
Lionfish caught at a derby in Curaçao.

The high density and rapid spread of lionfish are likely due to a number of factors:

- **Few natural predators** – native predators (sharks, groupers, etc) appear to be reluctant to consume lionfish, though some predation has been reported.
- **Multiply quickly** – capable of producing over 2 million eggs per year, spawning multiple times throughout the year and reach sexual maturity at less than one year of age.
- **High diversity of prey consumed** – lionfish consume a wide variety and sizes of fish and crustaceans.
- **Spread quickly** – lionfish larvae are estimated to spend between 20 and 35 days drifting in the plankton. This is sufficient time for the larvae to disperse over large distances and colonise distant reefs.
- **Prey naïvete** – their natural camouflage, slow movement and use of flared fins to herd fish mean lionfish can confuse their prey which, in the Caribbean, have not encountered such methods before.
- **Wide habitat range** – lionfish have been found from depths of 300m to the surface and on coral reefs, in mangroves, river estuaries and sea grass beds.


Lionfish on measuring board.

FURTHER INFORMATION

Morris, J.A., Jr. (Ed.). 2012. Invasive Lionfish: A Guide to Control and Management. Gulf and Caribbean Fisheries Institute Special Publication Series Number 1, Marathon, Florida, USA. 113 pp. Available online at: http://lionfish.gcfi.org/manual/

Mumby PJ, Harborne AR, Brumbaugh DR. 2011. Grouper as a natural biocontrol of invasive lionfish. PLoS ONE 6(6) e21510. Available free online at: www.plosone.org

MANAGEMENT IMPLICATIONS

Lionfish are here to stay on Caribbean reefs, but management actions can help alleviate some of the problems. Management options for lionfish will depend on the resources available but might include three components:

Education and awareness

Campaigns to promote understanding lionfish and the impacts they have on reefs can help to reinforce the management of lionfish in a number of ways:

- Reduce risk of people being stung and injured by lionfish.
- Increase support for other management measures.
- Raise awareness of the damaging effects lionfish have on the ecosystem.
- Mobilize support for removal programmes, particularly amongst divers and dive shops.
- Encourage consumption of lionfish.
- Prevent further introductions of invasive species, including additional lionfish.

Removal

Where the density and size of large-bodied grouper is high – after 30 years protection – evidence exists that lionfish densities are relatively low on outer forereefs. However, 99% of Caribbean reefs lack the levels of grouper found on these reefs so grouper are unlikely to serve as a form of biocontrol (Mumby et al 2011). The only ways at present to control lionfish numbers is by active removal. This is normally done by scuba divers using adapted pole spears and sometimes nets or bags. Removal efforts have only a limited effect on lionfish numbers as populations will always be replenished from other reef areas and removal of all lionfish even at a small scale is practically impossible. However sustained local removal efforts can help reduce lionfish numbers on local reefs, thereby reducing their effect on the local reef ecosystem. It is important that removal programs do not harm the very reefs they are trying to conserve hence divers must take no other fish except lionfish and should not damage the reef while hunting for lionfish. Diver safety should also be stressed. To ensure rules are followed, some managers require that divers wishing to hunt lionfish are registered and undergo a training program. Removal of lionfish through the involvement of recreational divers has been effective in places such as Bonaire and the Florida Keys. Derbies are organized where a day or weekend of lionfish hunting and events take place, not only removing large numbers of lionfish from the reefs but also encouraging awareness of the scale of the problem. Consumption of lionfish is also being promoted in many places as they are seen as a sustainable and ‘reef-friendly’ food source.

Monitoring

Monitoring of lionfish can determine the spread of lionfish on local reefs and the efficacy of any removal programs as well aiding in their improvement, e.g. removal efforts can be targeted on reefs where lionfish are most abundant. Commonly used surveys methods such as AGRRA, REEF and Reef Check already include lionfish in their protocols. Other innovative methods of monitoring include using data from recreational divers; Bonaire has a website devoted to mapping of lionfish around the island using volunteer submitted data: www.lionfishcontrol.org/

Managing parrotfish harvesting with habitat protection zones

THE ISSUE

Stoplight parrotfish (*Sparisoma viride*).

Parrotfish are an important fishery in many parts of the Caribbean and as populations of preferred fishery species such as groupers and snappers have declined, there has been a tendency for fishers to shift increasingly towards targeting lower value herbivorous fishes such as parrotfish. Fishing of parrotfish also occurs when fish traps are used, even if parrotfish are not the target species. However, sustainable fisheries – as well as other ecosystem services – require a healthy and structurally complex reef habitat which parrotfish play an important role in maintaining through their function as grazers of macroalgae.

To maximise the quality of reef habitat for continued fisheries, the best option to consider is a complete ban on herbivore fisheries. However, in areas where fishers are highly dependent on parrotfish, an alternative management strategy is needed that minimises impacts on reefs while still permitting fishing.

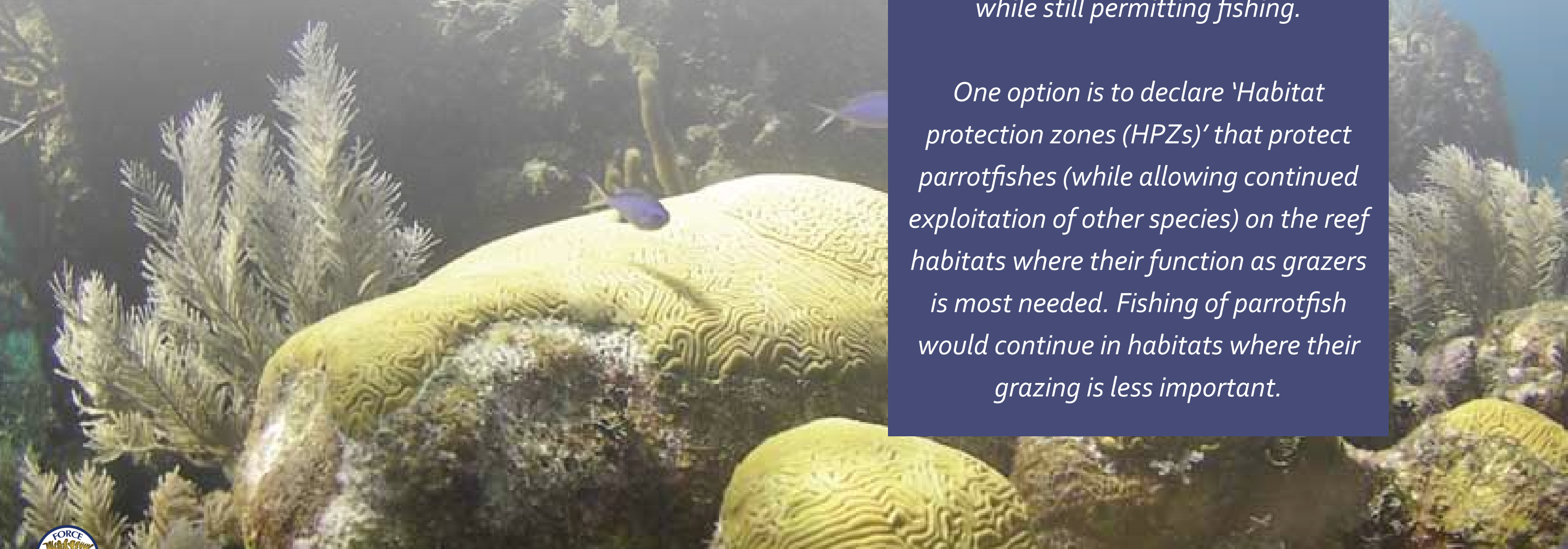
One option is to declare 'Habitat protection zones (HPZs)' that protect parrotfishes (while allowing continued exploitation of other species) on the reef habitats where their function as grazers is most needed. Fishing of parrotfish would continue in habitats where their grazing is less important.

THE EVIDENCE

In practical terms, there are two major forereef habitat types: '*Orbicella* (previously *Montastraea*) reef' and 'gorgonian plain'. The *Orbicella* reef is structurally complex, high in biodiversity, sustains large parrotfish populations and is where much of the 'reef-building' takes place. Gorgonian plains, in contrast, are relatively featureless flat pavements dominated by gorgonians (e.g. sea fans, whips and rods). *Orbicella* reefs require high levels of parrotfish grazing to help keep macroalgal cover in check. In contrast, data from Belize and the Bahamas showed no relationship between parrotfish biomass and macroalgal cover in gorgonian plain habitats, suggesting that algal growth in this habitat is controlled by other mechanisms such as wave exposure.

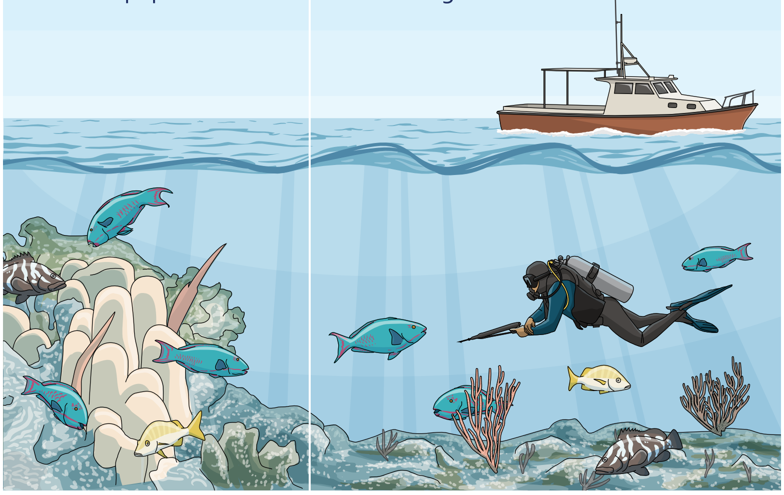
THE APPROACH

The creation of HPZs that cover *Orbicella* reefs would help maintain good fish habitat for a host of fisheries species by protecting parrotfish where they are most needed. Harvesting of parrotfish would be allowed on gorgonian plains where parrotfish do not appear to play such an important role as grazers and habitat damage due to fishing is less likely due to the featureless nature of the plains. Such a compromise would allow fishers to continue harvesting parrotfish and fisheries management could focus on sustaining the fishery on the gorgonian plains. The total area of gorgonian plain often dwarfs that of *Orbicella* reef, implying that many areas would be fished as usual.



Managing Parrotfish Fisheries in the Caribbean

Protecting these animals on one part of the reef may allow for abundant populations of other fish throughout the reef.



Orbicella reef

Complex, massive corals. Strong relationship between parrotfish abundance and algal cover. Low wave exposure relative to the gorgonian plain. Fishing for parrotfish prohibited, but allowed for other species.

Gorgonian plain

Flat and few corals. No strong relationship between parrotfish and algal cover. More extensive than the Orbicella reef areas. Fishing for parrotfish allowed.

MANAGEMENT IMPLICATIONS

Ecosystem-based management of fisheries has been widely endorsed for its principle of sustainable fisheries management based on maintaining ecosystem function. The habitat protection zones proposed here offer one more tool for ecosystem-based management of coral reef fisheries. By protecting structurally complex reef habitat managers will help maintain fisheries productivity, thereby balancing the needs of fisheries with those of a healthy coral reef ecosystem.

FURTHER INFORMATION

Linking coral reef complexity p.71, Fisheries brief 7 p.90

Mumby PJ. 2014. Stratifying herbivore fisheries by habitat to avoid ecosystem overfishing of coral reefs. Fish and Fisheries. (doi: 10.1111/faf.12078)

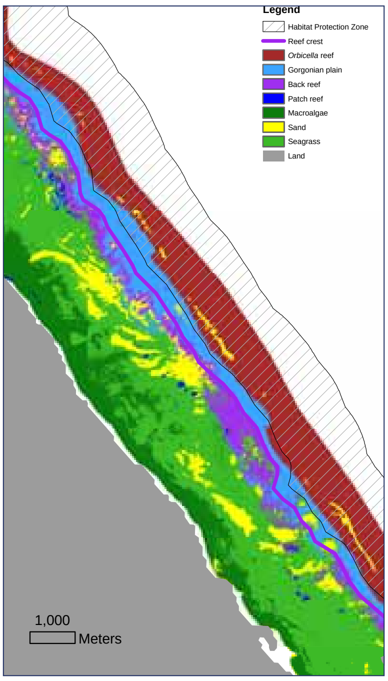
Mapping of reef habitats can be done using the simple relationship described in Chollett & Mumby (2012) and wave exposure data available via the FORCE WebGIS, http://force-project.eu/

Chollett, I., Mumby, P., 2012. Predicting the distribution of Montastraea reefs using wave exposure. Coral Reefs 31, 493-503.

HOW IS IT DONE?

Orbicella reef and gorgonian plains can be mapped using a variety of methods including the use of high resolution airborne images, boat-based acoustic surveys of seabed roughness or mapping of wave exposure. Managers may already have habitat maps of reefs that would allow mapping of the two habitat types. These maps can then be used to set HPZs encompassing *Orbicella* reef areas. Inevitably there will be some overlap between the two habitat types and zoning plans will have to find a compromise between protection of the maximum amount of Orbicella reef and the complexity of the resulting zoning plan.

