labrosse, Kulbicki, and Ferraris 2002). Water visibility is important and should be close to 10 m to facilitate fish identification. The observer records the taxa to the level of family, genus or species according to their skill and the focus of the monitoring (e.g. key species targeted by fisheries). The size of fish is estimated and the number of fish is also counted. Together this information allows for the estimation of fish biomass in an area of habitat (in units of kg/ha). If the focus of observations are rare taxa such as sharks it is advisable to increase the area sampled by extending the length and width of transects (e.g. 500 m length and 20 m width).

This method requires a relatively skilled SCUBA diver who is also skilled and experienced at fish identification. The observer should progress along a transect at a steady speed, paying attention not to count the same individual fish more than once. The diver identifies and estimates the size of all fish inside the area of the belt transect. Fish smaller than 3 cm are ignored, unless there is a specific interest in juveniles which requires greater skill and experience. Alternatively for practical reasons, and to focus on fish more relevant to fisheries, observers may ignore fish smaller than 10 cm, but this should be decided after an appraisal of the size of fish caught in local fisheries. Two divers are necessary for safety, and it is not advisable to pair a diver observing fish with a diver observing benthic organisms. Usually observers swim one direction counting the larger fish which are more motile and likely to be scared from the survey area by a divers presence, then observers count the smaller territorial fish (e.g. damsel fish) in reverse direction along the transect. One diver can count larger fish and the other smaller fish (e.g damsel fish) or simply lay the transect tape.

The multiple observations made during a fish belt survey can make written records confusing and it is advisable to use a well planned data sheet during surveys. We suggest a data sheet which is widely used by WCS scientists for fish belt surveys in appendix 2.

Fish biomass is calculated as a metric to assess fish abundance. In its simplest form the biomass of individual fish is calculated using the allometric length-weight conversion:

Equation 2. Fish allometric length-weight conversion

$$W = a \times TL \times b$$

Parameters a and b are species-specific constants, TL is the individual total fork length in cm of a fish and W is the fish weight in grams (Kulbicki et al. 2005; Froese and Pauly 2020). Fish biomass is converted to kg/ha to enable standardized comparisons with other regional studies (Graham et al. 2017). Dedicated data entry platforms such as Mermaid (See section 7) automatically correct species name entries, highlight unusual sizes and calculate the biomass values using a and b parameters listed in FishBase (Froese and Pauly 2020). Identification of fish also allows their separation into functional and trophic groups which can enable the interpretation of ecological interactions with ecosystem level effects, such as predation or herbivory.

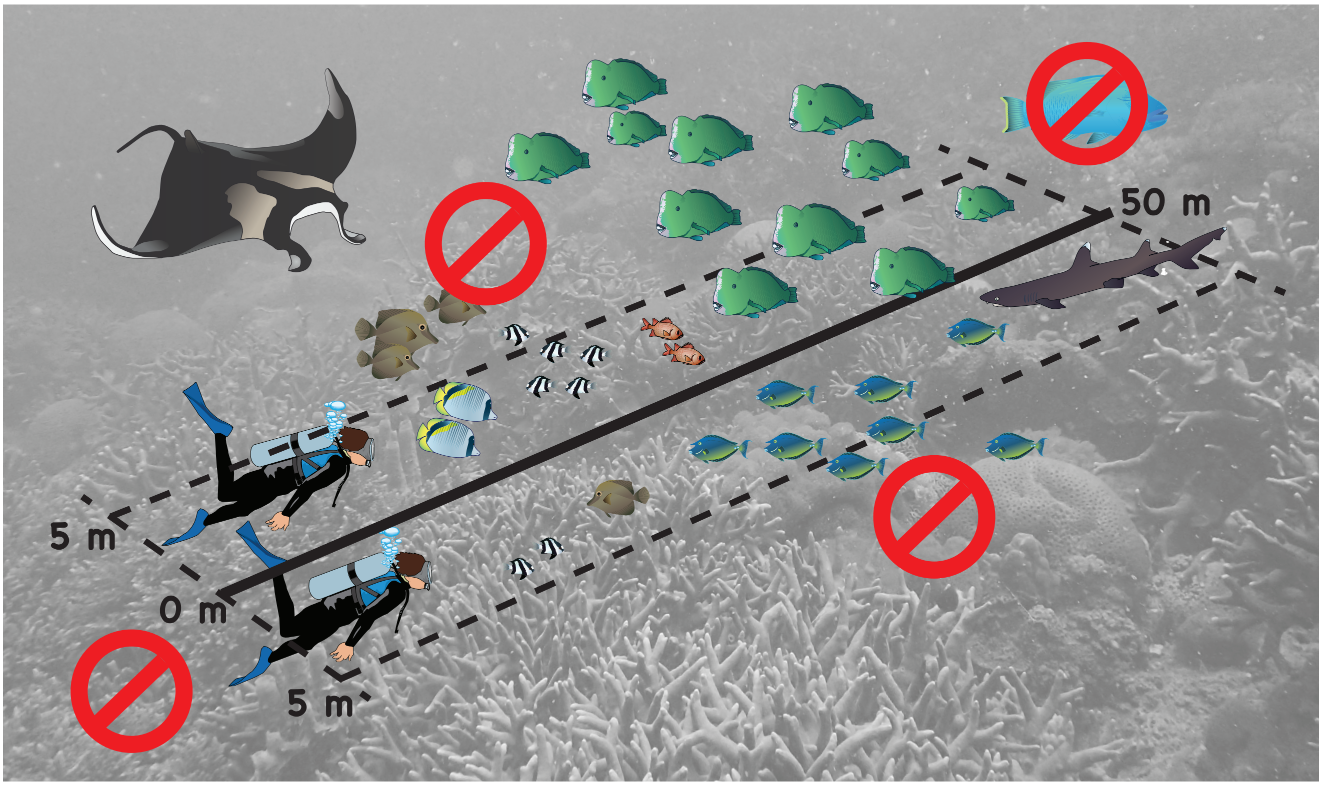


Figure 6. Image of a pair of divers undertaking a fish belt transect survey as part of an Underwater Visual Census (UVC). The bold central line represents a 50 m transect and the dashed lines represent the limits of the area surveyed at 5 m to each side of the transect tape. Symbols from "Integration and Application Network (IAN), The University of Maryland Centre for Environmental Science, https://ian.umces.edu".

4.8. Non-baited remote underwater video

Setting up a non-baited video camera to survey marine creatures in a specific location is a method that can be used to describe fish diversity, relative spatial abundance between sites, and relative temporal abundance between times or seasons. The method is useful for describing fauna use of sites (e.g. cleaning stations, channels) or times of presence and aggregation (e.g. manta rays, sharks, spawning events), which can make it appealing to SCUBA diving operators. The method does not disturb the fish community behaviour in the same way that the presence of a diver, snorkeler and even a boat can. Unlike baited videos the observations are not biased towards predators. The method can allow for longer observations at a single site, for example several hours according to battery power and storage space on the camera, which is suitable for rare organisms. This is an advantage over observations made by a person who is limited in the time they can spend SCUBA diving or snorkelling.

One or multiple video cameras can be deployed at a site by people with basic training in how to use a camera, how to use a GPS device to record the location and how to attach the camera at a survey site so it is not lost. A dive or swim is necessary to deploy the camera and to retrieve the camera, or this may even be deployed from a boat and marked with a float for retrieval. Because deployment and retrieval are relatively quick tasks the method can be used at greater depths than visual survey which require more time using SCUBA. Imagery can be analysed without specialised software and enable careful consultation of taxonomic guides to identify organisms. The method is appealing for popular recreational dive sites as it can engage recreational divers in the surveys and can gain insight that helps plan dives for greater chances of wildlife encounters.

Ideally observations are replicated, and simultaneous deployment of cameras at different sites is ideal because it minimises differences in the data caused by environmental variation associated with factors such as tides, daylight intensity, temperature and the stage of the lunar cycle. It is best to link the method to a sampling design that complements other survey methods (e.g. benthic PIT and fish belt transects) and covers an area representatively. Sites would best include a variety of management regimes and not only tourist dive sites.

Similar to photo-quadrats the method generates a permanent record that allows for more time to be taken to identify and count organisms, as well as allows images to be revisited to survey organisms that were not an original focus. This can create opportunities for intern projects to be defined without dependency on fieldwork or to be undertaken remotely. The method may also improve confidence in the quality of data by allowing multiple observers to verify each other's work and standardise observations.

The video may partially include the substrate for reference, however a 360 image of the habitat should be collected when deploying the camera so that this can also be used to assess habitat state and at least quantitatively describe changes over time. The video imagery of a site can also be used for presentations and communication material (e.g. social media). There are disadvantages to the method. The method does not enable a quantitative estimate of biomass per unit area (e.g. kg/ha), unlike the visual belt transects, because it is hard to define the area surveyed in an image. Fish that swim in and out of frame can be repeatedly captured in the images. The method does not allow accurate estimation of fish sizes (unless stereo images and dedicated software are used). Therefore this method is best combined with visual belt transects. Theft or accidental removal of equipment by persons not involved in the monitoring are a risk and so it is best not to visibly mark the location of an unattended camera, and/or to establish agreements with local groups to respect and guard the equipment. The video imagery consumes considerable memory space on hard drives and computers, and also takes considerable time to analyse. Meanwhile, cameras have become less costly and GoPro or similar action cameras may be suitable for surveys to 40 m. Several cameras can be deployed simultaneously which increases the power of monitoring with replicate observations and also reduces variations between observations by standardising environmental variables such as tide, time of day, and temperature.

4.9. Baited-video and stereo-video surveys (BRUVS)

Baited video presents similar characteristics to non-baited video, however is likely to attract larger predator taxa (e.g. grouper, wrasse, sharks), and this is advantageous to survey biota that are rare or present in low densities. Attracting predators may influence the behaviour of other taxa leading them to be under estimated, whilst the predators are overestimated. It is important that the bait used is consistent in quality and quantity to make records comparable between time and place (e.g. 1 kg of sardines or other oily fish). From a safety perspective, baited videos should also be undertaken in remote areas because attracting sharks can pose a risk to people in the water especially if they are unaware of the monitoring activity.

There are some important survey design considerations for conducting surveys with video. To avoid pseudoreplication, baited cameras should not be deployed simultaneously within 500 m of each other so as not to impact the observations of other cameras, repeatedly sample the same organism or overlap the sampled areas. It is also advisable to standardise the approach used to other regional and global efforts to make the results more comparable, and protocols such as those used by Global FinPrint should be consulted (https://globalfinprint.org/about/_assets/global-finprint-basic-bruvs-protocol.pdf).