To enforce the HPZs, three systems are possible: (1) direct enforcement using patrol boats; (2) bans of fish traps in HPZs, (3) indirect monitoring of fishing vessels through the use of a high-resolution monitoring system such as automated identification systems (AIS). AIS is a high resolution vessel monitoring system . If all fishing vessels had such a system installed and regulations stated that parrotfish cannot be caught on fishing trips that enter a HPZ, the AIS system could be used to check unambiguously if landed parrotfish could have been caught in an HPZ. In practice, fishers would have to decide whether to fish the HPZ on a given day and if they do, then the harvest of parrotfish outside the HPZ would not be feasible on that trip. If parrotfish were targeted on a given day then the HPZ would have to be avoided. If fishing was conducted outside the HPZ but no parrotfish were caught then other species could be targeted in the HPZ on the same trip.



Map showing habitat protection zone and reef habitats.

Using vessel monitoring system data for sustainable management of reef resources

THE ISSUE

Shrimp trawlers at dock.

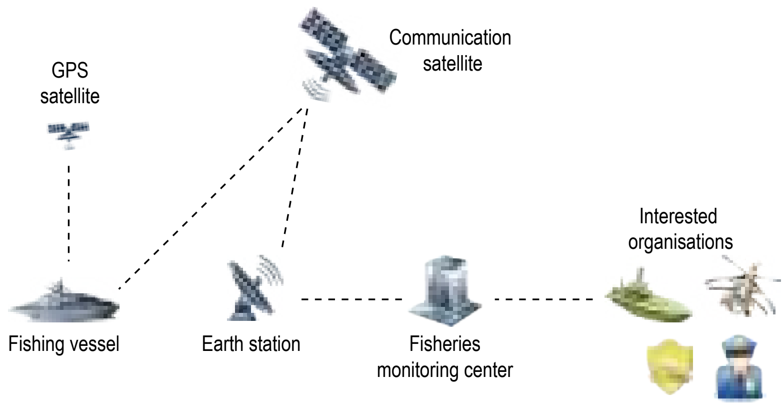
Coral reefs serve as habitat for many commercially important species targeted by fisheries. Many people rely on reef resources as a source of income and for food. Well managed reefs can yield between 5 and 15 tons of fish and other seafood per square kilometre per year, however, more than 55% of the world's shallow reefs do not produce this potential as they are severely over-fished.

A number of management tools such as spatial (fishing zones) and temporal closures (harvesting seasons), as well as gear and species restrictions, are required. Enforcement of the first two of these management strategies is dependent on knowledge of the movement of fishing vessels. Vessel Monitoring System (VMS) provides relatively cheap, reliable and constant access to this information.

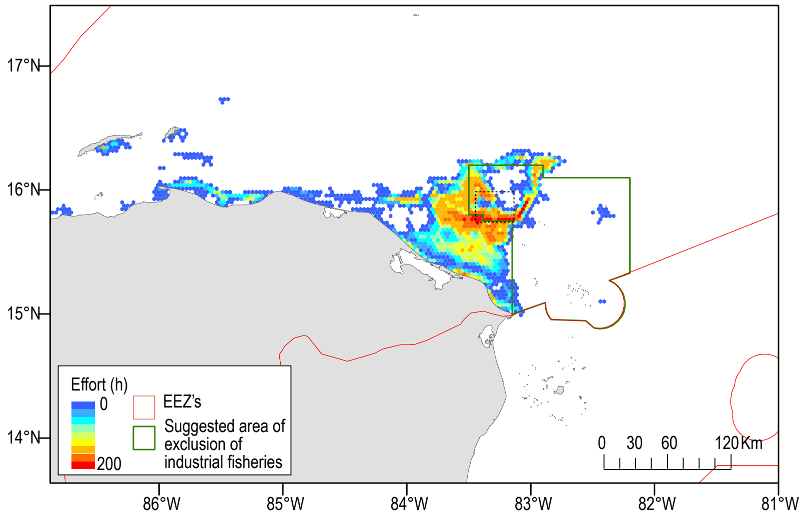
THE EVIDENCE

A Vessel Monitoring System (VMS) is a satellite-based tracking system for monitoring in near real-time the location of vessels equipped with the technology. VMSs provide continuous information every hour on the position of fishing vessels, even when they are in port. This information can be transformed into outputs useful for resource management and conservation following simple GIS processing steps.

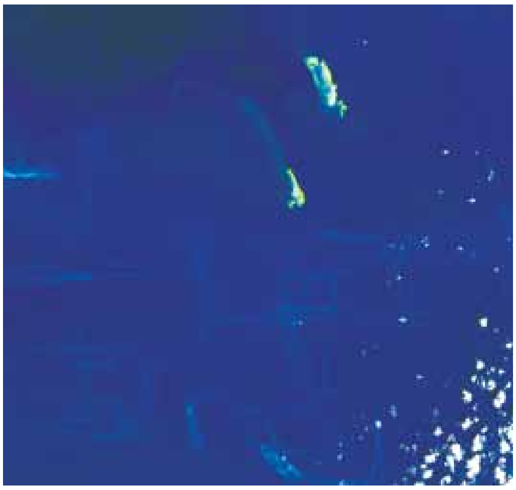
VMS is widely used in many countries throughout the world. In the Caribbean, Jamaica, Colombia, Honduras, Panama, Mexico and the USA have active VMS systems within their industrial fleets.



VMS system: the boat has a VMS unit with an inbuilt Global Positioning System (GPS) receiver and an antenna on board. A satellite picks up the signal and relays it in real time back to earth, where a station collects the data and distributes it to the users.



Map of fishing effort (hours) for shrimp fisheries boats in Honduras (2010-2012). This map collates information from 54 boats and 634,930 hourly records.



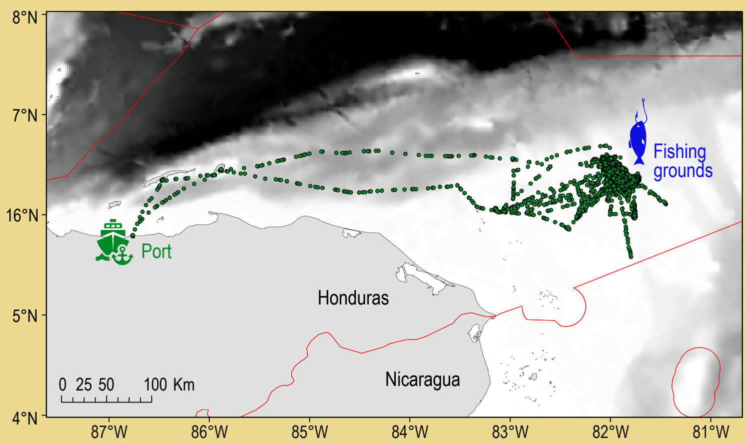
Satellite imagery showing scars left by trawling boats (in black dashed rectangle on map) inside the suggested area of exclusion of industrial fisheries.

MANAGEMENT IMPLICATIONS

VMS data can be used for a variety of management uses:

- Safety, used as an aid in search and rescue activities.
- Identification of poaching or incursions into protected waters.
- Identification of exceeded quota if the number of days at sea is limited.
- Identification of compliance with seasonal bans if there are temporal harvesting restrictions.
- Fisheries research and analysis by providing an estimation of spatial fishing effort.
- Maps of fishing effort can be used for reserve design. Maps can aid quantifying potential displacement of effort and spatial mobility of the fleet, or the fleet's ability to accommodate the management restriction and fish in other locations.

For enforcement activities to take place, government agencies need to monitor their data in real-time, in order to detect harmful or suspicious activity (i.e. wrongly entering into a marine reserve or patterns of movement that suggest prohibited fishing activity). In the Caribbean, installing the system is not the only priority; the data also needs to be made available to control centres.



VMS hourly positions of an industrial fishing boat in Honduras. Economic Exclusive Zones marked in red; bathymetry is shown in the background with darker colours showing deeper areas.

FREQUENT ASKED QUESTIONS

How much would this technology cost?

A VMS unit is about US $1,500 and a daily network plan that guarantees the satellite transmission of the data is about US $2 per day. However, many countries offer subsidies to vessels.

What should I do if I need to monitor smaller vessels?

For smaller vessels a cheaper alternative is the Automatic Identification System (AIS) which does not use expensive satellite connection to transfer data. AIS records position more frequently and therefore is more useful to monitor smaller, faster vessels. However, set-up of the system requires a one-off investment and the building of a network of radio repeaters throughout the area to ensure full signal coverage.

What about the monitoring of foreign vessels in my MPA?

Regulations can make the installation of VMS or AIS units mandatory to all vessels entering the park boundaries. The devices can be provided at rental cost, as is being planned in the Galapagos Marine Reserve.

FURTHER INFORMATION

Chollett I, SJ Box, PJ Mumby. Displacement of fishing effort by an imminent MPA closure: when is it an issue? In preparation.

THE ISSUE

Close-up, recently spawned eggs.

Setting boundaries and managing stocks of animals and plants is much easier on land than in the ocean. Since we cannot fence the sea, its inhabitants move freely among different areas, either as adults (by swimming or floating), or as offspring (larvae). Most marine organisms release larvae into the water column, where they are subjected to the prevailing currents, at times spending months in the water and covering perhaps hundreds of kilometres before finding a new home.

As a result, effective management of many marine species transcends international boundaries and requires international cooperation. Even if a country manages its own marine resources appropriately, the success or failure of its management will rely, in part, on the activities undertaken by neighbouring countries because of various organisms' transboundary connections.

To add an extra level of complexity to the issue, connectivity patterns differ among species. While some resources might be shared among neighbouring countries, others might not. Since resources for biodiversity conservation are limited, joint management activities and the development of networks, partnerships or regional coordinating institutions can enable the pooling of those resources to minimize duplication and maximise management benefits.

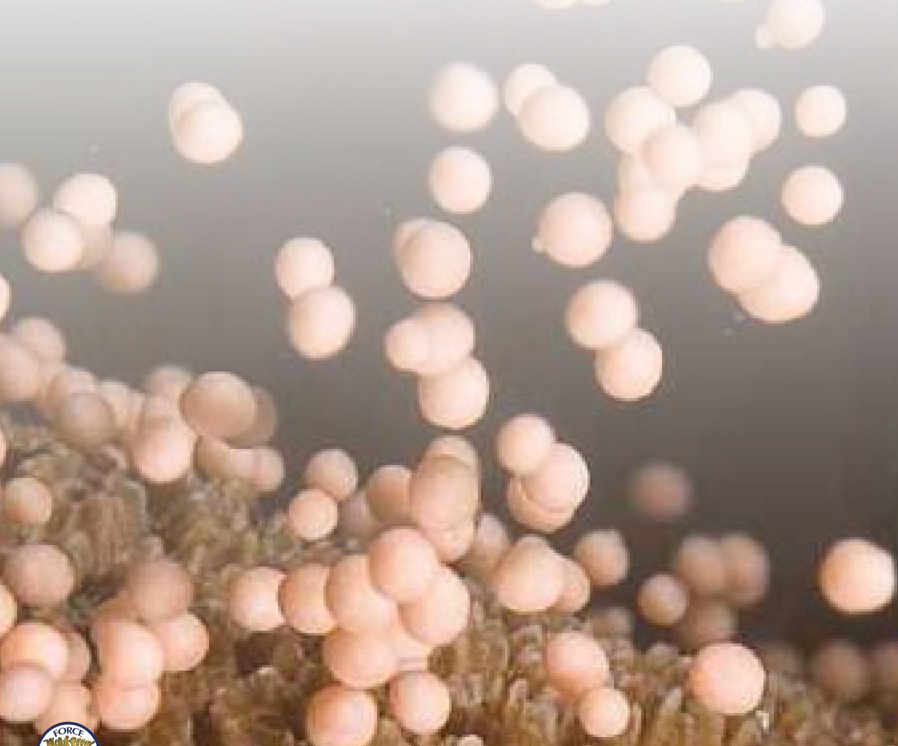
Using connectivity for the transboundary management of reef species

THE EVIDENCE

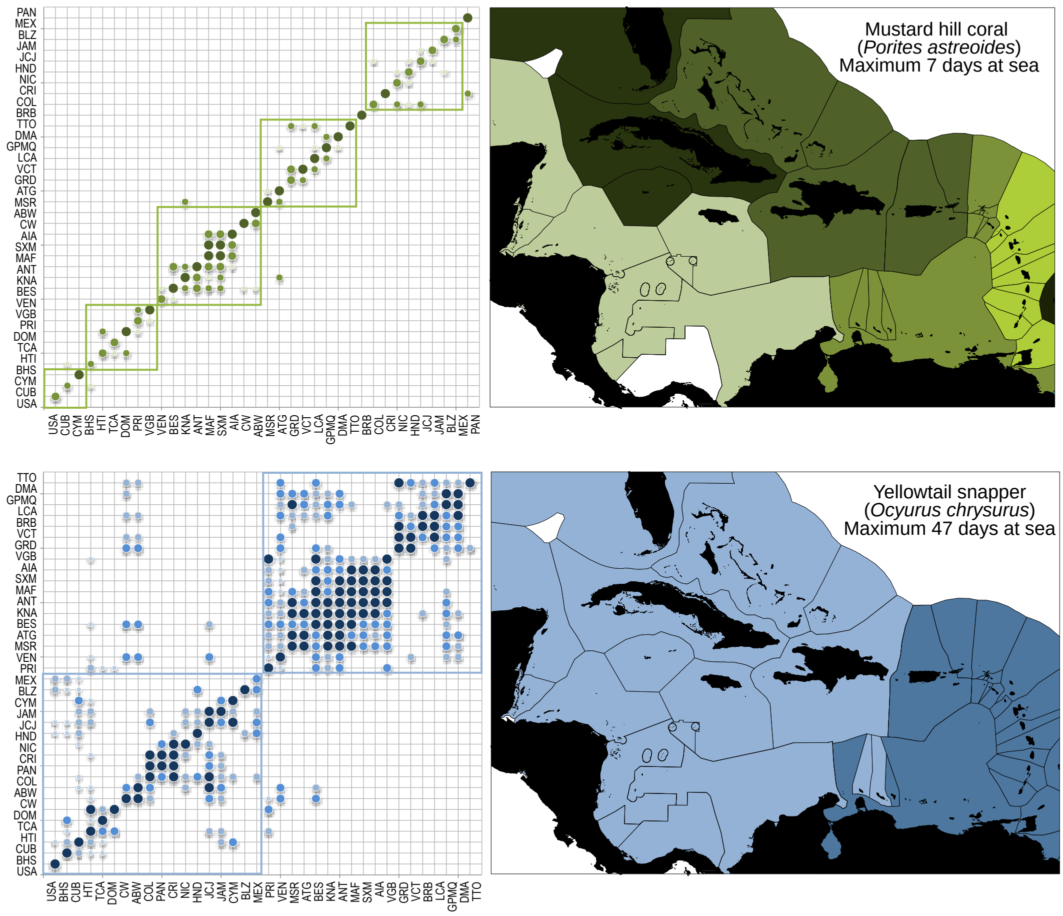
Larval connectivity patterns of a variety of species can be understood using realistic models. These models incorporate maps of reef locations, detailed 3D models of ocean and coastal currents, and information on the biology of the species. An open- source model (the Connectivity Modeling System) incorporating all these complexities is now available to understand the connectivity patterns of different reef species within the Caribbean.

Models of larval dispersal efficiently predict real patterns in the field: for example, models for the most important Caribbean reef-builder, the boulder star coral *Orbicella annularis*, explain much of the genetic variability of these corals across the entire basin. Of course, many countries share connected resources – with larvae released in one country sustaining populations of fish and invertebrates in other countries downstream.

The relevance of transboundary issues for management and biodiversity conservation is being increasingly acknowledged. Worldwide, the number of transboundary protected areas has grown from 59 in the 1970's to 666 in 2001 to 3,043 in 2007.



Coral spawning.



United States (USA); The Bahamas (BHS); Cuba (CUB); Haiti (HTI); Turks & Caicos Is. (TCA); Dominican Republic (DOM); Puerto Rico (PRI); Venezuela (VEN); Montserrat (MSR); Antigua & Barbuda (ATG); Bonaire, Saint Eustatius and Saba (BES); St. Kitts & Nevis (KNA); Netherlands Antilles (ANT); Saint Martin (MAF); Saint Maarten (SXM); Anguilla (AIA); Virgin Islands, British (VGB); Grenada (GRD); Saint Vincent and the Grenadines (VCT); Barbados (BRB); St. Lucia (LCA); Guadeloupe-Martinique (GPMQ); Dominica (DMA); Trinidad & Tobago (TTO); Curacao (CW); Aruba (ABW); Colombia (COL); Panama (PAN); Costa Rica (CRI); Nicaragua (NIC); Honduras (HND); Joint regime Colombia/Jamaica (JCJ); Jamaica (JAM); Cayman Is. (CYM); Belize (BLZ); Mexico (MEX).

Connectivity matrices and possible transboundary management units for two reef species with contrasting biology. Connectivity matrices show the average proportion of larvae migrating from one country to another. Larvae originate from the left (rows) and settle at the bottom (column). Domestic connectivity (larvae that settled in their nation of origin) follows the diagonal. The strength of connections (size and colour of the bubbles) among sites is represented by five quantiles.This information can be used to categorize the Caribbean into management units which are more strongly connected within the units than among the units.To achieve this we used the clustering method of Girvan-Newman and the maximum modularity score to define the optimal partitions.

MANAGEMENT IMPLICATIONS

Management plans focusing on particular species would look at their specific connectivity patterns to identify those species that will benefit from a transboundary conservation approach. The larvae of some species don't spend much time in the water column and so tend to stay in the waters of their home country, limiting the benefits of a transboundary approach. On the other hand, the management of species whose larvae spend a long time in the water column will need wide collaborative efforts.

Connectivity matrices showing where the larvae originate and where they go can help identify the best country groupings for transboundary management efforts, where cooperation could improve conservation outcomes. For example, for the coral *Porites astreoides*, connectivity patterns suggest at least 5 management units (or country groupings), while for yellowtail snapper, *Ocyurus chrysurus*, with widely dispersed larvae, only two management units might be required.

There are large disparities between larval imports and exports among countries. Maintaining the health of reefs and stocks of species in the regions or areas that contribute disproportionately to the Caribbean larval pool should be an international priority. For example, for yellowtail snapper, Montserrat supplies larvae to 12 countries and receives larvae from 9.

This is does not reduce the importance of local reef management. Even if larvae can spend long periods in the water column, an important amount of larvae from each marine species stay within their home reef, which demonstrates that there is value in focusing on local conservation plans if transboundary approaches are not feasible at this stage.

FURTHER INFORMATION

Kough AS, Paris CB, Butler MJ IV (2013) Larval Connectivity and the International Management of Fisheries. PLoS ONE 8(6): e64970

Paris CB, Helgers J, van Sebille E, Srinivasan A (2013) Connectivity Modeling System: A probabilistic modeling tool for the multi-scale tracking of biotic and abiotic variability in the ocean. Environmental Modelling and Software. 42: 47-54

Holstein D, Paris CB, Mumby PJ (2014) Consistency and inconsistency in multispecies population network dynamics of coral reef ecosystems. Marine Ecology Progress Series. 499: 1–18.

Ecosystem Services and their Value

Ecosystem services are vital to life. Clean air and water as well as the food we eat are all services which are provided by the natural functioning of ecosystems. Countries with coral reefs are often highly dependent on the services the reefs provide such as dive tourism, fishing and coastal protection. In the Caribbean, these three services alone are worth more than US$3 billion annually and are important to the livelihoods of many communities. Failing to understand the value of ecosystem services can result in poor planning and decision making. Many methods exist for valuing ecosystem services and these are introduced within this chapter. For reef managers, valuations of ecosystem services can be useful in a number of different ways, principally for raising awareness of the value of reefs; to influence decision making and policies; in the calculation of compensation for damage to reefs; and to create sustainable financing schemes, such as marine park fees. Several valuation studies of coral reefs in Caribbean countries have already been conducted with the results being used to improve outcomes for both the reefs and the people who depend on them. Ecosystem services valuations are likely to play an increasingly significant role in policy decisions and planning and hence are an important tool for reef managers.

Dive boat in Honduras.

The natural functioning of ecosystems provides many services to us as human beings that we often take for granted. At the most basic level, the air we breathe and the food we eat are ecosystem services. Four broad categories of ecosystem services are widely used (Millenium Ecosystem Assessment Board 2005):

- Provisioning services – these are the products that humans harvest and consume such as food, fresh water, wood and oil.
- Regulating services – these services control the environment, providing protection from floods and droughts and regulation of the climate.
- Cultural services – aesthetic, spiritual, educational, recreational and tourism services are all included: those services that improve our cultural wellbeing.
- Supporting services – the essential services that support all ecosystems and thereby the provision of the three categories above. Examples are: primary production, nutrient dispersal and soil formation.

The UN Millennium Ecosystem Assessment found that two-thirds of ecosystem services worldwide are in decline which is having a negative effect on the well-being of the people who depend on them (Millenium Ecosystem Assessment Board 2005). As the world population continues to grow from 7.2 billion today to a predicted population of more than 9 billion by 2050 (UN-DESA 2013), increasing demands and pressures are being put on ecosystem services. These demands are causing further degradation and loss of the very services we are trying to exploit. From food to nutrient cycling, ecosystem services underpin human life. Yet, until recently their value had not been properly considered.

Local people enjoy weekends on the beach.

Fishing is one important provisioning service from reefs.

Valuing ecosystem services

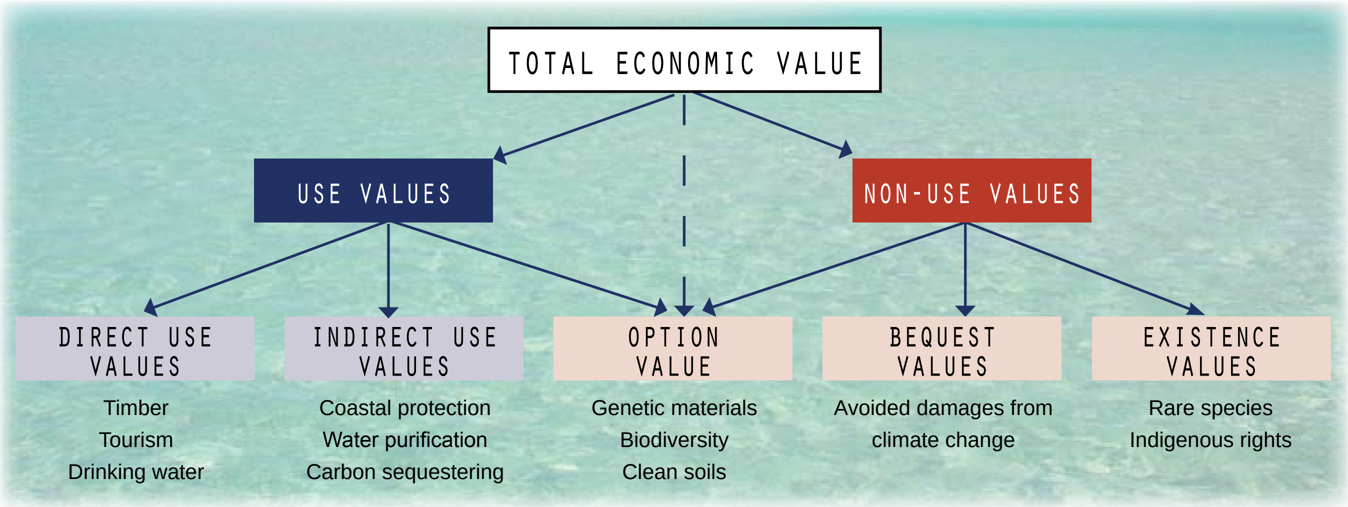
Whether the question is to develop a natural landscape in order to increase tourism or to protect a natural area, we implicitly put a value on nature by looking at the services that are provided by the natural environment. The value of these services is traded-off against the benefits that can be gained by development. Economic valuation of ecosystem services allows us to quantify the benefits they provide. This helps with understanding the effects of any changes in the supply of services on human well-being. Putting a monetary value on ecosystem services allows decision-makers to incorporate the true economic value of ecosystems and the environment into their decisions.

Some ecosystem services are relatively easy to put a value on, e.g. the value of fish from a coral reef can be seen in the price that people are willing to pay for them, although even this is more complicated than might at first seem, as fish might be worth more as an attraction for SCUBA divers than as food (Services Briefs 1 p.108 and Brief 2 p.110). However many ecosystem services have no direct market value, e.g. clean air is a vital service, but we don't pay for it directly. For these services it is important that we try and value them in other ways so that they can be included in decision making that might affect the ability of the ecosystem to deliver the service. Where ecosystem services are not valued, they are frequently left out of the decision making process, which can result in poor development and planning decisions.

Value concepts

To help understand and quantify the different values of ecosystems, the services can be split into different value categories. Total economic value (TEV) attempts to capture the value of services that we use ('use values'), such as food and water, as well as other 'non-use' values. Option values are considered a third group, since it is uncertain what sorts of services (use or non-use) might be provided by an ecosystem in the future.

VALUES AND METHODS



The components of total economic value for ecosystem services.

USE VALUES

Use values are divided between services that are used directly and ones that are used indirectly (regulate the provision of other services):

Direct use values

As the name suggests, are the values of services that are consumed directly. This can be in an extractive manner, when physical goods are taken from an ecosystem (e.g. wood from a forest as a building material). An ecosystem can also provide benefit in a non-extractive manner, like enjoying a dive on a coral reef or hiking in a forest. However, in order for a value to be categorized as a direct use value it is necessary for the consumer of the ecosystem service to be present and get some form of benefit. Direct use values are usually easiest to value, because people often pay to make use of the services they relate to.