Stereo video increases the quality of data relative to single camera recordings by making it possible to later analyse the videos with specialised software to measure the size of organisms (e.g. fish, sharks, whales). Therefore stereo data can be used to describe the size class frequency and demography of populations. The disadvantage is that analysis of stereo videos is time consuming, requires prior calibrations exercises, requires specialised software and requires training. Analysing a 1 hour video for megafauna such as sharks and rays may require approximately 2 hours of post fieldwork time. Seeking to identify and measure all fish present in a 1 hour video is more likely to take up to 8 hours depending on the abundance of organisms.

4.10. Forestry methods relevant to mangroves

Point Centred Quarters Method to survey mangroves

This sampling method is a distance based method used for mangrove surveys and described in detail in Cintrón and Novelli (1984). Sample points are located randomly along a transect line. At the sampling point four quarters are established by crossing the compass direction of the transect line with a perpendicular line (Figure 8). Measure the distance from the sampling point to the midpoint of the nearest tree in each quadrant and then calculate the average of the four distances, which estimates the square root of the mean area per tree. The total stem density is obtained by dividing the mean area per individual into the unit area on which density is to be expressed.

The accuracy of the method increases with the number of sampling points and a minimum of twenty points is recommended. A biased result will be obtained if tree measurements are made to the bark surface rather than to the center of the trunk. There are two limitations to the method that may cause problems. First, there must be a tree located in each quarter. Second, a tree must not be measured twice. Most often this is problematic in widely space stands. The method is useful for measuring species occurrence, density, basal area and frequency.

Diameter at breast height (DBH)

The measurement of tree diameters is a simple method to characterize the diversity of a stand. The diameter of a tree is closely related to stand development, and it is easy to convert diameter to another metric, basal area, which is the area occupied by the tree stems. It is also possible to predict other stand characteristics such as height, crown diameter and biomass from stem diameter. By convention, tree diameter is always measured at 1.3 m above ground level and this measurement is referred to as diameter at breast-height (DBH). In mangrove stands the measurement is made outside the bark and therefore includes the thickness of the bark unless otherwise specified.

The girth or circumference of the tree can be measured with any tape. The circumference measurements are converted to diameter by dividing by π (3.14), or a specialized forestry measuring tape with marking intervals of 3.14 units can be used. This is based on the mathematical relationship between the circumference of a circle and its diameter (circumference = π x diameter). If tree stems deviate from circular in cross section it is preferable to measure the diameter with a tree caliper, taking 'true' diameter as the average of the long and short axes. It is important to take care that when wrapping a tape round the stem of a tree this is level and stretched firmly against the trunk.

The shape and growth forms of mangrove trees sometimes complicate where to measure the diameter. If a stem forks below breast height, or sprouts from a single base close to the ground or above it, measure each branch as a separate stem. If the stem forks at breast height or slightly above, measure the diameter at breast height or just below the swelling caused by the fork. If the stem has prop roots or a fluted lower trunk, measure the diameter above these. If the stem has swellings, branches or abnormalities at the point of measurement, take the diameter slightly above or below the irregularity where it stops affecting normal form.

Basal area

Basal area is the space covered by a tree stem and by convention is the cross section of a stem at the point where DBH is measured. Basal area is a good measure of overall stand development and can be related to wood volume and biomass. The basal area of a stand is the sum of the individual basal areas of all trees greater than a certain diameter per unit ground area and is usually expressed as m^2 per hectare, for tree diameters of ≥ 2.5 cm, ≥ 5 cm or ≥ 10 cm.

The basal area (g) can be expressed in m^2 as a function of DBH measured in centimetres using the following formula: $g(m^2) = 0.00007854\ DBH^2$. The basal area of a stand is estimated by adding the basal area of all the trees larger than a specified size in a given area, usually extrapolated from subsampling a marked plot of known area.

Stand density

The density of a stand is the number of stems greater than a given diameter per unit area. To measure density, define a plot of known area (e.g. 10 m × 10 m) that does not include different habitat types (e.g. dry and wet substrates) and count all the trees within it. Growth forms of trees can complicate decisions of what to include, and Cintrón and Novelli (1984) recommend counting all branches formed below breast height as individual stems, or trees and when measuring species that coppice like *Avicennia* or *Laguncularia* to record the number of clusters and the mean number of stems per cluster as well as the total stem number.

Tree height

Tree height is the vertical distance between the ground and the tip of the tree crown. Tree height can be gained using a clinometer to measure the angle to the top of the tree, from a known distance and calculating height based on trigonometric relations. An optical range finder, or if trees are relatively small (e.g. < 6 m tall) a graduated pole can also be used to gain instantaneous measurements with no need to undertake calculations. The height of the observers eye must be added to the calculated tree height when using a clinometer or rangefinder. Both clinometer and rangefinder-based height measurements assume that the observer and tree are on level ground.

Canopy transparency

Canopy transparency is assessed by examining the tree canopy vertically from below, identifying where branches support foliage, and then assessing the amount of light transmission through that foliage (Day et al. 2018). Canopy transparency should be assessed at 10 randomly selected points within each monitoring plot. To indirectly measure of the cover of leaves in the canopy we measure light penetration through the canopy. The method is quick and the light can be measured quantitatively with light detecting instruments or qualitatively by visual observation using a reference card for relative transparency (Figure 1). Branches without foliage may still intercept light but should not be included in the rating (i.e., a fully defoliated tree has a 100% transparency).

Figure 7. Reference images for canopy transparency with three examples of 5 %, 15 %, 25 %, 35 %, 45 %, 55 %, 65 %, 75 %, 85 %, 95 % from left to right. Darkened areas represent tree canopy and white areas represent visible sky.

Healthy mangroves have green leaves all year round, and the loss of leaves can be a sign of stress. Loss of leaf cover from chronic stress must be distinguished from sudden defoliation caused by storms, especially hurricanes or acute freeze damage, and prior knowledge of such events is important.

Soil sampling procedures

Soil core samples are a standard approach to taking samples from mangrove soil (UNU-INWEH 2013). A half-arc soil sampler with a known diameter should be used to collect a core of approximately 1 m length. A clean soil sampler is inserted vertically into a section of mangrove soil to be sampled, and then rotated to cut the core free. The soil core should be at least 80 cm long and is separated into sub-samples for soil depths of 0-15 cm, 15–30 cm, 30-50 cm and 50-100 cm. From these sub-samples the central 5 cm from each sub-sample is collected for analysis of bulk density, organic content and carbon content. It is important to cut the samples cleanly and perpendicular to the core to enable accurate estimates. Further details for soil sampling procedures can be found in UNU-INWEH (2013) and Cintrón and Novelli (1984).

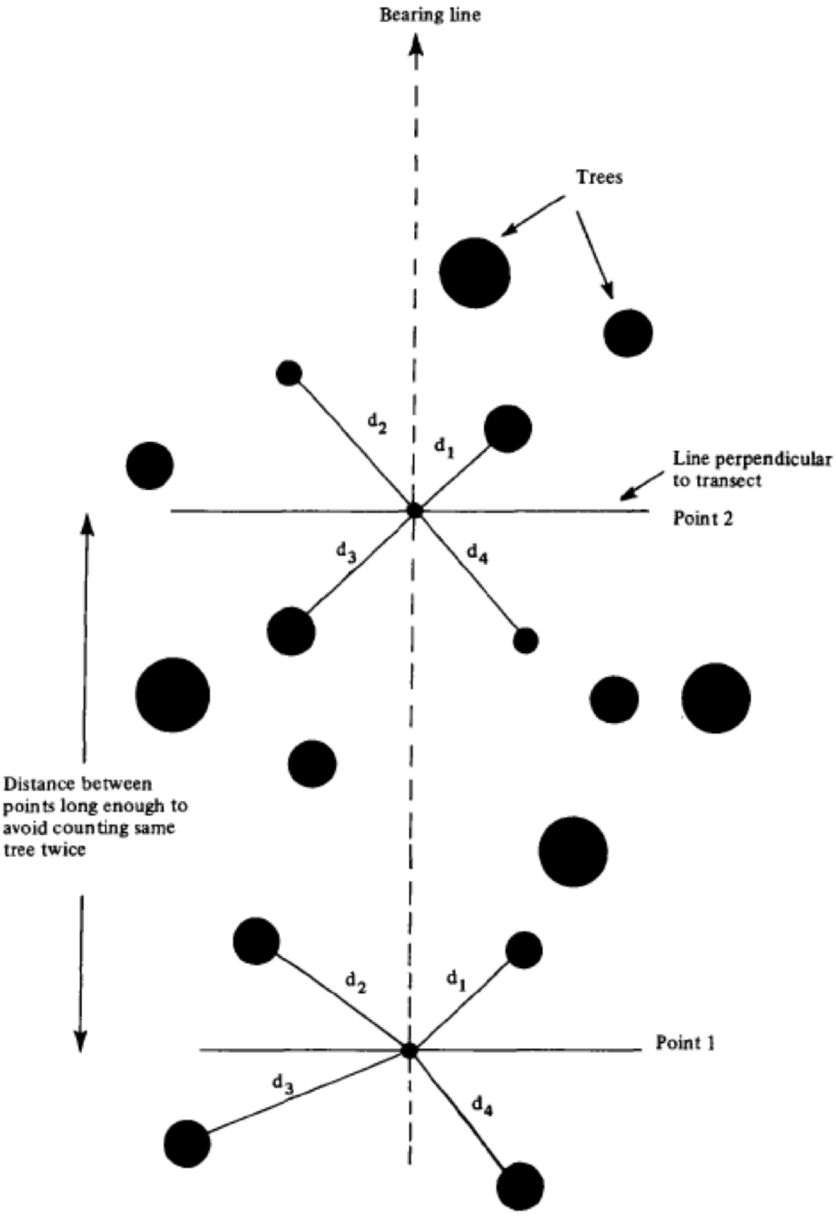


Figure 8. The Point-Centred Quarter Method adapted from Cintrón and Novelli (1984). Measure the distance from each point to the nearest trees in each of four quarters. The area around each random sampling point is defined into four quarters with a line perpendicular to the transect line (dashed line). The sampling points should be separated by a distance that the same prevents trees being recorded twice.