Indirect use values

These are ecosystem services that generate benefits beyond the ecosystem being valued. Think of coral reefs or mangrove forests that protect villages from storms, or a rainforest that filters water for a city downstream. These services are often harder to value since the connection between the ecosystem service and the beneficiaries is often not as clear and the services are often not paid for directly.

Direct use values: urchin harvesting.

NON-USE VALUES

Non-use values are the benefits that are provided by ecosystem services without making actual use of an ecosystem at the moment or in the future. There are three different types of non-use values:

Bequest value

This is based on the idea that we would like to preserve certain ecosystem services for the next generations. The willingness of many people to contribute to the reduction of global warming, although most of the effects are going to be felt by future generations, is an example of this category. Policy that aims to deal with long-term management or irreversible impacts on the natural environment is often based on bequest values.

Existence values

This is an attempt to capture the value of an ecosystem service simply continuing to exist. For example many people are very happy with the idea that endangered species are protected against extinction. Although most people will never visit the habitats and look at these species they are still willing to pay for the protection of these habitats and species. Just knowing that the species exists provides satisfaction.

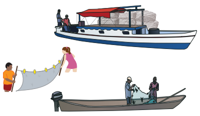
Option value

It incorporates the fact that we are uncertain of the future values of an ecosystem. These are not use values because they are not derived from current use; nor are they necessarily non-use values because the services may have future use. Option values are therefore best classified as a separate ecosystem service value category that can be thought of as an insurance premium that people are willing to pay to preserve the supply of potential services in the future, e.g. preserving biodiversity for possible medical applications that we are not aware of yet.

Existence values: people are willing to pay for the protection of iconic species, such as whale sharks.

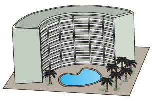
CORAL REEF ECOSYSTEM SERVICES AND VALUES

Coral reefs are important providers of ecosystem services including tourism and recreation, fisheries and coastal protection. Putting a 'dollar value' on these services helps us to understand their importance for people's livelihoods and allows them to be incorporated into decision-making and policy. Services that are commonly valued for coral reefs are:



Fishery value

Fisheries that are related to reefs can be important activities for both commercial, recreational and subsistence fishers. The value of the fishery is not solely related to the value of the fish sold or consumed because in many coastal communities fishing has social and cultural importance.



Tourism value

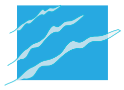
Many islands and coastal zones in the tropics depend on the healthy reefs to attract tourists. Tourism can be a threat and a curse to the reefs. While it is important to maintain the quality of the reefs, tourism also causes development and physical damage to this precious ecosystem. Think of construction, anchoring, human waste, inexperienced divers and snorkelers etc.

Recreational value

Coral reefs provide a broad range of recreational activities to both residents and tourists (e.g. snorkelling, diving and beach activities).

Coastal protection value

Coral reefs dissolve wave energy, which makes them important in protecting coastal areas from tropical storms and hurricanes. The healthier coral reefs are, the better they are at dissipating the waves and preventing physical damage to buildings and infrastructure. An important part of this value is mostly determined by the value of real estate and infrastructure that is protected by the reef ecosystem.

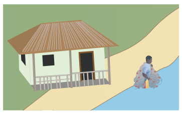


Coral reefs are important providers of a wide range of ecosystem services.

Amenity value

People like the view of clean beaches and proximity to healthy coral reefs. This is why beachfront houses on nice coasts usually sell for significantly higher prices then houses in less appealing areas. To calculate these values, the hedonic pricing method is used when analyzing house prices or hotel room rates. With this methodology the added value of houses near healthy marine ecosystems are measured.

Cultural values



Coral reefs often have a cultural importance to communities that live in the vicinity of coral reefs. In Saipan, for example, the appearance of migratory goatfish and juvenile rabbit fish are important events that bring families and friends closer together as they share in the catches. Less traditional, but very popular beach parties and barbeques also can be of cultural importance.

Non-use values

As diverse ecosystems and habitats for many species, coral reefs provide important non-use values. The desire from people around the world to preserve coral reefs for future generations leads to bequest values. The existence value comes from the value that people put on the mere existence of these ecosystems. Voluntary donations by non-users to NGOs that are concerned with coral reef protections demonstrate the importance of these non-use values.

Ecosystem service values (US$ millions)						
	Tourism	**Fishing**	**Shoreline protection**	**Amenity (house prices)**	**Local recreation and culture**	**References**
Tobago	100-130	0.8—1.3	18—33			Burke et al. 2008
St Lucia	160—194	0.4—0.7	28—50			Burke et al. 2008
Belize	135—176	13—14	120—180			Cooper et al. 2009
US Virgin Islands	103	3	7	37.1	51.1	van Beukering et al. 2011
Bermuda	405.9	4.9	265.9	6.8	36.5	Sarkis et al. 2010
Turks and Caicos	18.2	3.7	16.9			Conservation International 2008
Caribbean	2100	310	700—2200			Burke & Maidens 2004

Ecosystem service values of Caribbean coral reefs.

VALUATION TECHNIQUES

The values of ecosystem services can be determined using several different methods, some of which can only be applied to certain groups of services. Primary valuation methods are characterized by the collection of data that is directly connected to the ecosystems being studied, e.g. price of fish in a market, willingness-to-pay for entry into a marine park. Primary valuation methods can be categorized into direct market price, revealed preference and stated preference methods. Secondary valuation methods use primary studies from other locations to determine the value of the ecosystem services on which you are focusing. The values are transferred from one location or ecosystem to another. This method is normally referred to as value or benefit transfer.

Selecting valuation techniques

There is no single valuation method that is the best option for every ecosystem, in every location, to value all services. Instead, it is important to consider what the goal of the study is and choose the appropriate valuation methods.

Valuation method	Approach	Applications	Examples (tropical coastal ecosystems)	Limitations
Direct market price	Observe prices paid in markets	Good and services that are traded in markets	Fish, Scuba diving and other reef tourism activities	Prices can be distorted, e.g. by subsidies. Many services not traded directly in markets.
Revealed preference	Similar to direct market price method in that it uses market prices, however the markets are complementary or substitutionary markets, not direct market prices.			
Net factor income	Revenues from sales of ecosystem services, minus cost of other inputs such as labour and materials	Ecosystems that provide an input into the production of a good or service that is sold on a market	Commercial fisheries supported by reefs	Over-estimates ecosystem value
Production-function	Estimates value of ecosystem service as input in production of marketed goods	Ecosystems that provide an input into the production of a good or service that is sold on a market	Commercial fisheries supported by reefs	Technically difficult High data requirements
Hedonic pricing	Estimate influence of environmental factors on marketed goods	Environmental characteristics that vary across goods (usually houses)	Value of reef incorporated into house prices	Technically difficult High data requirements
Travel cost	Estimate value of ecosystem based on time and money people spend getting to the ecosystem	Recreation sites	MPAs and other parks, reefs in general	Technically difficult High data requirements
Replacement cost	Estimate cost of replacing ecosystem service with man-made equivalent	Ecosystem services that have a man-made equivalent that could provide similar benefits	Coastal protection by mangroves/ reefs	Often under-estimates value as man-made equivalents generally don't provide same benefits as ecosystem
Avoided cost	Estimate damage avoided due to ecosystem service	Ecosystem services that provide protection to property and infrastructure	Coastal protection by mangroves/ reefs	Difficult to relate damage levels to ecosystem quality
Stated preference	Peoples willingness-to -pay (WTP) for ecosystem services or willingness-to-accept losses in these good and services is estimated by asking them hypothetical questions, e.g. how much would you be willing to pay for entrance to a marine park? Normally done using surveys.			
Contingent valuation	Ask people's willingness-to-pay for ecosystem services	Any ecosystem service	Entrance fees for MPAs, species loss	Bias in people's responses
Choice modelling	Similar to contingent valuation, except different combinations of services are offered as choices	Any ecosystem service	Tourism values of reefs	Bias in people's responses Technically difficult.

The selection of valuation techniques to value a specific ecosystem service will be dependent on a number of factors. Questions to ask are: is the service traded directly or indirectly in a market? Who are the important stakeholders that are affected by the ecosystem service? What are the financial resources that are available for the valuation study? and What is the availability of existing information on the value of similar resources?

Using economic values in decision support applications

By developing scenarios, weighing different investments and evaluating or assessing policy plans, a valuation study is more likely to be used in the decision-making processes. The most suitable support tool or tools to use in the valuation study will depend upon the type of decision support application, and the information available.

When all the costs and benefits of a particular decision can be calculated the most logical tool to use is Cost-Benefit Analysis (CBA). This is the most commonly used tool for decision support. In a CBA all costs and benefits over a period of time are summed up and weighed against each other. The more the sum of benefits exceeds the sum of costs of a particular investment or intervention, the more favorable it is. Costs and benefits do not have to be expressed only in monetary terms; governments normally do CBA using costs and benefits to society, which includes welfare in a broader sense.

If there is a specific goal that should be reached and there are various ways to reach that goal it is easiest to perform a cost-effectiveness analysis (CEA). Benefits are determined upfront and the most effective way to reach the goal is evaluated.

If it is not possible to convert all societal costs and benefits into monetary terms, a multi-criteria analysis (MCA) can be used. In a MCA, you quantify your criteria in different units or qualitative terms, similar to ranking. By determining the relative importance of the criteria it is possible to compare different alternatives based on these criteria.

Shellfish souvenirs for sale in Honduras.

Industrial fishing boats, Honduras.

Total Economic Value (TEV): All ecosystem services contribute to socio-economic welfare. The sum of these ecosystem services is defined as the TEV of that ecosystem and is normally expressed as a yearly value, e.g. the annual TEV of Bermuda's coral reefs based on values of six ecosystem services was US$ 722 million (Sarkis et al. 2010). TEV can also be calculated for changes to the environment; for example, how much loss of a certain percentage of coral reef would cost in terms of economic value. It is important to understand that a TEV will fail to capture the total value of the ecosystem as there are some benefits that are simply too difficult to value properly, e.g. non-use values are frequently missed out due to the difficulty associated with understanding and valuing their benefits.

Valuations tools available for use

There are several online, freely available tools or guides that can be used to help in ecosystem services valuations of coral reefs:

- The World Resource Institute provides a very clear explanation of their methods for performing valuations and a set of tools for use in valuation of coral reef fisheries, tourism and recreation and the economic impact of MPAS: www.wri.org
- Another excellent guide is 'Valuing the Environment of Small Islands: An Environmental Economics Toolkit', which provides a step-by-step process for evaluation of ecosystem services, specific to small islands: www.jncc.defra.gov.uk/
- The Natural Capital Project offers a downloadable tool for ecosystem services evaluation called InVest. However only a few of the tools are tailored for the marine environment and considerable technical knowledge is required to use the tools: www.naturalcapitalproject.org/

To effectively and rigorously conduct economic valuation of reefs, technical expertise will often be needed. Reef managers seeking to conduct ecosystem services evaluations might consider partnering with universities, NGOs or consultancies with knowledge and previous experience.

Value mapping shows the spatial distribution of ecosystem goods and services. Mapping the value of ecosystems has several purposes:

- Knowing which areas are most important in supplying ecosystem services helps to target conservation measures.
- It specifies the impact of threats. If threats are present in a value 'hotspot' then action might be prioritised.
- Different uses of ecosystems and development of natural areas often conflict with one another. By mapping ecosystem services it becomes clear in which areas there is conflict between stakeholders and a zoning plan can be developed (see Decision making).

Ecological economic modeling and climate change: Climate change is predicted to have increasingly negative impacts on coral reefs (Hoegh-Guldberg et al. 2007). However, few valuation studies have specifically addressed the impact of climate change on the supply of ecosystem services from coral reefs. Difficulties lie in understanding the complex responses of coral reefs to climate change and how those changes might then affect the ecosystem services they supply. For example, one recent study modelled the impacts of climate change on the recreational values for snorkeling and diving on coral reefs in three U.S. locations as well as the effects on existence values of the reefs (Lane et al. 2013). However, only the effects of coral bleaching on coral cover were included in the model, whereas climate change is likely to have multiple impacts on corals, including the effects of ocean acidification (Climate Change p.55). The study acknowledges the considerable number of factors not included in the model and the large uncertainty in many of the values used. Such modelling studies represent a first step to understanding the impacts of climate change on ecosystem services from coral reefs.

Protected areas planning Honduras

MANAGEMENT USES OF VALUATION STUDIES

There are several reasons for conducting an economic valuation of ecosystem services. Five of the most common goals for economic valuation are:

- awareness raising and advocacy
- influence decision making and policies
- calculate damages for compensation
- create sustainable financing by identifying
- extractable revenues for environmental management.

Community meetings Honduras.