4.11. Methods for description of environmental parameters

Temperature

The temperature of a marine habitat can be recorded continuously with loggers deployed at sites and depths of interest to match observation of organisms such as corals. These provide a more accurate measurement of local temperatures than can be gained from averaged sea surface temperature measurements made available by for example BleachWatch and NOAA. Loggers require a diver to deploy them and should be firmly attached and protected from wildlife, and also disguised so that other people do not remove these. Loggers can record information for timeframes longer than a year. The temperature information may be useful for understanding coral bleaching or behaviour or presence of megafauna and fish. Requirements are loggers, software for downloading data and a coupler to connect the loggers to a computer. Basic training will suffice to download the data. Interpretation and presentation of the data will require data handling and graphing software (e.g. R, MsExcel) if it is desirable to represent the results in different ways to the logger software. Suggested loggers are HOBO Water Temperature Pro v2 Data Loggers. When set to record water temperature every 30 minutes the memory and battery will last over 12 months. The location and depth at which each temperature logger is deployed at should be recorded along with site maps and photos to make them easier to find. The cost per logger is approximately USD$130 and replication at as many sites as possible is advisable. The software license costs approximately USD$100 and a coupler is approximately USD$250. These loggers are reliable and durable.

Temperature should be graphed in a way that identifies seasonal variation and regional thresholds. A useful format for monitoring of coral reef habitats and other tropical marine environments is the format used by NOAAs Coral Reef Watch program to highlight coral bleaching stresses and thresholds (Figure 9).

Irradiance

Light intensity can also be measured throughout the year with loggers. However, loggers used for light must be maintained on a regular basis to remove fouling by algae and other marine organisms or sediments. This may be as frequently as each week in seasons of high algal growth rates. The loggers also require basic software and coupling devices to transfer data to a computer. Hobo also make a variety of irradiance or relative light level loggers. Costs vary and can be explored if this information is desirable.

Turbidity and Sediment

Turbidity and sediment levels are an important environmental parameter because they impact light reaching the substrate, and can be detrimental to the settlement of marine organisms or smother established organisms. Estimating visibility with a secchi disk is a simple method to measure vertical visibility as a

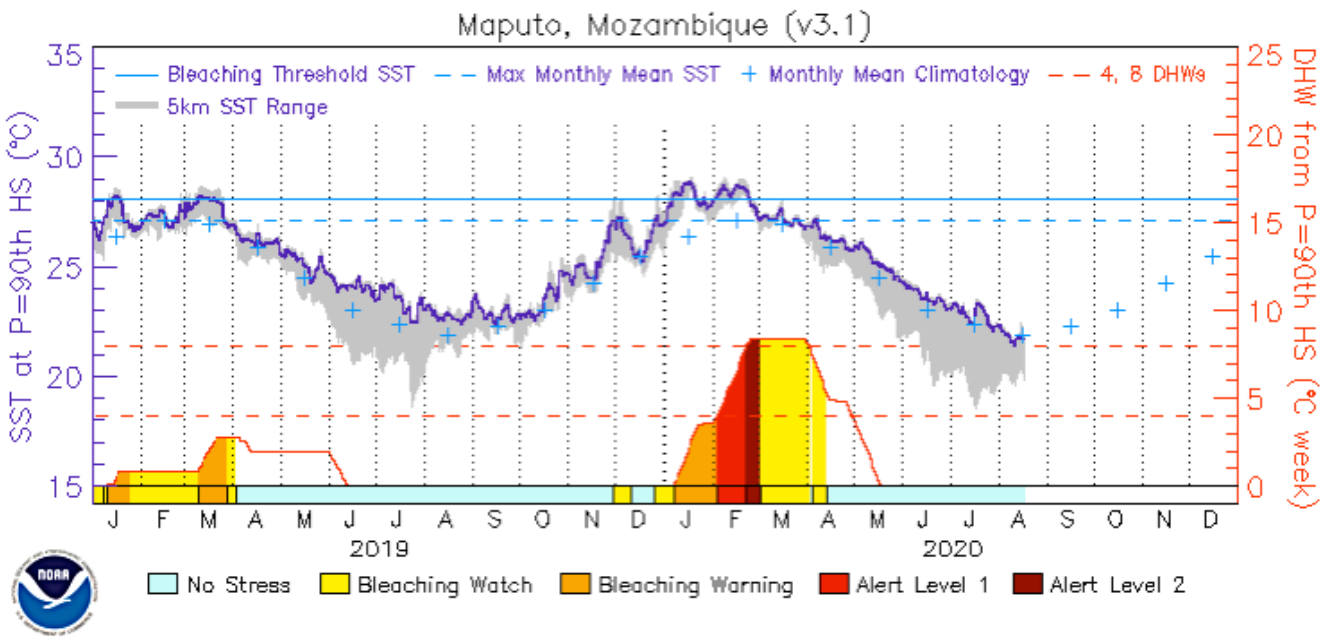


Figure 9. Coral Reef Watch data for Maputo, Mozambique between January 2019 and August 2020.

proxy for turbidity and can also be used as a proxy for phytoplankton abundance. A secchi disk is lowered from a boat at the site using a rope with marks for each metre of length. The observer in the boat notes the depth at which the distinction between black and white surfaces on the disk becomes unclear and this is the visibility. Disadvantages of using a secchi disk include the cumbersome nature of keeping these in a small boat along with other equipment (e.g. SCUBA cylinders), however it is a simple and reliable method.

It is possible, but more complicated, to measure rates of sediment deposition with sediment traps. Sediment traps can be simple in their design, for example an upward facing tube closed at the lower end is often used. However these require routine collection to retrieve the sediments that settle. Measuring sediments requires accurate scales and preservations techniques, such as using drying ovens, to standardise quantification of sediment that settles. Accurate use of sediment traps can also be complicated by activity of biota that attempt to nest in the traps and remove the sediments (e.g. coral dwelling fish).

Salinity

The salinity of water samples can be measures with a refractometer with minimal training needed. A drop of seawater is placed on the prism of the refractometer and visually assessed for the salinity level against a scale that illuminates according to the salinity level. Samples must be measured soon after collection and must not be contaminated during collection (e.g with fresh water or other samples). The procedure is simple and reliable.

Rugosity and reef complexity

Rugosity is a measure of reef complexity frequently measured with a chain of known length that a SCUBA diver lays fitted to the contours of the substrate along the line of a taught transect tape. The shorter the distance the chain extends along the transect tape the greater the reef rugosity.

Reef complexity can also be estimated quantitatively with visual categorisation of reef complexity. Macro-complexity can be classified at a site wide level by noting the overall structure of each site at intervals of no more than 5 m along each transect (e.g. PIT or fish belt transect) and classifying the overall structure of a site according to 6 categories (Figure 9). Micro-complexity may be described at every point of observation along a PIT transect with reference to 5 point scale (Table 11) (Wilson, Graham, and Polunin 2007).

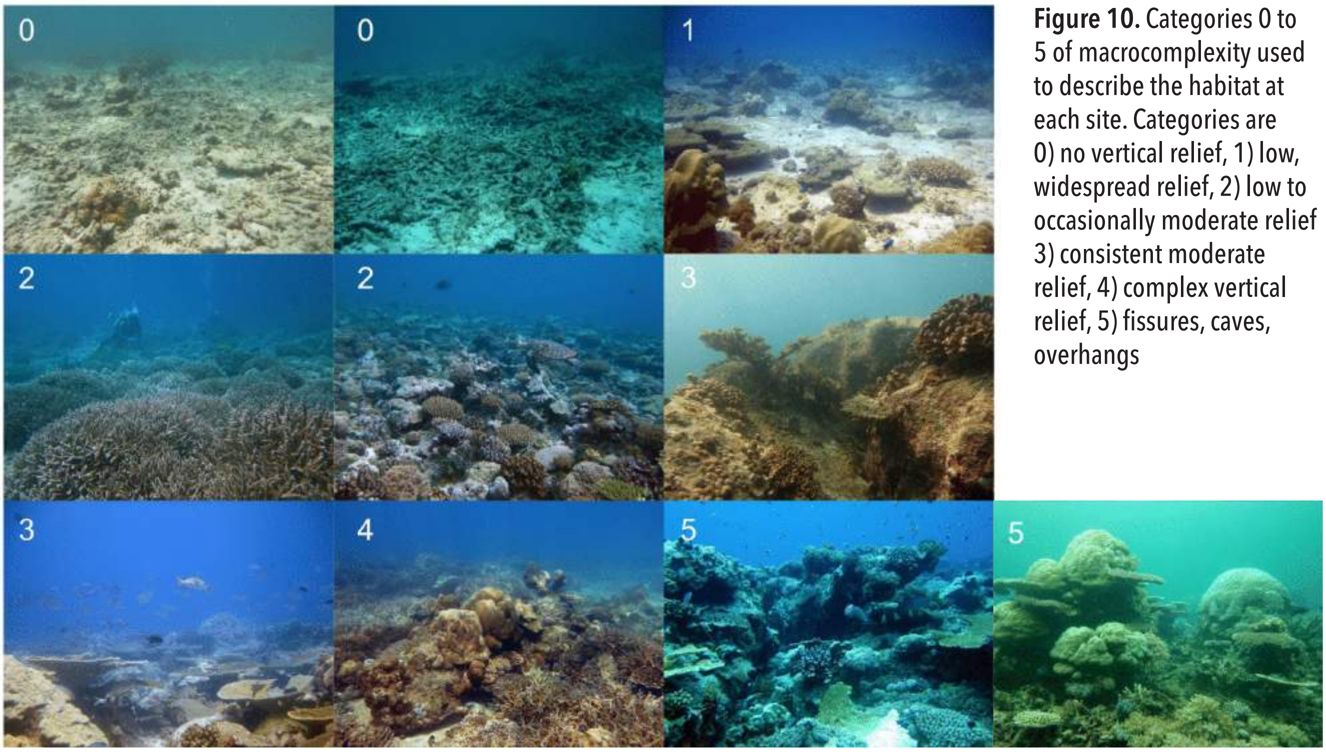


Figure 10. Categories 0 to 5 of macrocomplexity used to describe the habitat at each site. Categories are 0) no vertical relief, 1) low, widespread relief, 2) low to occasionally moderate relief 3) consistent moderate relief, 4) complex vertical relief, 5) fissures, caves, overhangs

Table 11. Categories of microcomplexity used to describe point along each PIT.

Microcomplexity	Category
Totally flat (e.g. sand)	1
Rubble; small patches; minimal relief	2
Mounding; medium structure	3
Sub-massive or coarse branching	4
Branching, complex and crevices	5

4.12. Fisheries monitoring and food security

Monitoring of fisheries provides some insight to the relative abundance of fish and identifies human impacted species, therefore it can inform management and conservation decisions that are relevant to community livelihoods. Fisheries monitoring usually aims to provide information of the catch per unit of fishing effort (CPUE), such as kilograms of fish per hour fishing per fisherman. It is suggested as a complementary monitoring activity to the actual monitoring of marine communities and is an activity that can engage the local community and also facilitate awareness raising exercises and community feedback sessions. However, fisheries monitoring is distinct from *in situ* monitoring of organisms and does not provide direct insight to ecological status of communities and sites.

For a CPUE monitoring program to be effective it is advised that trained observers are employed to routinely (e.g. weekly) monitor fishers catches and build a rapport with the fisher community. It is key that records are obtained consistently so that seasonal and temporal trends are described accurately. It is important to correctly identify fishing gears, separate the catch from each fishing gear, and the identify time spent fishing with each gear. The best results will be obtained when exact locations of fishing are known, for example by recording locations by GPS trackers placed on the fishing boats. It may also be most efficient and effective to focus on key fish taxa that are targeted by local fisheries, important to local livelihoods, and of relevance to habitats of interest (e.g. coral reefs). Alternatively more effort will be required to describe the entire local fishery and identify impacted taxa. This may be a component of monitoring best undertaken in collaboration with local fisheries authorities such as the IIP, a government institute that undertakes this type of monitoring on a yearly basis.

Information for a CPUE monitoring program should be gathered efficiently with a standard questionnaire that the interviewer can administer quickly to fishermen as they return form fishing. The interviewer should confirm key information such as location, time spent fishing, the fishing gear used and the number of fishers with the fishermen. Other information is gathered by observation of the catch such as species and weight of catch. The interviewer is responsible for completing metadata such as date of interview and name of fisherman and a failure to do so can invalidate the effort by omitting important information.

A suggested format for a CPUE questionnaire used in the WIO region by WCS is presented in Appendix 3. The initial section requests metadata such as the date, time, village, name of the interviewer and name of the fisher(s), gender of the fisher(s), number of fishers, whether a boat was used, what habitat was fished, the depth and weather features. The questionnaire then requests information for the five principal catches of the primary fishing gear used by the fisher(s). If more than one fishing gear was used then additional tables should be completed for each one. The fishing gear is described and the taxa of fish caught identified. Fish are counted and weighed.

A fisheries monitoring program is labour and time consuming, and will only be successful if supported adequately. It may be necessary to pay interviewers to motivate them to regularly collect information. The community should receive regular feedback regarding the state of the fisheries and a failure to do so can compromise the support for conservation and management of local communities and fishers. The effort to provide regular feedback may require a staff member to dedicate all or a substantial portion of their time to maintaining and reporting on the fisheries monitoring program. Failure in any step of the process can undermine the whole fisheries monitoring program.

The fisheries monitoring program can also be combined with food security and community livelihood surveys. Ideally, an independent socio-economic monitoring plan should be developed with questions that can provide insight to the dependence on marine ecosystems (Cinner et al. 2009). For example: "How often do you or your household eat locally caught fish or seafood that was caught by you or someone in your community?"

Questions should gain insight into food security indicators such as:

Dependence on local fisheries for livelihoods and food security

a) Number of households with fishing as a primary livelihood
b) Number of household members that have an income other than fishing and what proportion of the household income this contributes.
c) Percent of fish that is consumed directly by fishing households
d) Frequency of consumption of local seafood

Short-term (acute) food insecurity – percentage of households that did not have enough to eat in the previous week.

Long-term (chronic) food insecurity – percentage of households that worried they would not have enough food in the previous 12 months

Meal frequency – the typical number of meals consumed by a family during one day.

Diet diversity - using a 24-hour recall, families are asked what foods they have consumed, which are classified into 7 standard food groups (e.g., starchy staples, animal protein, fruits and vegetables, dairy, etc.). Previous studies in Madagascar have shown that simple food group diversity indicators are linked to micronutrient adequacy in children (Moursi et al. 2008; Arimond and Ruel 2004; Arimond et al. 2010).

Protein consumption – The short-term consumption of fish or other proteins can be inferred from a 24-hour diet recall.

5. RECOMMENDED SURVEY METHODS FOR EACH CLASS OF ORGANISMS

For each group of organisms or habitat type we propose core monitoring methods, which we suggest should form the basis of a monitoring program to gather data for key indicator variables. We also recommend complementary methods, which if combined with the suggested core monitoring will provide data that considerably increases the potential to assess the state of an ecosystem or community. For an overall view of the methods applicable to each ecosystem please refer to (Table 12)

5.1. Corals and benthic organisms:

Proposed core monitoring:

- Point Intercept Transects (PIT) or Line Intercept Transects (LIT)
- Photo-quadrats
- Visually assessed quadrats

Complementary monitoring:

- Timed random search observations, preferably with photographic records, from a sites with defined habitat characteristics (e.g. depth, reef zone) can be used to gradually describe the total taxonomic diversity at these sites. It is accepted that the more effort applied to species surveys at a site the more species are likely to be recorded, and therefore it can be useful to quantify the effort by timing the search effort, however the increase in species recorded declines exponentially as effort increases. Photographic records are also useful for training local participants and can be verified by more experienced participants. These observations do not need to be restricted to the precise area where quantitative survey methods are applied such as the immediate vicinity of transects and quadrats.
- Size class measurements in belt transects to provide insight to the demographic structure of a coral community. Measuring the largest diameter of a coral colony and the diameter perpendicular to this provides basic information to estimate the surface area of a coral, and also enables colonies to be differentiated into size related groups that can infer age or reproductive output. This demographic information can provide insight to the recovery potential of a coral community from disturbances.
- General habitat mapping and ground truthing of satellite or aerial images (e.g. Allen Coral Atlas).
- Parallel observations of physical environmental parameters such as temperature, visibility, light intensity, rugosity and habitat complexity are also recommended as they can provide insight to baseline conditions and stresses.

5.2. Fish

Proposed core monitoring:

- Visual belt transects of 50 m × 10 m to monitor fish abundance, diversity and biomass. Observations should be made of fish taxa and size. Identification of taxa can be to family, genera or species according to skill and experience of the observer. Fish size estimates should be to bins of 10 cm or less. The belt transect width can be reduced to 5m if visibility is low or fish abundance is very high, and transect length can be increased to better target rare taxa, but it is advised to keep the size consistent to avoid biases.

Complementary monitoring:

- Non-baited video camera (remote underwater video) to monitor fish diversity and abundance. Stereo imagery may also enable the size class frequency structure of a fish community to be described. If baited cameras are used to describe shark and ray communities then some information, mostly of predator fish, may also be obtained.

In water surveys of fish generally require visibility of at least 5 m. If diving is unsafe, for example at deeper sites, in estuaries or in conditions of low visibility, it may be possible to use non-baited video camera to gather observations of fish diversity and abundance.

5.3. Seagrass and other benthic organisms

Proposed core monitoring

- Quadrats 1 m × 1 m combined with 20 to 50 m transects to guide their placement. Aim to assess diversity and abundance of taxa, seagrass locations, species distribution, seagrass condition, and to identify pressures.
- Photo-quadrats, which can be taken with a drop camera in deeper water or to reduce in water time. Produce similar observations to quadrats, but enable permanent records and allow faster surveys and more time consuming descriptions.

Complementary monitoring

- General habitat mapping and ground truthing of satellite or aerial images (e.g. Allen Coral Atlas).

5.4. Mangrove vegetation

Surveys in mangroves can focus on the vegetation that create the habitat, the biota that inhabit the submerged and lower structure of mangrove habitats, such as fish and crustaceans, or biota present in the non-submerged and upper structures such as birds, reptiles, and insects. There can thus be a variety of survey methods used according to the focus. Here we focus on the vegetation that creates the habitat.

Proposed core monitoring of vegetation:

- Quadrats and/ or belt transects to assess diversity and abundance of taxa, mangrove locations, species zones, mangrove condition, regenerative potential by assessing reproductive propagules and saplings and to identify pressures.
- Photo-quadrats for similar observations to quadrats and photo-quadrats, but which may enable permanent records and allow faster surveys and more timely descriptions.

Complementary monitoring

- General habitat mapping and ground truthing of satellite or aerial images.
- Monitoring of permanent plots to describe community structure, height and diameter of trees, density of seedlings.
- Monitoring of fish communities as described above. The focus may relate to mangrove based fisheries or juveniles of reef fish.

5.5. Megafauna (e.g. sharks, manta rays)

Proposed core monitoring

- Non-baited and baited cameras single or stereo (e.g. Baited Remote Underwater Videos - BRUVS). Baited cameras are useful to record predators, and are useful for rare biota such as sharks because they attract individuals. Non-baited cameras to record species without or with less bias caused by impact on behaviour, and will avoid attracted predators influencing the presence of potential prey. However, greater sampling effort may be required to detect certain taxa (e.g. sharks)
- Cameras can be positioned repeatedly at the same site to identify times animals are present, gain population and demography data (especially if stereo camera systems are used), and to describe patterns related to season, lunar cycle, diurnal cycle or tidal cycle.

Complementary monitoring

- Relatively large belt transects, for example of 500 m × 50 m, can be undertaken to describe the abundance of megafauna by area (e.g. per hectare). Monitoring of biota with low density or that are rare requires larger search areas in surveys to avoid dominance of zero counts in the results.
- Beach surveys, for example using transects, to identify the timing and frequency of turtle nesting.
- Transects to record dugong feeding scars in seagrass habitats as an approach to identifying habitat used by dugongs
- Tagging of key biota (e.g. satellite and acoustic tags) to describe local ranges and migration patterns
- Acoustic monitoring of the activity and presence of marine mammals (e.g. whales, dolphins, dugong).

5.6. Environmental parameters

Knowledge of environmental parameters can be useful to interpret changes in ecological communities and can usually be monitored in parallel to other activities at a site and recorded as metadata for a survey.