Awareness raising

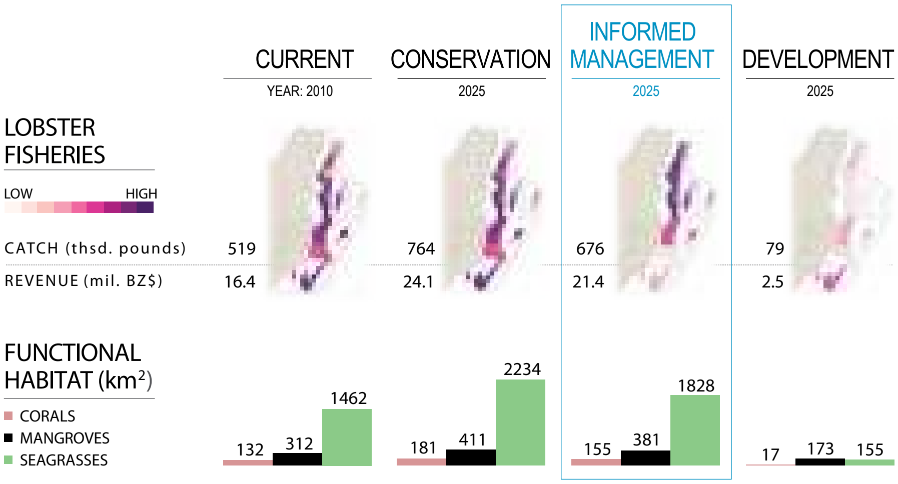
Putting values on the services that coral reefs provide helps raise awareness of how important reefs are for the economy and people's livelihoods. Ecosystem service valuations that have been carried out for a number of countries and services in the Caribbean demonstrate the economic importance of reefs to these countries and can help both decision makers and those involved in reef related activities understand understand the importance of the conservation of their reef resources (Bonaire case study p.105).

Ecosystem service valuations also highlight the role that coral reefs play in the livelihoods of local people. Many coral reefs are in small island developing states where the coral reefs are a significant source of income and food. Changes in the state of the reefs can cause considerable losses to those involved in reef based activities such as diving (Services Brief 1 p.108). and fishing (Services Brief 2 p.110).Valuation of these losses can help guide management decisions, leading to improved outcomes for the livelihoods of the people who depend on the reef.

Decision making

Nature generally has a low priority in decision-making. To integrate the value of nature into management and policy decisions it is often necessary to have an estimate of the economic importance of ecosystems. Ecosystem services valuations provide such estimates and have been used in several Caribbean countries to influence policy decisions (Table page 103).

The use of scenarios and value maps can help decision makers understand the relative costs



Changes in lobster fishery value under three potential scenarios.Example from InVEST ecosystem service analysis for Belize's integrated coastal zone management plan.

and benefits of potential development or conservation plans. The Natural Capital Project in Belize developed value maps for three important ecosystem services: lobster fisheries, recreation and coastal protection, using data, computer models and expert opinion (Clarke et al. 2012). The changes in values by 2025 were then predicted for three different scenarios; conservation, development and compromise (which represented an informed management, balancing conservation and future development needs). The resulting maps will be used to help policy makers see the potential changes in ecosystem services under different scenarios and balance the costs and benefits of development (Figure above).

Although valuations provide a monetary value of an ecosystem service, such values will never incorporate all values of ecosystems; there are some values that cannot be simply reduced to monetary terms. Valuations can therefore help guide policy but should not be seen as the total value of services provided or the only input into the planning process. This is particularly important in the case of some services which are particularly hard to value, such as the spiritual, religious and inspirational values of ecosystems.

Country	Study Site	Ecosystem	Ecosystem services valued	Policy influence of economic valuation	References
Belize	National-level	Coral reefs/ mangroves	Tourism/ fisheries/ shoreline protection	Supported action on multiple fronts, including (a) a landmark Supreme Court ruling to fine a ship owner an unprecedented and significant sum for a grounding on the Mesoamerican Reef; (b) the government's decision to enact a host of new fisheries regulations (a ban on bottom trawling, the full protection of parrotfish, and the protection of grouper spawning sites); and (c) a successful civil society campaign against offshore oil drilling.	(Cooper et al. 2009)
Dominican Republic	La Caleta Marine Reserve	Coral reefs	Dive tourism	Findings were used to justify a significant increase in user fees. Additional revenue has been used to help establish an aquatic center, a conservation fund to support park management, and a community fund to support local development projects.	(Wielgus et al. 2010)
Netherlands	Bonaire National Marine Park	Coral reefs	Dive tourism	Justified the Bonaire Marine Park's adoption (and later increase) of user fees—making it one of the few self-financed marine parks in the Caribbean.	(Dixon et al. 1993; Thur 2010; Uyarra et al. 2010;)
St. Maarten	Man of War Shoal Marine Park	Coral reefs	Tourism	Used by the government of St. Maarten to establish the Man of War Shoal Marine Park—the country's first national park. The valuation results are currently being used to sue for damages caused by the sinking of a boat inside the Man of War Shoal Marine Reserve.	(Bervoets 2010)
United States	Florida Keys National Marine Sanctuary	Coral reefs	Tourism	Established a schedule of escalating fines for injury to living coral based on the area of impact, resulting in the Florida Keys National Marine Sanctuary recovering millions of dollars for reef restoration after ship groundings.	(NOAA 2012)

Selected coastal valuation success stories in the Caribbean.

2003, M/V Kent Reliant grounded at the entrance to San Juan Harbor, Puerto Rico.

Damage assessment

Valuation of ecosystem services can be used to justify claims for damages to an ecosystem. The claims include the cost to restore the natural resource to its original state, plus costs associated with the loss of ecosystem service function, because the ecosystem can rarely be returned to its exact original state. In the Florida Keys, economic valuation of the coral reefs has been used to make claims for damages due to ship groundings (NOAA 2012). Such claims have yielded millions of dollars to restore the damaged reefs. A note of caution should be added as successful restoration of reefs is often not possible due to the difficulties associated with reef restoration efforts and the fact that damages may have fundamentally altered the physical environment of the reef area.

Stakeholders in the damage assessment process can include the community, business and government level organisations. The ideal damage assessment should assess the lost or reduced benefits from the ecosystem services to all groups. Damage claims based on ecosystem services valuations are likely to become more common in court cases as valuations become more extensive and comprehensive.

Sustainable Financing

Directly charging for the use of an ecosystem service offers one way of sustainably financing the management and conservation of ecosystems. A common example of this in the context of coral reefs is charging entrance fees for marine protected areas (MPAs). Bonaire National Marine Park (BNMP) is a frequently cited case study of how entrance fees can be used for the sustainable financing of a MPA. A willingness-to-pay (WTP) survey (contingent valuation, Table p.100) of visitors to Bonaire was conducted in 1991 and the results were used to help justify the introduction of a US $10 admission fee for SCUBA divers in the park (Dixon et al. 1993; Thur 2010). This resulted in the park becoming self-funding by the end of 1992, with the money being used to fund conservation, monitoring and enforcement of park regulations. The admission charge for divers was raised to $25 in 2005 based on the results of another WTP survey and the need to increase funds for management (Thur 2010). A charge of $10 for other marine park users was also introduced at the same time. Other marine parks within the Caribbean have followed suit and used economic valuation studies to justify the introduction of user fees (Table p.103).

Surveys conducted by FORCE researchers revealed considerable WTP from visitors for higher abundances of large fish, as well as avoiding encounters with fishing gear (Brief 1). Such results can be used to justify fees for reef management and conservation programs.

Visitors' fees help maintain national parks in Bonaire.

THE VALUE OF NATURE IN BONAIRE

The economy of Bonaire is highly dependent upon tourism, with fishing also playing a significant cultural role on the island. Both of these activities are highly dependent upon the healthy functioning of the ecosystems of the island. To gain a fuller understanding of the value of nature to Bonaire's economy and the wellbeing of the inhabitants, an economic valuation of the main ecosystem services was conducted, commissioned by the Dutch Ministry of Economic Affairs. The approach covered both terrestrial and marine ecosystems and more than 10 different ecosystem services were valued.

More than 1,500 people were surveyed, including 400 tourists, 65 fishermen, 400 local residents, and 800 citizens of the Netherlands. During the surveys the willingness of individuals to pay for the protection of nature in Bonaire was estimated, as well as mechanisms (e.g. user fees) through which such payments could be transferred.

The total economic value (TEV) of the ecosystem services valued in this study was US $105 million per year. The results of this study gained considerable attention with an associated documentary shown regularly on TV in Bonaire and local newspapers and NGOs reporting and publicizing the findings. The study has helped obtain €10 million in funding from the Dutch government for the conservation of nature in the Dutch Caribbean (including Bonaire, Saba and St Eustatius). The non-use value has been used by WWF Netherlands to secure a 3-year conservation budget for the Caribbean Netherlands.

The Dutch Chamber of Parliament has cited the coastal protection valuation in debates regarding new construction projects in the Bonaire marine park. The ecosystem service values have been used to create more insight for important decision-making.

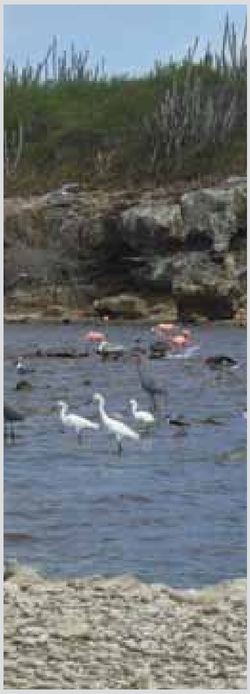
Kayaking in the mangroves in Bonaire.

Analysis of different future scenarios for ecosystem services values provided clear evidence that it is more efficient to prevent damage than attempt to restore the environment, or in the words of the study: "an ounce of prevention is worth a pound of cure". With current threats unmanaged, the TEV of nature in Bonaire will decrease from US $105 million today to around $60 million in ten years and to less than $40 million in 30 years.

The value maps that have been produced for the study will most probably be used for the strategic environmental impact assessment in the coastal waters of Bonaire. The considerable impact of this study can be attributed in part to the media coverage and associated documentary as well as the accessible online reports and policy briefs. Engagement with stakeholders and their interest in the project helped ensure its success.

FURTHER INFORMATION

What's Bonaire's nature worth? Policy Brief and reports available at www.ivm.vu.nl



Birds in Bonaire National Park.

ECOSYSTEMS → VALUES → TOOLS → APPLICATIONS

Nature in Bonaire

Terrestrial
Marine
Biodiversity

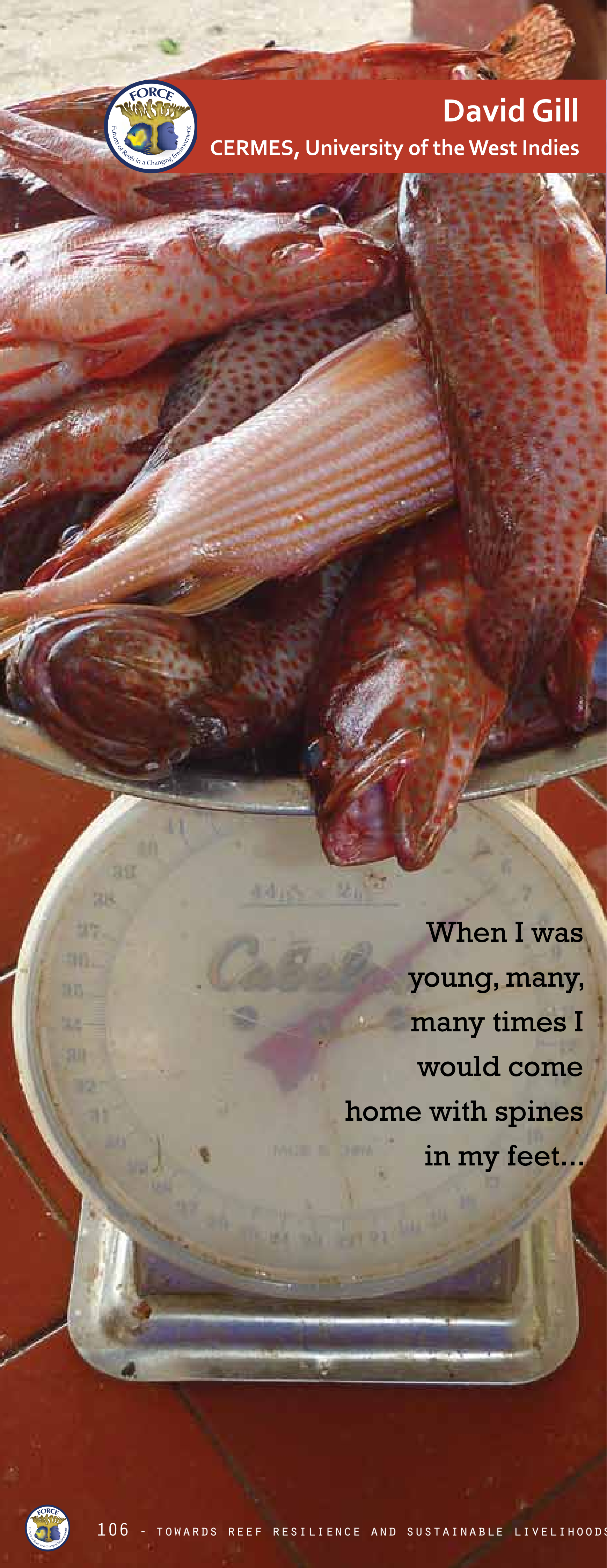
Primary data survey:
Culture & Recreation
Non-use
Coastal Protection
Fisheries

Secondary data desk:
Tourism
Real Estate
Biodiversity
Medicinal
Research

Tools:
Marine model
Terrestrial model
Value maps
Surveys
Stakeholder engagement

Applications:
Extended cost benefit analysis (CBA)
- Pier constructions
- Cruise tourism expansion
- Goat control
- Sewage treatment plant
- Solid waste management
- Etc.