Proposed core monitoring:

- Temperature measurements of seawater can provide detailed insight to events at a site, such as the onset of coral bleaching. These can be continuous with the use of relatively affordable loggers that can be visited once a year. Satellite data is a freely available alternative, but is generally only available for the seawater surface and is usually averaged over an area.
- Salinity is also a useful environmental parameter that can be measured routinely with low cost equipment such as a refractometer. This can also provide insight to stresses such as coastal floading and lower salinity.
- Water clarity or visibility is often an environmental parameter that is a useful proxy for biological activity (e.g. to estimate levels of phytoplankton).
- Reef rugosity or reef complexity is frequently correlated with the abundance of reef fish because it relates to the diversity of habitat niches available. It can be measured quantitatively or estimated visually.

5.7. Summary overview of the application of survey methods

Overall the methods described in this guide can often be applied to more than one of the marine and coastal ecosystems and organisms of Mozambique. We have suggested the core and complementary methods above. An overview of the potential application of each

Table 12. Suggested application of each method to monitoring interest in the marine environment. * random walks or timed searches on land or areas where walking is possible (e.g. low tides) may replace swims.

Method	Level of priority	Coral	Macroalgae	Seagrass	Fish	Megafauna	Predatory megafauna	Sand dune vegetation	Mangrove vegetation	Habitat mapping	Questionnaires
Point intercept transects	1	x	x					x	x		
Line Intercept Transects	1	x	x					x	x		
Quadrats	1	x	x					x	x		
Photo-quadrats	1	x	x					x	x		
Benthic belt transects	1	x	x	x				x	x		
Fish belt transects	1				x	x	x				
Random swims and timed swims with photographic records	2	x	x	x	x	x	x	x*	x*		
Manta tows	2	x	x	x	x	x	x			x	
Photo-quadrats drop camera	2	x	x	x						x	
Video non-baited	2				x	x					
Video baited	2				x	x					
Aerial photography/satellite imagery	3	x	x	x				x	x	x	
Satellite and acoustic tags						x	x				x
Acoustic monitoring						x	x				x
Fisheries monitoring											x

Note: Levels of priority for monitoring activities:
1) Should be undertaken regularly (e.g. seasonal fish surveys, CPUE or annual coral surveys),
2) can be undertaken when the opportunity arises, but will best be done repeatedly (e.g. timed swims to describe total site biodiversity),
3) can be undertaken once or at low frequency (e.g. habitat mapping).

6. SURVEY METADATA

One of the most important considerations when collecting monitoring data is to record metadata, data that describes the conditions and circumstances for each site and when it was surveyed. Knowledge of when a site was surveyed enables organisation of datasets and can help understand variation in the results later. For example many motile marine organisms are known to aggregate at specific times of the lunar cycle and surveys at this time might result in relatively high abundance estimates. In the event that depth, tides, time of day or other features are not consistent between monitoring surveys then knowledge of this is valuable to interpret the results. Records of who collected data can also be useful to understand variation between observers, or handle bias errors in data. An initial proposal of the data to record is listed in below (Table 13) and this can be expanded based on knowledge of the ecosystem and community that will be surveyed as well as the specific focus of the monitoring activity.

Table 13. Example table of metadata that should be collected every time a site is surveyed.

Information	Example of record
Survey name:	Coral surveys 2020
Date:	17 January 2020
Time (start):	10:24 am
Time (end):	10:53 am
Observer:	J. Sparrow
Site name:	Tofo site 12
Longitude (Easting/ Degrees, minutes, seconds):	35.556082 (Easting) / 35 ° 33′ 21.8952″ E
Latitude (Northing/Degrees, minutes, seconds):	-23.854643 (Northing) / 23° 51′ 16.7148″ S
GPS Datum:	WGS84
Waypoint name:	Tofo_12
Transect number:	1 of 3 at this site
Transect compass bearing:	Direction to swim at start of transect, 330°
Depth (m):	18
Temperature (°C):	25
Tide state:	Rising
High tide info:	Time nearest high tide: 12:01 pm, High tide height: 3 m 78 cm
Low tide info:	Time nearest low tide: 02:32 am, Low tide height: 1 m 08 cm

7. DATA ENTRY, TIDYING AND INTERPRETATION

It is important to streamline data entry and handling, whilst also ensure quality control of the data. Data entry and handling can be time consuming and tidying data is generally a time consuming activity for a monitoring program. Therefore it is advisable, and cost efficient, to use existing platforms that facilitate data entry, ensure consistency in entry, reduce the data entry errors and reduce the time required to enter and tidy data. These platforms also facilitate comparison with data from other regions or monitoring programs and provide basic tools for visualising and communicating results. This increases the ability to prepare and communicate results within a reasonable timeframe for use in management and conservation decisions. We suggest the data entry platforms Data Mermaid, CoralNet and SeagrassWatch described below. Some methods are not yet catered for in these platforms and will require entry of data to project specific spreadsheets in software such as MsExcel, and these will require post entry identification of mistakes and efforts to tidy data.

Data Mermaid: https://datamermaid.org

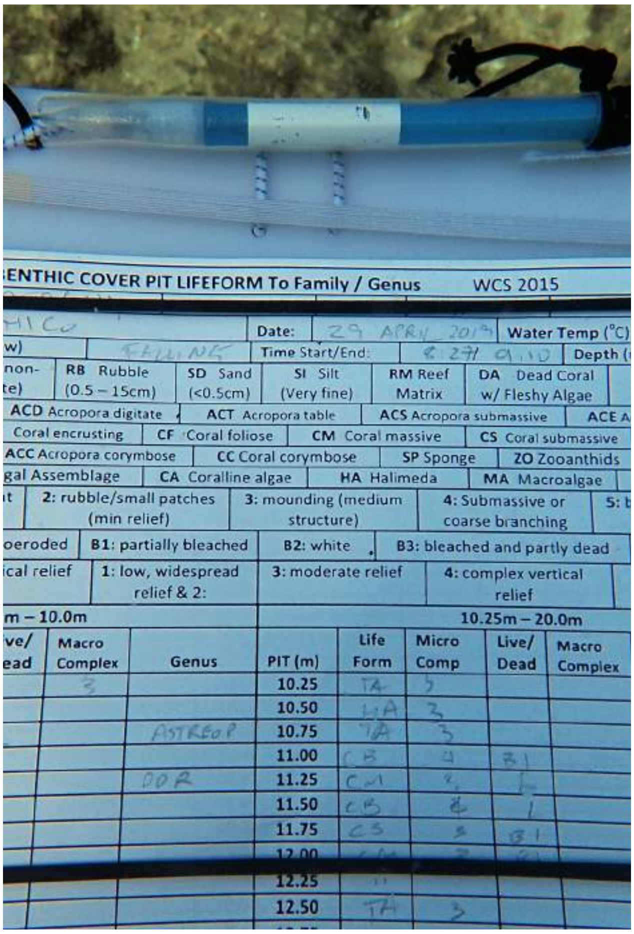
This is a data entry and data tidying platform currently available for fish belt transects, Point Intercept Transect (PIT) data and rapid bleaching assessments data. The platform facilitates data tidying, data back-up and data sharing as well calculation of fish biomass to speed up reporting of results. There is also the benefit of offline use when internet connections are limited and the platform is a free backup of data. The Mermaid platform has been developed with the support of WCS and WWF to facilitate field data entry and is free to users, who have the choice of keeping their data private.

CoralNet: https://coralnet.ucsd.edu

CoralNet is an online platform used for semi-automated description of points in photo-quadrats, and has close ties to CPCe, which is a Windows based software for identifying points in quadrat images. CoralNet also provides a backup for data but can require greater internet access. The platform requires reasonable internet access to upload images and automated identification of points is based on prior identification of a subset of points by an observer. It therefore requires some human effort and is best for general categories such as coral versus sand or macroalgae which are identified most correctly by the automated options. The more human effort in verifying automated point identifications the more detailed analysis can be done, for example to the level of coral genus. Users are required to share their data for the international benefit of coral reef research and conservation.

SeagrassWatch: https://www.seagrasswatch.org

Seagrass watch has been developed by experienced researchers as a standardised global protocol for the training or participants and coordination of seagrass monitoring. Training and monitoring resources are provided and the program is adopted by many NGOs including WCS in the Western Indian Ocean. Data sheets and online data entry platforms are made freely available to trained participants and this increases the ability to ensure data quality, accelerates the application of monitoring data in management and conservation decisions, makes results more widely comparable and overall is a cost efficient way to improve the quality of monitoring data.



8. RESOURCES NEEDED

8.1. Time and financial requirements

Monitoring will require personnel, time and resources allocated to data collection and fieldwork, data entry and analysis, reporting and communication of results. Most fieldwork for monitoring activities will require a team of 3-4 people. For example a boat driver, boat assistant and two scuba divers can undertake in water monitoring in a coral reef or seagrass habitat. An outline of requirements is presented for each habitat in Table 14.

To survey 30 sites once a year, regardless of the habitat, is likely to require 15 days of fieldwork. In most instances it will be possible to survey 2-3 sites during a day of fieldwork depending on the travel required and the specifics of the survey work. Undertaking surveys using SCUBA is limited by dive profiles that are likely to allow each person to undertake 2-3 dives in a day. Transect or quadrat surveys are likely to take longer than deploying and retrieving cameras or loggers. We make suggestions for the timing and frequency of monitoring activities in section 2.3. "Frequency and timing of monitoring activities".

Data entry can often take as long as the data collection activities and should be undertaken during fieldwork. Ideally data should be entered on the same day as it is collected, to optimize the workflow, to identify and to quickly address doubts or errors, and to make it possible to correct or collect any missing information without delay. Photographs or videos should also be saved and organised, and cameras cared for on the same day as fieldwork is undertaken. This will avoid losing data and optimize the equipment care and survey time. For this reason it is important to allocate part of the working day to these tasks.

Data analysis and the preparation of reports and presentations are likely to take weeks to months of dedicated work after fieldwork, depending on the complexity and detail required and the skills and experience of the persons involved. It is advisable for more than one person to undertake data analysis and interpretation to facilitate discussions, checks and identification of errors. It is also advisable for the people who collected the data to be involved as they will greater appreciate the importance of diligence in earlier steps, such as data entry and checks, and can also provide greater familiarity with the data and survey sites. While repetitive monitoring activities, for example yearly surveys, will enable templates and formats for data analysis and reporting to be prepared, which can streamline the analysis and reporting process.

Videos and photographs that require post fieldwork analysis are likely to require several days of analysis to extract data. For example, to survey an hour of video for megafauna is likely to take 2 hours, whilst it is likely to take up to 8 hours to identify fish. Similarly to gain data from photo-quadrat images will take approximately 15 minutes per image for basic observations such as the identification of 20-30 points.