Awareness raising
Policy development & scenarios analysis
Damage assessment
Sustainable financing



David Gill

CERMES, University of the West Indies

Coral reefs are extremely important for many reasons. We get a lot of goods and services from them. We commonly associate people such as fishermen and people in tourism from benefiting from reefs but we also benefit in other ways as well. They protect our shores and provide us with sandy beaches and a lot of space for recreation as well.

Yes, I have definitely noticed changes in coral reefs. One good example is the spiny sea urchin. When I was young, many, many times I would come home with spines in my feet from the beach and after about 5 years I wasn't getting any spines in my feet and also when I went snorkelling I wasn't seeing any of the long-spined urchins.

When I was young, many, many times I would come home with spines in my feet...

MY RESEARCH
is looking at what is the economic value of reef fish – to the fishing industry and to the diving industry in the Caribbean.

1

Economic value of reef fishes to the dive tourism industry: the implications of reef fish decline

2

Potential economic impact of reef fish decline on Caribbean reef fisheries

Economic value of reef fishes to the dive tourism industry: the implications of reef fish decline

THE ISSUE

Dive tourism is an important source of income for many Caribbean countries.

Every year, dive tourism contributes billions of dollars to Caribbean economies and funds marine conservation in many locations. However, the coral reefs and associated fish species that attract millions of dive tourists each year are stressed from factors such as climate change and fishing. With the current financial downturn in global economies, consumers are more conscious of their spending and want more for their money. Lower quality reefs may cause conscientious consumers to go elsewhere to experience the quality of reefs they are willing to pay for. Areas with degraded reefs and declining fish populations could therefore experience significant losses due to a decrease in their share of the dive market.

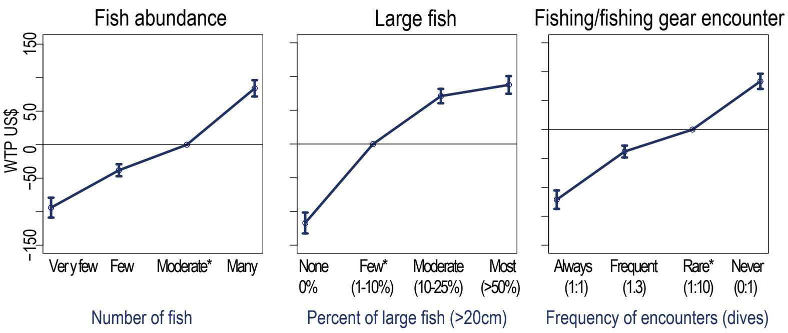
THE EVIDENCE

A large-scale survey of divers in Barbados, St. Kitts and Nevis and Honduras looked at their willingness to pay for dives with varying levels of fish life as well as to avoid encountering fishing/fishing gear. Divers stated they would be willing to pay US$51-$79 more to dive with moderate numbers of large fish (10-25% of fish greater than 20cm) compared to current conditions (i.e. 1-10%). Further, divers were willing to pay US$93-$110 more to avoid diving with very few fish compared to current conditions. Although these values do not directly represent the price that can be charged for a dive trip, the results confirm that divers are willing to pay significant sums to see abundant and large fish life and that healthy reef fish communities are a very important component of the dive experience.

If nothing is done to stem the decline of the sizes and numbers of reef fish in the Caribbean, the losses to the dive tourism industry could be significant. For example, based on the number of divers in Barbados and St. Kitts and Nevis, annual losses of US$1.2-2.1 million in diver consumer surplus (i.e. reductions in willingness to pay for diving) could be expected in each country. In the Bay Island sites (Honduras) with extremely high diver traffic, total losses could be as high as US$7.6-$12.2 million annually. Although it is not possible to exactly determine how this will affect diver numbers, divers will not utilise an area when their willingness to pay falls below the price of a dive.

School of reef fish in Honduras.

Divers willingness to pay (WTP in US dollars) for a two-dive package with varying numbers of fish, amount of large fish and fishing/fishing gear encounters, relative to the baseline/current conditions (average model with mean and standard errors). * indicates current conditions.



MANAGEMENT IMPLICATIONS

Investment in conservation

With such potential losses from declines in reef fish, spending a portion of the potential lost value to ensure the sustainability of reef fish populations appears to be justified. If fish populations are sustained or even improved, divers will receive considerable satisfaction from these areas, increasing their likelihood of return.

Investment in conservation and user fees

In order to fund conservation activities, some of the diver consumer surplus can be captured by charging user fees. For example, the operation of marine protected areas in Bonaire and Saba is almost entirely funded through user fees. Furthermore, in the current study, divers were willing to pay significant amounts to avoid fishing gear. It is therefore financially feasible to designate no fishing areas where entrance fees are charged. These no fishing areas are best chosen with some form of consensus from all marine users.

Tourism can provide a source of funding for marine reserves and management.

FREQUENTLY ASKED QUESTIONS

Aren't divers just happy to dive in warm water?

Although the dive market consists of many novice divers who may be less concerned about reef quality, more experienced divers spend more to visit higher quality sites. If your fish population degrades to the point where it is not worth their money (i.e. below their willingness to pay), they will go elsewhere to find better reefs. Better reefs gain a better reputation and more reputable reefs bring more divers, increasing revenue to local communities. This also applies to snorkeling and other underwater viewing activities.

How does dive tourism benefit the rest of the economy?

The spill-over effect of dive tourism is tremendous. The average diver spends almost twice as much as the average tourist during their stay. In many areas, the presence of a strong dive industry has also promoted environmental awareness and involvement by local resource users.

From a fisher's point of view, how does it benefit me? Does this mean that I will have to stop fishing?

Other studies have shown that protecting fish stocks in one area has had noticeable benefits to fishing on neighbouring reefs. The aim is not to rob fishers of their livelihood but to manage areas to improve the benefits to all stakeholders. Areas for SCUBA diving where fishing is not allowed can co-exist with and benefit zones with priority for fishers. Some jurisdictions have also created no-SCUBA areas where only fishing is permitted.

As a manager, what are the best ways that I can spend money based on these results?

Fish abundance is closely linked to the quality of the habitat. Spending funds on reducing stressors to coral reefs such as fishing, pollution, and physical damage will help maintain the quality of the reef habitat that high fish populations are dependent upon. Fishing reduces the average size of fish on the reef. To see improvements in the overall size of fish, fisheries-related management should be a priority. As divers appear to be averse to seeing fishing activity/gear, designating separate recreational and fishing zones can improve the dive experience as well as reduce conflicts between user groups.

Potential economic impact of reef fish decline on Caribbean reef fisheries

THE ISSUE

Reef fish catch.

In many coastal communities in the Caribbean, reef fishing represents a significant source of revenue and nutrition. However, recent declines in reef fish populations as a result of unsustainable fishing and habitat degradation threaten the livelihoods of those that depend on this fishery. Another major problem is the limited availability of data on reef fishing and other small-scale fisheries, thus affecting the ability of policy makers to make informed management decisions.

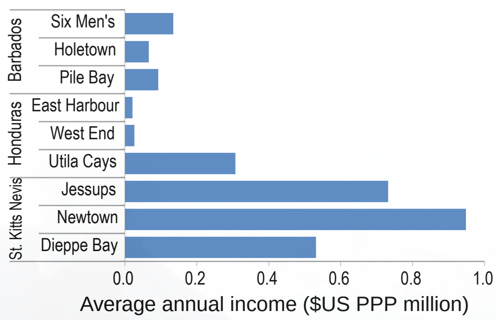
THE EVIDENCE

Fisherman with catch in Honduras.

Socioeconomic and fisheries data were collected from over 215 commercial fishers through face to face interviews and local focus groups in nine coastal communities in three countries (St. Kitts and Nevis, the Bay Islands [Honduras] and Barbados). In addition to collecting data on their fishing practices, fishers were also asked if they would change their fishing behaviour if there were changes in the numbers and sizes of fish in their catch in the future.

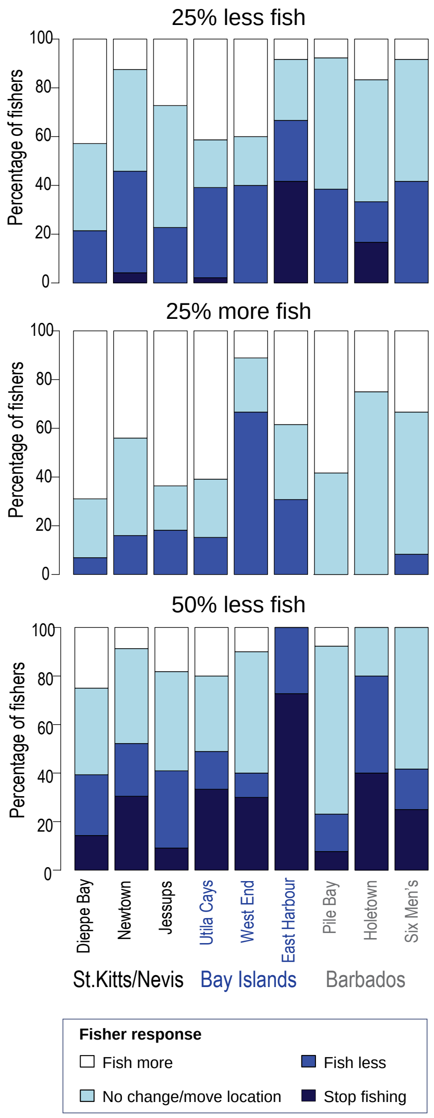
For the nine study sites, estimated annual net revenues from reef-associated fishing ranged from US$0.03-0.95 million (PPP dollars) with average net revenues per fisher ranging from US$2,549-26,489 per year.

Fishers gave varied responses to questions regarding hypothetical changes in the size and quantity of fish in their catch but overall, many fishers stated that they would not change their fishing effort.



Estimated average annual net revenue from reef-associated fishing (total per site) based on interviews with commercial reef fishers in nine coastal communities in St. Kitts and Nevis, the Bay Islands (Honduras) and Barbados.

With a scenario of increases in the numbers and sizes of fish in their catch, most fishers stated that they would fish more while others stated that they could fish less and get the same amount of fish. A scenario involving a drastic decline (50%) in the number of fish, however, led to 27% of fishers stating that they would stop fishing altogether, which could translate into economic losses due to lower catch and fishers leaving the fishery. Estimated losses in revenue at each site ranged from US$17,246 in West End, Honduras to US$618,349 in Newtown, St Kitts and Nevis. Similarly, with a 50% reduction in the mean size of fish in catch, 20% of fishers stated they would stop fishing, translating into potential economic losses ranging from US$15,919 (West End, Honduras) to US$632,090 (Newtown, St Kitts and Nevis). Importantly, these scenarios are consistent with predictions for future fish productivity if reef habitat is allowed to flatten (Fisheries: Linking coral reef complexity p.71).



Hypothetical responses of commercial reef fishers interviewed in St. Kitts and Nevis, the Bay Islands (Honduras) and Barbados to scenarios relating to changes in the size and abundance of fish in their catch five years in the future.

MANAGEMENT IMPLICATIONS

The results show that reef fishing is a significant revenue-generator in Caribbean coastal communities. Given that many rely on this fishery for income and nutrition, there is justification for substantial investment in the conservation of reef fish resources to avoid significant social, economic and ecological losses in the region.

Three options available to managers are:

Business as usual
The current regional trends of declining catch per unit effort and decreased abundance of high value species, such as lobsters, snapper and grouper (both on reef and in catch), indicate that if nothing is done to stem these declines, considerable economic and societal losses should be expected in association with declining reef health.

Restrict fishing effort
Many areas in the Caribbean with restricted fishing zones have seen an increase in the numbers and sizes of fish on the reef. To see greater benefits, the size and location of restricted fishing areas and the enforcement capacity of the managing organisation need to be considered in the planning process. Connectivity of marine species between protected areas should also be considered to improve the outcomes of all protected areas in a network (Fisheries Brief 8 p.92).

Ecosystem-based management approach
The results indicate that declining fish stocks could cause a reduction in fishing pressure, with differing responses dependent on the site, even within a country. Although this will result in significant economic and societal losses, a reduction in fishing effort would be welcomed by many managers as this could allow fish stocks time to recover. Nevertheless, reduced fishing pressure alone does not address all the driving factors behind reef fish decline, including poor water quality from land based activities and reef damage.

On the other hand, with improvements in reef fish catch, many fishers indicated that they would increase fishing effort. Therefore, if a successful MPA were to increase fish biomass outside of its borders, or if stocks were to improve after a closed season, these effects may quickly be offset by increased fishing pressure. A similar response can be seen in the intensive fishing that occurs at the beginning of open seasons when healthy, recovered stocks are rapidly overfished within the first few days.