8.2 Personnel and skills

It is possible to engage participants with a variety of skills and experience and with different stakeholder association in monitoring activities, but it is desirable for there to be at least basic instruction to prepare personnel to undertake surveys in a standardised way. The suggested methods differ in the amount of training and experience required to apply them correctly (Table 15), and in environments where communication is easier such as walking on mudflats, reef flats or seagrass at low tide it may be possible for a group coordinator to guide inexperienced participants in surveys. The participant backgrounds will somewhat dictate which methods they can participate in (Table 15), but participants can learn individual skills to change this. It may not be necessary for a participant to hold all skills but these should be available amongst the survey team. It is also possible for individuals to gradually develop their skills and experience so that they can participate more in each of the monitoring activities. We comment on some of the individual skills that are required for monitoring below, and identify what level of each skill is required for each activity in Table 15, then we suggest who may be most appropriate for particular monitoring activities in Table 16.

Specific skills:

- SCUBA – will enable participants to undertake monitoring activities in habitats deeper than 2-3 m such as coral reefs.

- Snorkelling skills – will enable participants to undertake monitoring in shallow water <3 m
- Taxonomic skills: basic identification of types of marine organisms can be learnt in training workshops to enable general surveys (e.g. of coral morphology, seagrass, algae types). More detailed surveys will require more specialised taxonomic identification skills (e.g. coral genera, seagrass species). Training and identification resources can be resourced online and purchased to have physically at hand.
- Use of GPS: Knowledge of how to use a GPS to record the location of a site and to navigate to a site.
- Use of a camera in water: basic photography to obtain standardised images of quality that enables the identification of organisms. Care for equipment used in saltwater environments. Knowledge of procedures to save and analyse images.
- Ecological monitoring procedures: use of quadrats and transects to quantitatively assess the abundance of organisms

8.2.1. How to engage local community members in monitoring activities

It is important to engage local community members in monitoring activities to maximise the likelihood of success and acceptance of resulting management and conservation decisions. It is our belief that local community members possess both local knowledge of the environment and skills that make them valuable participants in monitoring activities. It is important to harness this knowledge and these skills. To do so requires introduction and guidance into the more academic concepts of survey design and ecological survey methods. This can be achieved by means of community presentations and workshops. It is advisable for there to be guidance during surveys from key scientific personnel with greater understanding and experience in ecological survey techniques, and we recommend that these people are also involved in the analysis and reporting of the results. This is an approach that bridges personal worlds and personalises conservation and management efforts. It is highly recommended to also create avenues for personal learning and development, with options for increasing responsibility of community members who may gradually take ownership of monitoring activities and provide greater input to management and conservation discussions. As a starting point we provide some general suggestions for the skills required to apply each method (Table 15) and which methods are most appropriate for each participant (Table 16), however we also encourage flexibility in the application of these recommendations to capture the enthusiasm of participants.

Table 14. Preliminary outline of requirements for monitoring activities

Habitat	Focus	People needed	Days fieldwork	Days data analysis	Days report preparation
Coral reef and benthic community	Coral and benthic community	4	15	15 to 45	15 to 45
	Fish community	2 if combined with benthic surveys, otherwise 4	15	15 to 45	15 to 45
	Megafauna	2 if combined with benthic and fish surveys, otherwise 4	15	15 to 45	15 to 45
Seagrass	Seagrass community	At least 2 if walking at low tide	15	15 to 45	15 to 45
Mangrove	Mangrove vegetation	4	15	15 to 45	15 to 45

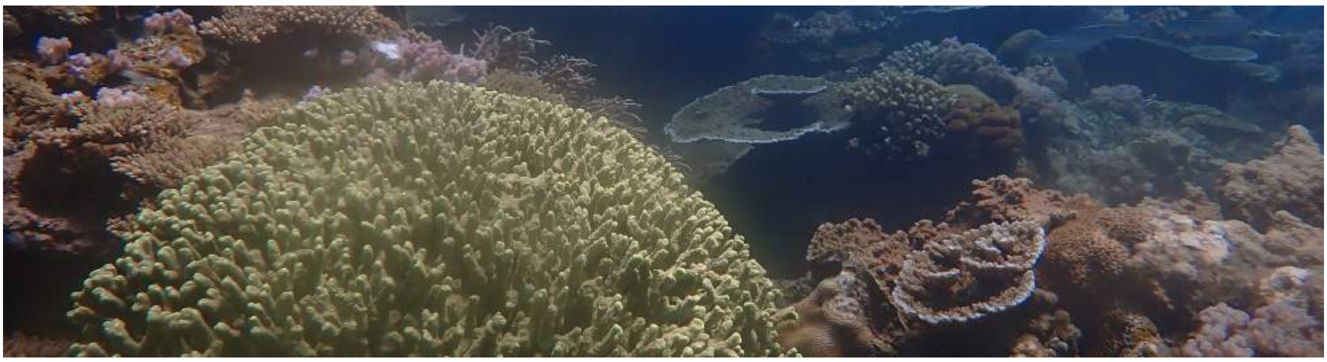


Table 15. Skill requirement and suggested participants for monitoring methods

Method	Skill level				Training	
	Beginner / basic	Some experience/	Experienced / intermediate	Experienced / Advanced	Not necessary	Necessary
Point intercept transects	x	x	x	x		x
Line intercept transectsx	x	x	x		x	
Quadrats		x	x	x		x
Photo-quadrats divers/snorkelers	x	x	x	x		x
Belt transects	x	x	x	x		x
Random swims, timed swims and photographic records	x	x	x	x		x
Photo-quadrats drop camera	x	x	x	x		x
Video – non baited	x	x	x			x
Video baited		x	x			x
Aerial photography/satellite imagery	x	x	x	x		x
Community questionnaires	x	x	x	x	x	x

Table 16. Suggested appropriateness of methods for participants of different backgrounds

Method	Local community	Local fishers	Tourist snorkelers	Tourist divers	Local NGO staff	Scientific interns	Experienced scientists
Point intercept transects	x				x	x	x
Line intercept transect	x					x	x
Quadrats	x		x	x	x	x	x
Photo-quadrats divers/snorkelers			x	x	x	x	x
Benthic belt transects	x				x	x	x
Fish belt transects					x	x	x
Random swims and timed swims with photographic records	x	x	x	x	x	x	x
Manta tows					x	x	x
Photo-quadrats drop camera					x	x	x
Video – non baited			x	x	x	x	x
Video baited					x	x	x
Aerial photography/satellite imagery					x	x	x
Fisheries monitoring	x				x		

9. DATA ANALYSIS, INTERPRETATION & PRESENTATION OF RESULTS

Each monitoring activity will generate data that must be analysed and interpreted before preparing reports and other communications. The stepwise process will require:

a) Data to be entered, checked and tidied
b) Descriptive and exploratory analysis through graphs, tables and summary statistics (e.g. averages, estimates of variation)
c) Statistical analysis to determine the significance of results
d) Description and communication of the most relevant findings

Data to be entered, checked and tidied

Data entry, checks and tidying are frequently given less attention than merited, but if the quality of the data is not assured and errors are introduced then this can reduce the value, and in worse case scenarios invalidate the entire monitoring effort. Data entry should be undertaken by the persons collecting the data and should be done as soon as possible, with the ideal situation being that data is entered on the day it is collected. Data entry should be considered an essential part of fieldwork. This way the data is entered for each site as fieldwork progresses and at the end of fieldwork there are less delays in starting to explore the results, and there is less chance of errors in data entry. Information such as site conditions and descriptions are often missing on fieldwork data sheets, whilst infrequently observed taxa may be incorrectly identified or described with notes, and a daily data entry and checks approach gives the monitoring team a chance to detect these issues, fill in the gaps, and adapt performance in subsequent efforts.

The entered data, including the metadata, should be checked by a second person even when a data entry platform is used. It is common to introduce errors during the data entry stage. Data must also be backed up, which is an advantage of using the data entry platforms recommended in section 7. Alternatively, hard drives can be used to store the data but these should be replicated and should not all be kept in a single locations where they could be simultaneously lost or damaged (e.g. fire, flood, theft). Suggestions are made for the use of data entry platforms and MsExcel spreadsheets (Table 17).

Descriptive and exploratory analysis through graphs, tables and summary statistics

The data can be explored with graphs and general descriptions once it has been entered. Visualisation of the data will rely on graphs and tables and several iterations are likely in the initial stages to identify the approaches that best communicate the results. This process will be simplified as monitoring programs repeat the process, preferred formats are identified, and templates are created. A simple approach is to used software such as Microsoft Excel, Google Sheets or Numbers (apple), which all provide basic descriptive statistical tools and graph options. Commercially available alternatives include dedicated statistical software such as SPSS or SAS-JMP, but yearly licences can be costly (in excess of USD$1000 per year). The recommended approach is to use R, a freely available programming language developed by statisticians to analyse and visualise data. Using R is challenging and requires training and experience, however learning resources are freely available online and R enables analysis scripts to be prepared for repeated use or sharing, which allows more experienced users to support others. The most likely R packages for descriptive and exploratory analysis are included in the package family "tidyverse", which includes the package "dplyr" for tidying data and producing summary statistics, and the package "ggplot" for visualising data as graphs and maps (Table 17). It is recommended this step be undertaken by experienced scientific personnel, or supervised junior scientific staff and interns.

Statistical analysis to determine the significance of results

The statistical analysis of the data strengthens the interpretation of results and their credibility in publications. Statistical tests take data interpretation beyond the speculative interpretation of summary results and visual interpretation of graphs, and can extract more subtle relations in data and strengthen confidence in interpretations. Again R is the recommended platform for this given it is freely available and developed for this purpose. The specific statistical tests will differ according to the specific monitoring data and a variety of options are freely available in packages such as "lmer" for single response variables, and in "vegan" for multivariate community ecology analysis (Table 17). Commercially available software may also be used such as SPSS, SAS-JMP or Primer for analysis of multivariate data (www.primer-e.com; software licenses are approximately USD$1000 and training, which can be done online when workshops are running, is recommended at further cost). Some statistical analysis tools are also available in Microsoft Excel. It is recommended that the data analysis step is undertaken by more experienced scientific staff with training and experience in the analysis of ecological data as well as broad awareness of the monitoring program. Consultation with or engagement of a statistician in the process may improve the quality and efficiency of any analysis undertaken.