All of these factors highlight the need for a holistic, ecosystem based approach to cope with changes in reef fish resources and user behaviour. To reduce the probability of overexploitation after stock improvements, fishing effort and the entry of new fishers could be limited during the opening of a season or in areas surrounding replenishment zones. Further, responding to poverty and resilience needs by supporting livelihood diversification and exploring more sustainable fisheries practices to meet local food demand are other solutions that could be considered.

Governance

The Wider Caribbean Region (WCR) consists of a diverse group of countries connected through the waters of the Caribbean Sea and the North Brazil Current. Marine resources such as fish move freely across national boundaries and the effects of land and marine-based pollution from one country can easily impact neighbouring nations. Coral reef based tourism and fishing both play a significant role in the economies of many Caribbean nations. Marine resources also play an important cultural and spiritual role in the lives of many people within the region. Cooperation to ensure the sustainability of marine resources is therefore in the interest of all nations. There are already many organisations dealing with marine resource governance within the WCR and the Caribbean Large Marine Ecosystem (CLME) project, briefly introduced here, aims to improve engagement and coordination among organisations. Improved governance across all levels, from local to global, is vital to ensuring improved management of coral reefs and other marine resources throughout the region.

Marine Park Office in Roatan.

GEOPOLITICS IN THE WIDER CARIBBEAN REGION

Countries of the Wider Caribbean Region.

The Wider Caribbean Region is one of the most geopolitically complex regions in the world due to the high diversity of cultures, languages, sizes of states and levels of development of countries within the region. Large continental countries, such as Colombia, are represented, as well as small island states, such as St Kitts and Nevis, with development levels ranging from some of the world's most developed countries, such as the USA, to some of the least developed, such as Haiti. In total there are eighteen small island developing states within the WCR. The region as a whole is strongly dependent on marine resources for the tourism and fishing industries which make up a large part of many countries' economies.

Many of the marine resources within the region are shared and/ or connected: fish populations move across the marine boundaries between countries; corals and reef fish produce larvae that travel freely across international boundaries. Marine transportation connects the region as large amounts of both goods and passengers (e.g. cruise ships) pass through the territorial waters of many nations. The Panama Canal is the main focus of international shipping with 5% of the world's trade passing through it.

Fishing and tourism are the main sources of income in many of the nations within the WCR. The cultural, recreational and spiritual value of marine resources is integral to the lives of many within the Caribbean.

The impacts humans have on marine resources are frequently felt across boundaries, for example pollution and land-based run-off can easily travel across the waters of several nations. The high density of small states within some areas of the region makes cooperation particularly important, although this is complicated due to disputes over exclusive economic zones (Blake & Campbell 2007; Perez 2009).

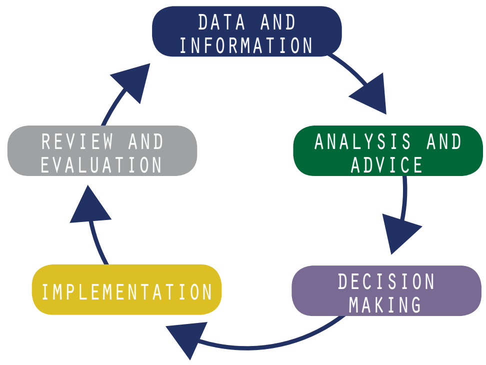
International agreements that have been signed by all countries include the UN Convention on the Law of the Sea (excluding the USA and Venezuela), Agenda 21 and the Convention on Biodiversity (excluding the USA). These agreements already allow for regional cooperation on ocean governance and there are at least 30 regional and sub-regional organisations that provide some level of governance though mainly focused on single sectors such as fisheries, pollution, biodiversity and tourism. In addition to these 'higher level' organisations there are a large number of local and national level groups and organisations, such as fisherfolk cooperatives, conservation NGOs and fisheries departments, that have a role to play in marine governance.

Given the large number of organisations already dealing with governance issues, it would be redundant to create a large region-wide organization to handle all aspects of ocean governance within the WCR. Rather it is better to create a system that enables the existing organisations to communicate and feed into the decision-making process at the appropriate level. This is one of the main aims of the Caribbean Large Marine Ecosystem (CLME) Project which covers the WCR.

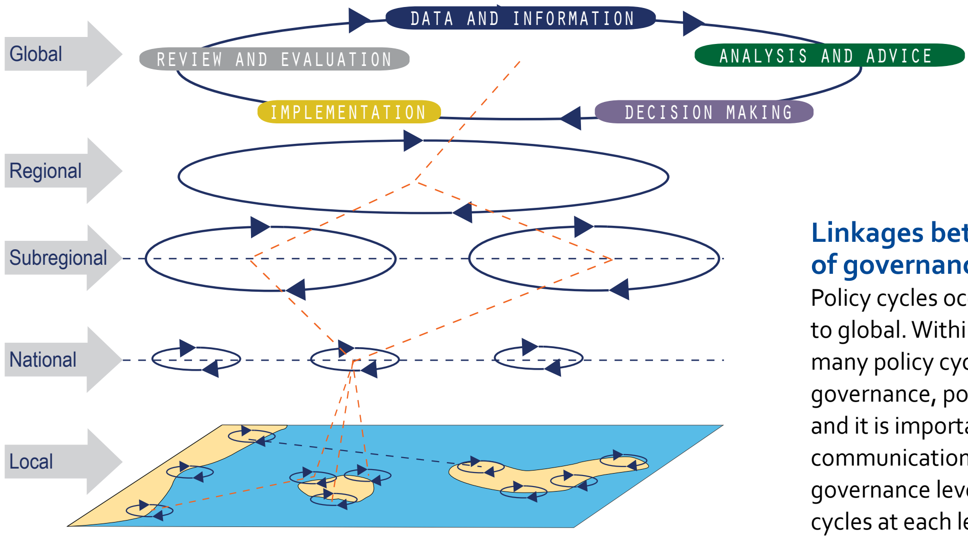
Beach tourism in the Caribbean.

THE LARGE MARINE ECOSYSTEM (LME) GOVERNANCE FRAMEWORK

A framework has been developed to help understand and improve the governance of large marine ecosystems and this framework is now being used for the CLME. It consists of two fundamental parts of the governance system: a policy cycle and a multi-scale multi-level component (Fanning et al. 2007). The policy cycle attempts to encapsulate the generic decision-making process at any level (local, national, etc.).



Generic policy cycle.



Schematic of linkages between and within levels of governance. Horizontal blue: linkages across within a level, vertical red linkages between the different levels of governance.

Linkages between and within levels of governance

Policy cycles occur at several levels from local to global. Within each level there may be many policy cycles. For an efficient system of governance, policy cycles need to be complete and it is important that there is two-way communication not only among the different governance levels but also across the policy cycles at each level. This reciprocal communication sharing allows for data and information exchange to inform improvements in governance using ideas from all levels.

Policy cycle with caribbean large marine ecosystem stakeholders for the reef fisheries and biodiversity pilot project

DATA AND INFORMATION

NGO's (Coral Cay Conservation, Coralina, TNC, WWF, WRI, Reef Check, AGGRA, CARICOMP, CZMUs, USG, Center for Climate Change), Universities & Research institutions (UWI, CERMES, ORE MU, INVEMAR, Center for Marine Sciences, CEHI), Fishers/Fishers org., Government Departments (e.g. environment, fisheries), CFMC, Databases (e.g. IABIN, SERVERE, GCRM), CCA, IFREMER. CTO, CRFM, MBRS, ICRAN, MAR, ICRAN, GCFI, Diving associations, UNEP-CAR/RCU, OSPESCA, Local MPA sites (SMMA, Buccoo Reef Trust, Sandy Island, TCMP).

ANALYSIS AND ADVICE

Buccoo Reef Trust, Fishers/Fishers Org. TCMP, SMMA Government departments, IMA, CZMU, CRFM, WECAFC, UWI & Academic Institutions, CANARI, Association of Caribbean Marine Laboratories, TNC.

DECISION MAKING

Government, CARICOM, ACS, OECS, CARIFORUM, CITES, Private sector (seafood industry), Fishers organizations, FAO, UNEP, CCAD.

IMPLEMENTATION

CBO's, NGO's, Fishers co-operatives, Local governance, TCMP,SMMA, Buccoo Reef trust, Government organiza-tions, private sector (hotels, seafood industry, diving), Enforcement & legal entities, Donors facilitating implementation.

REVIEW AND EVALUATION

(Buccoo Reef Trust), Fishers/Fishers Org. TCMP, SMMA, Government departments, IMA, CZMU, CRFM, WECAFC, UWI & Academic Institutions, CANARI, Association of Caribbean Marine Laboratories, TNC.

Coral reef fisheries and biodiversity in the CLME

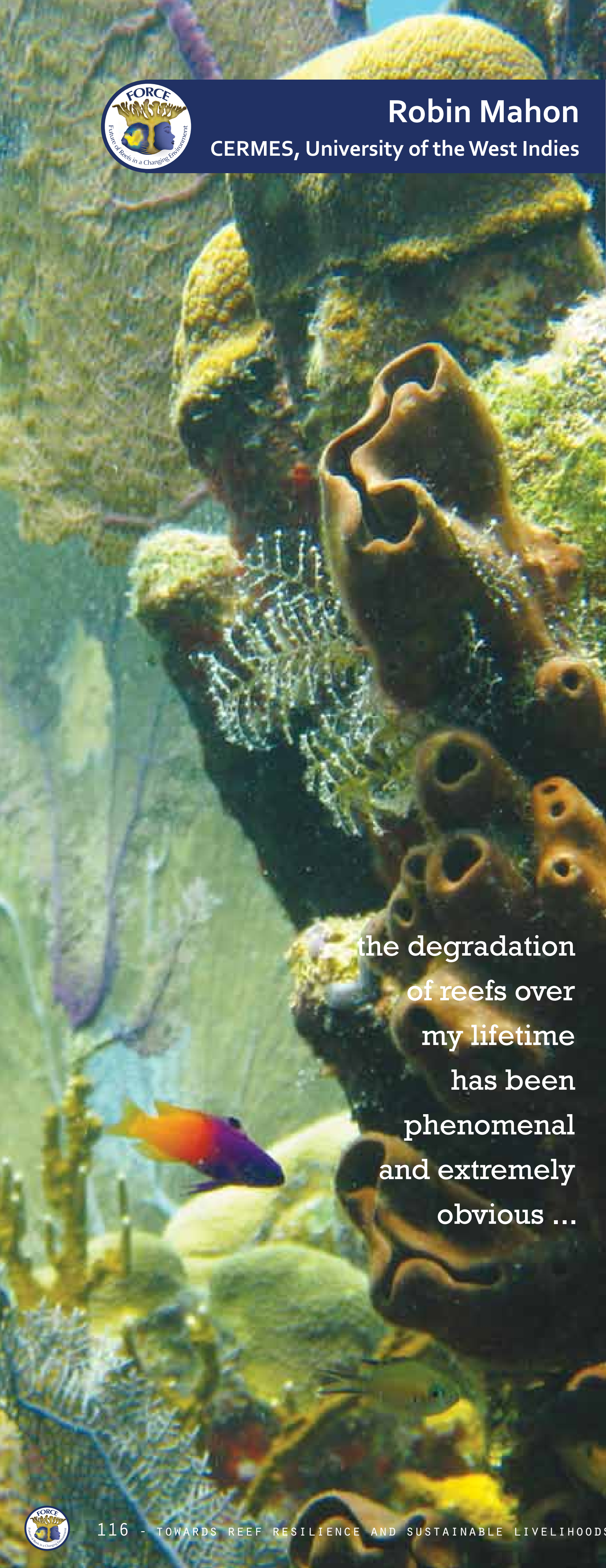
Two components of the CLME Strategic Action Programme (SAP) that are important for reef managers include addressing the issues of habitat degradation and community modification, unsustainable exploitation of resources and pollution. The focus is on a participatory approach to management involving local people in the management of their own resources. The number of organisations that can be involved in multi-level governance and contribute to each stage of the policy cycle is highlighted above. Fostering improved communication and cooperation among these organisations will help the management of coral reef resources throughout the WCR.

FURTHER INFORMATION

The CLME governance system is reviewed and explained in greater details in (Mahon et al. 2011; Fanning et al. 2013)

For a complete review of the LME framework see (Fanning et al. 2007)

Full details of the CLME project available at: http://www.clmeproject.org/



Robin Mahon

CERMES, University of the West Indies

Coral reefs are important for people in the Caribbean for so many reasons ranging from production of food, fish and other things we eat off of reefs, for production of sand to go on beaches, for protection of beaches, for people to enjoy, for tourists to visit and pay money so that tourism operators can earn a living as well. The list goes on but those are the main ones.

.

Well, you can see from colour of my hair that I've been around for a while and yes, I've seen huge changes in coral reefs from when I was young and growing up in Barbados and Jamaica and going to the sea on weekends from as early as I can remember. And the degradation of reefs over my lifetime has been phenomenal and extremely obvious to anybody who puts their head under the water. So the depletion of fish and reduction of coral cover and just the way the reef looks, from a healthy reef to one that's covered with algae, just hits you like a ton of bricks.