Description and communication of the most relevant findings

The final step is to identify the findings of most interest and relevance to the stakeholders. These results should be framed in a comparative context to other regions and highlight unique local features of the results. The implications for conservation and management actions should also be highlighted and if more data is required to explain or gain insight to trends, then the monitoring program should be adapted accordingly. It is also recommended that this step is undertaken by more experienced scientific staff and project managers with broad awareness of the program goals. However, discussions with environmental managers and policy makers can identify value in results. Communicating the results to local communities and decision makers (local, provincial and national authorities) is a key part of connecting environmental monitoring with management and conservation decisions. This usually requires an integrated approach, where all stakeholders are involved, or at least have the opportunity to participate, in the whole process from planning surveys to deciding on conservation measures in response to the results. Failure to implement this approach might result in absence of buy-in from stakeholders and cause a project to fail. Technical and scientific reports can be confusing to people with different backgrounds and it is important to communicate results in language and formats that can be understood by the various stakeholders. Sessions with the communities using a participative approach, exhibitions, workshops, webinars, leaflets, flyers, brochures, posters, outdoor panels, popular and scientific peer reviewed articles, small books, photos, videos, social media, WhatsApp groups, radio interviews and talk shows, TV and policy briefs are some of the tools that can be used to communicate the results.

Table 17. Steps in handling data collected and its preparation for reports. References to R provide suggested packages in brackets. * Options for statistical procedures include mixed effects models, generalised linear mixed models, ordination techniques and cluster analysis but must be selected with specific knowledge of the data.

Data type	Data Entry	Data tidying	Data Visualisation	Data Analysis	Who can perform
Corals and other benthic organisms	Mermaid, MsExcel, CoralNet	Mermaid, R ("tidyverse")	R ("ggplot"), Mermaid	R ("lmer", "vegan") MsExcel, SPSS, SAS-JMP CoralNet, CPCe	Skilled personnel, ecologists, statisticians
Fish data	Mermaid, MsExcel	Mermaid, R packages: "tidyverse"	Mermaid, R packages: ggplot	R ("lmer", "vegan"), MsExcel, SPSS, SAS-JMP *	Skilled personnel, ecologists, statisticians
Seagrass	SeagrassWatch, MsExcel	SeagrassWatch, R packages: "tidyverse"	SeagrassWatch, R packages: ggplot,	R ("lmer", "vegan") MsExcel, SPSS, SAS-JMP *	Skilled personnel, ecologists, statisticians
Mangroves	MsExcel	R packages: "tidyverse"	R packages: ggplot,	R ("lmer", "vegan") MsExcel, SPSS, SAS-JMP *	Skilled personnel, ecologists, statisticians
Megafauna	MsExcel, Eventmeasure (BRUVs software from SeaGIS)	R packages: "tidyverse"	R packages: ggplot,	R ("lmer", "vegan") MsExcel, SPSS, SAS-JMP *	Skilled personnel, ecologists, statisticians
Fisheries monitoring	KoboToolbox, MsExcel	KoboToolbox , R packages: "tidyverse"	R packages: ggplot,	R ("lmer", "vegan") MsExcel, SPSS, SAS-JMP *	Skilled personnel, ecologists, statisticians

10. THRESHOLDS AND BENCHMARKS

The recommendation and use of benchmarks and thresholds that can be used as targets against which to assess the performance of a marine ecosystem should be undertaken with caution. These should always be based upon scientific research and expert opinion and avoid a narrow focus (e.g. a single threat). It is also important to consider adapting the application of thresholds to local circumstances (e.g. fishing pressure) because threats and interventions will be unique to different places. The emphasis should be on outcomes that increase the function and health of an ecosystem (McLeod et al 2019), and this should be assessed against trajectories described with adequate monitoring data. Here we list some thresholds and benchmarks for coral reef habitats currently used by the WCS Global Marine Programme.

WCS scientists consider a percentage cover of hard coral cover of 30 %, to be the desired conservation threshold to sustain biodiversity and fisheries on a coral reef (Wildlife Conservation Society 2020). However, it is important to appreciate that general recommendations for coral reefs are unlikely to be appropriate to all coral reefs, especially coral communities that are atypical or in marginal habitats (e.g. high latitudes or mesophotic reefs). In general, a minimum percentage cover of hard corals of 10 % is considered the threshold for shallow reefs to accrete at a faster rate than the rate at which they erode (Perry et al. 2013). A percentage cover of hard corals of 50 % is considered necessary for the balance of reef accretion and erosion to enable shallow reefs to keep up with sea level rise associated with Representative Concentration Pathway of RCP 4.5 (Perry et al. 2018, IPCC 2013). Whilst, a hard coral cover of 70 % or more is considered necessary for the balance of reef accretion and erosion to enable shallow reefs to withstand an average sea level rise of 0.5 m which predicted for the Western Indian Ocean by 2100 under RCP 8.5 (IPCC 2013, Perry et al. 2018) (Table 18).

WCS scientists recommend that a reef fish biomass of at least 500-600 kg/ha is needed to maintain fisheries productivity, ecosystem function and biodiversity (Wildlife Conservation Society 2020). Benchmarks for fish biomass at reef sites of the East African coast, including Mozambique, are proposed as 1150 kg/ha for desirable conservation outcomes, 600 kg/ha, to maintain diversity in fish communities, and 450 kg/ha to allow for artisanal fishing to be sustainable (McClanahan et al. 2011, 2015, McClanahan 2018) (Table 19).

Table 18. Thresholds and benchmarks for coral reef habitats currently used by the WCS Global Marine Programme for the indicator Hard Coral Cover.

Threshold	Benchmark
10% Hard Coral Cover	Shallow reef accretion to exceed the rate of erosion.
50% Hard Coral Cover	The balance of reef accretion and erosion enables shallow reefs to keep up with sea level rise associated with RCP 4.5.
70% Hard Coral Cover	The balance of reef accretion and erosion to enable shallow reefs to withstand an average sea level rise of 0.5 m which predicted for the Western Indian Ocean by 2100 under RCP 8.5.

Table 19. Thresholds and benchmarks for coral reef habitats currently used by the WCS Global Marine Programme for the indicator Reef Fish Biomass.

Threshold	Benchmark
450 kg/ha of fish biomass	Minimal biomass for sustainable artisanal fisheries.
600 kg/ha of fish biomass	Minimal biomass to maintain diversity in fish communities.
1150 kg/ha of fish biomass	Minimal biomass to achieve desirable conservation outcomes.

11. AUTHORIZATIONS AND LICENSING

Ecological monitoring and surveys qualify as a form of scientific and social investigation and are therefore governed by specific laws and regulations within Mozambique. Appropriate authorizations and permits should be obtained from the concerned authorities before data is collected or steps are taken to implement a monitoring plan.

This section provides an overview of the relevant legislation in force and the basic steps to be taken in order to obtain permits. This is not a comprehensive description of the legal process, but rather an initial indication of the steps to take. The full regulations should be consulted with regards to each specific purpose and checked regularly for updates and amendments throughout the life of any project.

There are two legal documents which guide scientific marine research in Mozambique:

- The Sea Law (Law 20/2019 of 8 November) presents a specific section on scientific marine research, providing the overall guidance on this topic. According to this law, marine scientific research comprises the set of works, carried out for purely scientific purposes. It is the responsibility of the Government body responsible for the area of the sea to authorize and monitor the development of activities related to marine scientific research carried out in Mozambican maritime waters, as well as on the continental shelf.

- The Marine Scientific Research Regulation (REICIM from its Portuguese acronym) approved by decree 30/2019 of 19 April, establishes the full set of rules concerning the conduct of research and marine scientific research activities in the National Maritime Space, providing detailed guidelines relevant to applications for permits and authorization required to undertake marine scientific research by both national and foreign entities.

As prescribed both by Article 60 of the Sea Law and Article 12 of the Marine Scientific Research Regulation, authorizations for carrying out marine scientific research, requested by foreigners - individual or legal entity, governmental or private organisations or by international organisations - are granted only when arising from contracts or agreements entered into with national institutions. Still according to Article 12, these provisions do not apply when no Mozambican entity or institution has shown an interest in concluding contracts or agreements to carry out the requested marine scientific research and investigation.

According to Article 61 of the Sea Law, the main requirement of this law is that marine scientific research is for exclusively peaceful purposes and in accordance with the provisions of the law and other applicable national legislation as well as international acts in which the republic of Mozambique is bound.

In summary, the law presents seven main conditions in Article 62 that must be satisfied by the institutions and entities interested in carrying out marine scientific research in Mozambican maritime waters, as well as on the continental shelf:

1. Guarantee space for a representative appointed by the Government body responsible for the area of the sea, and at least one scientist appointed by any of the sectors and institutions concerned, to participate and monitor all operations related to the intended scientific research, without any expense for the State;
2. Provide preliminary reports to the Government body responsible for the sea area, 90 days after the end of the scientific research;
3. Send to the Government agency responsible for the sea area, up to 180 days after the end of the research, all data, information and results obtained, accompanied by a detailed and complete assessment, as well as, whenever requested by applicable, provide all collected samples that can be divided without prejudice to their scientific value;
4. Provide, to the representative of the Government agency responsible for the sea area and to Mozambican scientists appointed to accompany work on ships or airplanes, ample access to all compartments, equipment, instruments and on-board records;
5. Ensure the inclusion of nationals in joint post-cruise studies, related to scientific research carried out;

6. Remove, unless otherwise agreed, all structures and equipment installed in Mozambican marine waters, as soon as the scientific research or investigation is finished;
7. Disseminate, at the national and international level, with the prior authorization of the Government body responsible for the sea area, the results of scientific research in which there is a direct impact on the exploitation and use of living and non-living natural resources, after their delivery to the State Mozambican.

Articles 9 and 12 of the Marine Scientific Research Regulation details how the request to carry out marine scientific research in the National Maritime Space should be submitted by national (public body, municipality, private entity, individual or Mozambican legal entity) and international entities, respectively. According to the regulation, an application may be submitted, respecting the above deadlines, in a digital format, through the online portal of the ministry responsible for the sea.

One extremely important factor to consider is that Article 8 of the Marine Scientific Research Regulation states that the results of marine scientific research are the property of the State and are handed over to the Institute responsible for marine scientific research, which is responsible for establishing the appropriate mechanisms for their management and sharing.

The same Article 8 and also Article 66 of the Sea Law state The results of marine scientific research are analyzed by the Government agencies responsible for the areas of the sea and science and technology, including other interested bodies that request data for analysis, when applicable. Article 66 reinforces that it is the responsibility of the Government agency responsible for the area of the sea to forward, to the other interested institutions, the material received from the executors of marine scientific research.

Finally, Article 8 of the Marine Scientific Research Regulation starts that the disclosure of the results of marine scientific research by physical or legal entities, national or foreign, whenever they have a direct impact on the exploitation or use of natural resources, require authorization from the Minister who oversees the sea area.

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13. **APPENDIX**

APPENDIX 1. Example of a Point Intercept Datasheet, with space for observations at 25 cm intervals along a transect. The header of the data sheet allows for collection of metadata and also lists categories to use for observations. This example is a two sided data sheet for a 50 m long transect.

BENTHIC COVER PIT LIFEFORM To Family / Genus WCS 2015

Site Name:		**Transect number:**		**Deep/Shallow:**	
Data recorded by:		**Date:**		**Water Temp** (^{o}C):	
Tide: (Rising / Full/ Falling/ Low)		**Time** Start/End:	/	**Depth** (m):	

Life-Form Categories	**RC** Rock (non-carbonate)	**RB** Rubble (0.5 – 15cm)	**SD** Sand (<0.5cm)	**SI** Silt (Very fine)	**RM** Reef Matrix	**DA** Dead Coral w/ Fleshy Algae	**CCA** Crustose Coralline Algae

ACB Acropora branching	**ACD** Acropora digitate	**ACT** Acropora table	**ACS** Acropora submassive	**ACE** Acropora encrusting

CB Coral branching	**CE** Coral encrusting	**CF** Coral foliose	**CM** Coral massive	**CS** Coral submassive	**SC** Soft coral
CMR Coral mushroom	**ACC** Acropora corymbose	**CC** Coral corymbose	**SP** Sponge	**ZO** Zooanthids	**OT** Other biota
MC Microbial	**AA** Algal Assemblage	**CA** Coralline algae	**HA** Halimeda	**MA** Macroalgae	**TA** Turf algae

Micro-Complexity	**1:** totally flat (e.g. sand)	**2:** rubble/small patches (min relief)	**3:** mounding (medium structure)	**4:** Submassive or coarse branching	**5:** branching, complex and crevices

Live/Dead	**L:** live	**E:** bioeroded	**B1:** partially bleached	**B2:** white	**B3:** bleached and partly dead	**PD:** partly dead

Macrocomplexity	**0:** no vertical relief	**1:** low, widespread relief & 2:	**3:** moderate relief	**4:** complex vertical relief	**5:** fissures, caves, overhangs

0.25m – 10.0m						**10.25m – 20.0m**					
PIT (m)	**Life Form**	**Micro Comp**	**Live/ Dead**	**Macro Complex**	**Genus**	**PIT (m)**	**Life Form**	**Micro Comp**	**Live/ Dead**	**Macro Complex**	**Genus**
0.25						**10.25**					
0.50						**10.50**					
0.75						**10.75**					
1.00						**11.00**					
1.25						**11.25**					
1.50						**11.50**					
1.75						**11.75**					
2.00						**12.00**					
2.25						**12.25**					
2.50						**12.50**					
2.75						**12.75**					
3.00						**13.00**					
3.25						**13.25**					
3.50						**13.50**					
3.75						**13.75**					
4.00						**14.00**					
4.25						**14.25**					
4.50						**14.50**					
4.75						**14.75**					
5.00						**15.00**					
5.25						**15.25**					
5.50						**15.50**					
5.75						**15.75**					
6.00						**16.00**					
6.25						**16.25**					
6.50						**16.50**					
6.75						**16.75**					
7.00						**17.00**					
7.25						**17.25**					
7.50						**17.50**					
7.75						**17.75**					
8.00						**18.00**					
8.25						**18.25**					
8.50						**18.50**					
8.75						**18.75**					
9.00						**19.00**					
9.25						**19.25**					
9.50						**19.50**					
9.75						**19.75**					
10.00						**20.00**					

20.25m – 37.5m						35.25m – 50.0m					
PIT (m)	Life Form	Micro Comp	Live/ Dead	Macro Complex	Genus	PIT (m)	Life Form	Micro Comp	Live/ Dead	Macro Complex	Genus
20.25						35.25					
20.50						35.50					
20.75						35.75					
21.00						36.00					
21.25						36.25					
21.50						36.50					
21.75						36.75					
22.00						37.00					
22.25						37.25					
22.50						37.50					
22.75						37.75					
23.00						38.00					
23.25						38.25					
23.50						38.50					
23.75						38.75					
24.00						39.00					
24.25						39.25					
24.50						39.50					
24.75						39.75					
25.00						40.00					
25.25						40.25					
25.50						40.50					
25.75						40.75					
26.00						41.00					
26.25						41.25					
26.50						41.50					
26.75						41.75					
27.00						42.00					
27.25						42.25					
27.50						42.50					
27.75						42.75					
28.00						43.00					
28.25						43.25					
28.50						43.50					
28.75						43.75					
29.00						44.00					
29.25						44.25					
29.50						44.50					
29.75						44.75					
30.00						45.00					
30.25						45.25					
30.50						45.50					
30.75						45.75					
31.00						46.00					
31.25						46.25					
31.50						46.50					
31.75						46.75					
32.00						47.00					
32.25						47.25					
32.50						47.50					
32.75						47.75					
33.00						48.00					
33.25						48.25					
33.50						48.50					
33.75						48.75					
34.00						49.00					
34.25						49.25					
34.50						49.50					
34.75						49.75					
35.00						50.00					

APPENDIX 2. Example of a fish survey data sheet (two sided) for fish visual belt transect surveys.

Fish form UVC Avril 2016 WCS - copie.doc **PAGE /**

Survey |________________| Site |______________________________| Diver |__|__| Transect |__|__|__|

Date |__|__|/|__|__|/20|__|__| Lat.|__|__|°|__|__|,|__|__|__|' Long.|__|__|__|°|__|__|,|__|__|__|' WP: |_______|

COMPL|__| DEPTH|__| TEMP : |__| Management|__________| HAB1|___________| HAB2|____________|

ST	SCIENTIFIC NAME	Number	Length	COMMENTS

Fish form UVC Avril 2016 WCS - copie.doc **PAGE /**

ST	SCIENTIFIC NAME	Number	Length	COMMENTS

APPENDIX 3. Example of a catch-per-unit-effort (CPUE) data sheet (Portuguese language version)

Inquérito de pesca	**Numero de referencia do inquérito:**	_ _ _ _ _ _ _ _ - _ _ _ - A _ _ Wildlife Conservation Society	
Observador:	Data: Hora (24hr):	Aldeia:	
Pescador Sexo : M / F	Numero de pessoas no barco:	Homens:	Mulheres:
O que tentou apanhar hoje?			
Momento do dia da atividade de pesca: Serrão / noite / alvorada / manha / tarde	Saída: Data Hora (24hr):	Volta: Data Hora (24hr):	
Propulsão do barco:	Tempo dedicado a pesca (hr):	Tempo de viagem	
Lugar de pesca: :	REF lugar de pesca	Distancia a boca de rio (km):	
Habitat: recife / arenoso / lama / mangal / rio / outro :	Profundidade (m):	Numero de barcos:	
Maré : descendente / baixo / subindo / alto — Nuvens: /8	Vento (Beaufort) ?	Chuva?	

Aparelho de pesca primário					**proporção (%) do pescado capturado por este equipamento?**			
Equipamento :	**Numero**	**Tipo**	**Profundidade (m)**	**Isco**	**Forca (kg):**	**Detalhes:**		
☐ Linha						numero de anzóis:	tamanho min:	max:
☐ Longline						numero de anzóis:	tamanho min:	max:
☐ Rede						comprimento (m):	altura (m):	aberturas (cm):
☐ Arpão manual					**Notas complementarias:**			
☐ Arpão								
☐ Armadilha								
☐ Outro								

Produtos da pesca com o aparelho principal da pesca :					**Amostra (1 - 5):**				
Nomes locais/ espécie	Numero	peso total (kg)	Para consumo próprio (kg)	Preço por kg (MT)	1 cm / kg	2 cm / kg	3 cm / kg	4 cm / kg	5 cm / kg
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
Total :				**Notas:**					

Segundo aparelho de pesca					**proporção (%) do pescado capturado por este equipamento?**			
Equipamento :	**Numero**	**Tipo**	**Profundidade (m)**	**Isco**	**Forca (kg):**	**Detalhes:**		
☐ Linha						numero de anzóis:	tamanho min:	max:
☐ Longline						numero de anzóis:	tamanho min:	max:
☐ Rede						comprimento (m):	altura (m):	aberturas (cm):
☐ Arpão manual					**Notas complementarias:**			
☐ Arpão								
☐ Armadilha								
☐ Outro								

Produtos da pesca com o aparelho secundario da pesca :					Amostra (1 - 5):				
Nomes locais/ espécie	Numero	peso total (kg)	Para consumo próprio (kg)	Preço por kg (MT)	1 cm / kg	2 cm / kg	3 cm / kg	4 cm / kg	5 cm / kg
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
Total :				**Notas:**					

Terceiro aparelho de pesca					proporção (%) do pescado capturado por este equipamento?			
Equipamento :	**Numero**	**Tipo**	**Profundidade (m)**	**Isco**	**Forca (kg):**	**Detalhes:**		
☐ Linha						numero de anzóis:	tamanho min: max:	
☐ Longline						numero de anzóis:	tamanho min: max:	
☐ Rede						comprimento (m):	altura (m):	aberturas (cm):
☐ Arpão manual					**Notas complementarias:**			
☐ Arpão								
☐ Armadilha								
☐ Outro								

Produtos da pesca com o terceiro aparelho de pesca utilizado:					Amostra (1 - 5):				
Nomes locais/ espécie	Numero	peso total (kg)	Para consumo próprio (kg)	Preço por kg (MT)	1 cm / kg	2 cm / kg	3 cm / kg	4 cm / kg	5 cm / kg
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
					/	/	/	/	/
Total :				**Notas:**					

NOTAS COMPLEMENTARIAS : Exemplo: captura de espécies ameaçadas (e.g. dugong, golfinho) com descrição da espécie, comprimento da espécie capturada (cm) lugar de pesca, e outras informações gerais.

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