... the degradation of reefs over my lifetime has been phenomenal and extremely obvious ...

RESEARCH

As part of the social science (team) and governance team we are investigating what are the major factors influencing the governance of reef systems and what kinds of approaches or governance reforms are needed to addresss the problems.

BRIEFS GOVERNANCE

Governance framework to support reef management

THE ISSUE

Policy cycle with feedback from meeting participants.

Many countries and people in the Wider Caribbean Region (WCR) depend on reefs for livelihoods, food security, culture and recreation amongst many possible benefits. The health of Caribbean reefs has deteriorated because management arrangements have failed to cope with pressures like overfishing and pollution, and now climate change is adding further pressure to the reefs.

Reef management – arrangements in place to achieve sustainable use of ecosystem goods and services from coral reefs – is often pursued without consideration of the broader governance (decision-making) structures within which it takes place. Good governance structures and processes, such as transparency, fairness, accountability and inclusion of stakeholders in decision-making are important to ensure that management is context-specific and more likely to be supported by resource users.

A Regional Ocean Governance Framework (ROGF) aimed at promoting good governance within the WCR was developed in the Caribbean Large Marine Ecosystem (CLME) Project. The ROGF is mainly about regional level arrangements; however, these can only be effective if supported by good governance at local to national levels.

THE EVIDENCE

Research in the FORCE project has pursued evaluation of governance arrangements at local to national levels within the context of the broader, multilevel ROGF. It seeks to broaden the understanding of good governance for reefs at these important local and national levels and to provide recommendations on how to strengthen these arrangements to better support management efforts.

'Everything has to do with the governance, I think Governance needs to involve all actors'

Meeting participant, Honduras 2011

Basic features of the ROGF

The ROGF reflects two key governance ideas: the need for a complete policy cycle and nested, multi-level arrangements . In a nutshell, the theory states that if you have a complete policy cycle then good governance is more likely. Good governance is considered a prerequisite for management efficacy and needs to take account of multi-level arrangements. The multilevel schematic reflects the lateral and vertical linkages that must be in place within and between policy cycles at different levels which are needed for effective governance (Policy cycle p.119).

There are over 25 organizations involved in regional ocean governance leading to a set of nested arrangements addressing the key issues of over-exploitation, pollution and habitat degradation. The reef governance arrangements that are the focus of FORCE research are nested in the ROGF.

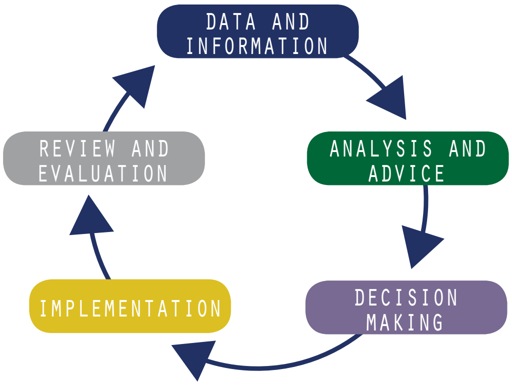
Workshop participants in Barbados discuss the policy cycle for coral reef management.

THE APPROACH

The policy cycle is a generic governance process that may occur at any level (local to global) and must be complete in order to be effective. A policy cycle review was designed to explore the groups and organisations involved in reef management and governance. This process involved:

- Identifying the government, non-government and private sector stakeholder groups involved in formal and informal governance structures that exist and govern natural resource use;
- Identifying groups involved in the governance policy cycle;
- Identifying strengths and weaknesses in the cycle.

The policy cycle exercise was undertaken at national level meetings in four countries – Barbados, St Kitts and Nevis, Belize and Honduras.



5 STAGES OF THE POLICY CYCLE

To achieve effective governance, a complete policy process is advisable. This includes the ability to take up data and information, generate advice, make decisions, implement decisions, and review all aspects of the process. Key strengths and weaknesses in the policy cycle were identified by participants at meetings in the four countries studied as part of the FORCE project.

'For smooth governance of the people you've got to earn the people's trust'

Meeting participant, Barbados 2011

DATA AND INFORMATION

Honduras
Improved data analysis, greater communication, and information-sharing is needed to support policy. Organisations are seen to be competing rather than working towards common goals due to unclear objectives despite complementary roles and responsibilities.

Barbados
Stakeholder involvement is present in the 'data and information stage', but the information is not currently being used by decision makers.

St. Kitts & Nevis
Transparency and collaboration between departments is weak. It is difficult and time-consuming to share data between agencies due to lack of standardised system for data collection and management

ANALYSIS AND ADVICE

Honduras
It was perceived that recommendations about reef management proposed by stakeholder groups are not considered by central government. Much data has been collected but few are able to analyse the data and form recommendations.

DECISION MAKING

Barbados
Participants noted that the decision making authority is highly centralised, mainly residing in the Prime Minister's office. Data are not being used in decisions made.

IMPLEMENTATION

St Kitts & Nevis
Country has received funding, though desired environmental outcomes have not always been achieved. Projects are duplicated and/ or implemented haphazardly.

Belize
Resources in the implementation phase were perceived to be lacking; decisions and management plans are created, but not enough resources to implement them.

Honduras
Participants felt improvements to the policy cycle could include greater resources for implementation (particularly for enforcement).

REVIEW AND EVALUATION

Belize
Participants identified a lack of review and evaluation, and a lack of feedback in the system. Not enough people focused on adaptive management, more groups needed in this area.

Honduras
Although many stakeholders generate information relating to reef management, participants felt there is little review and evaluation of this information, and data is not communicated effectively to decision-makers.

MANAGEMENT IMPLICATIONS

Identifying actors (individuals or organisations) involved in a policy cycle, along with its strengths and weaknesses, as well as opportunities for improvement, can build awareness of the many organisations that can potentially be better involved in reef governance. Fostering improved communication, coordination and cooperation among these organisations through application of good governance structures and processes at different levels should improve the management of coral reef ecosystems throughout the WCR.

FURTHER INFORMATION

In depth information on the Caribbean Large Marine Ecosystem Governance Framework is available via:
http://cermes.cavehill.uwi.edu/LME_Gov.html

An introduction to social network analysis for coral reef governance

Fishers and tourism operators in Barbados.

THE ISSUE

A wide range of actors both public and private are involved in the use, management and governance of coral reefs. These actors range from those who depend on the reefs for their livelihoods, to the local organisations who manage the reefs, to government agencies involved in policy and legislation development.

Management benefits from an understanding of the interactions between people and coral reefs. Similarly, relationships between the actors involved can contribute to the failure or success of governance and management outcomes. Social network analysis (SNA) is one tool that is being used to better understand these relationships.

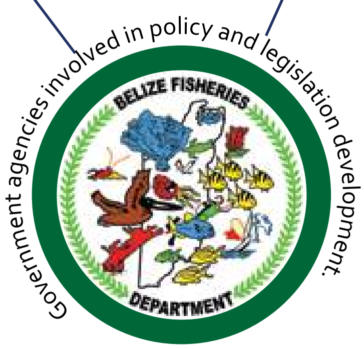
Social network analysis (SNA) is the study of actors (individuals or organisations) and the relationships that connect these actors.

THE APPROACH

In SNA, data are collected on relationships between individuals and/or organisations. Some examples of these relationships include: family ties, exchange of resources such as money or information, assistance given or received, membership of similar groups and shared attitudes or beliefs.

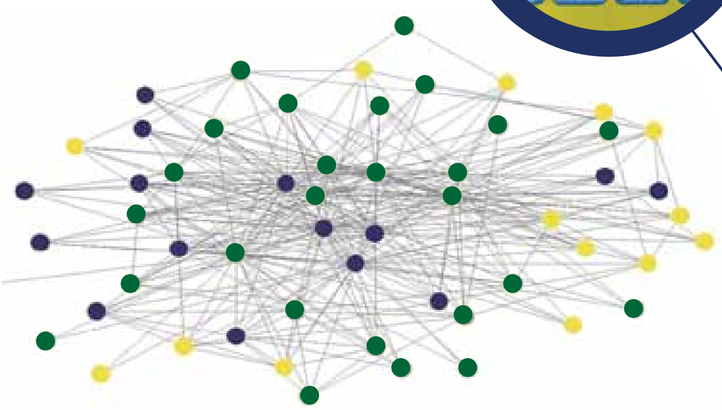
Example: To study relationships between fishers in a given community, a researcher might ask, *"Which fishers in this community do you share information with about fishing?"* or *"Which of the fishers in this community would you consider a friend?"* These questions would elicit two different networks from the same group of fishers; each potentially having a different use for managers. A network based on information sharing might be useful for managers when trying to disseminate information to fishers or gain understanding of how local ecological knowledge is transferred. A friendship network may be more important when trying to build support for new management measures.

THE TIES



ACTORS-NODES

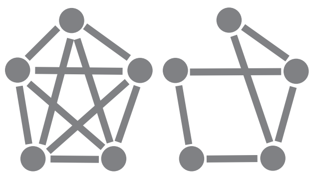
- Government agencies
- Organisations
- Resource user groups and associations



SNA can be used to create sociometric maps. This diagram presents a coral reef information sharing network for Belize. The nodes (dots) in this network include national level actors and local actors from three communities. Ties (lines) represent information sharing to or from another actor.

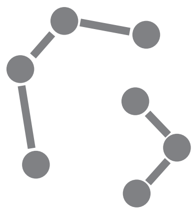
DENSITY

Total number of ties as a proportion of total possible ties.
Positive: High densities can lead to greater communication, knowledge development, exchange of ideas and resources, and build trust.
Negative: Potential for high densities to reduce input of new information and knowledge, resulting in reduced adaptive capacity, resilience, and innovation.



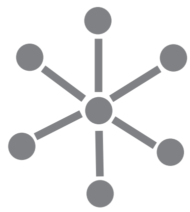
PATHLENGTH

Distance between any two nodes.
Long path length: Information and resources typically not available or accessible. Flows between nodes less efficient.
Short path length: Information and resources more accessible. Shortened feedback loops can help maintain and build resilience



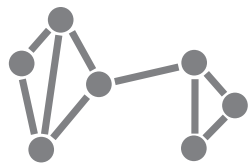
CENTRALITY

Identifies nodes that are more 'central' based on the number of ties they hold.
Positive: Actors with high centrality can coordinate and help spread diverse knowledge and resources
Negative: An actor may be unaware of their position, unwilling, or unable to facilitate exchange, functionally blocking the connections between other actors



SUBGROUPS

Subsets of nodes that have a high density within the subset.
Positive: Subgroups can be important for holding varying information and ideas, facilitating work and progress towards goals, and can increase adaptability. Greater ability to build and maintain trust and cohesion within groups.
Negative: Potential of forming an 'us vs. them' mentality.



MANAGEMENT IMPLICATIONS

There are several ways SNA could be applied to coral reef management:

- With knowledge of an information-sharing network, managers can target a few select individuals in the best positions to help them spread new information more effectively. This might be useful when new rules or regulations have been put in place but previous attempts at advertising these changes have not been effective.
- Leaders and influential individuals may not be directly obvious to a manager, yet may be critical in building support for a new initiative. SNA can identify these individuals and allow managers to better understand the roles of these individuals in the network.
- People or groups that are marginalised or isolated can be identified, allowing managers to build outreach and engagement activities to better include these actors.
- Individuals or organisations can be in positions critical to the flow of information. However, they might not be aware of the importance of the position they hold, potentially blocking or reducing information sharing in the network. Their removal from the network (like an individual leaving a job or moving to another community) could remove the only pathway for information to be shared between different groups. Identification of these critical individuals or organisations can allow managers to support them in their role, while promoting additional relationships to reduce reliance on a single individual or organisation.
- SNA can identify decision-makers' sources of information, e.g. are decision makers connected to information representing different types of stakeholder groups? Local ecological knowledge? Research institutions? Evidence-based decision-making requires information from a range of sources; SNA can highlight gaps or bias in information received by decision-makers.

Fisheries enforcement officer badge Belize.

Local marine map from Honduras.

Networks in Caribbean reef governance

Reef-related information sharing networks show different patterns of interactions. In St. Kitts for example, information sharing was found to be highly centralised around a single government department responsible for marine resources. In the Bay Islands of Honduras, fishing and tourism resource users were primarily exchanging information with local NGOs in charge of managing MPAs and had virtually no contact with government agencies. Belize, by comparison, had high levels of information sharing between resource users, local NGOs, and government agencies.

THE ISSUE

Local dive operator, Roatan Honduras.

Information brokers in reef governance

Coral reefs are part of complex social-ecological systems and successful management of these systems requires the integration of people that use and depend on the reefs for their livelihoods. Including resource users in decisions made about reefs, especially those decisions that may impact their activities with reefs, can give rise to many benefits such as increased compliance with regulations and reduced management costs. However, many resource users are often not involved in or made aware of the decision-making process.

Brokers connecting resource users to decision-making bodies are thought to be critical in adaptive management. In coral reef governance, brokers are often local reef managers, though could be resource user associations such as a fisherfolk cooperative, individuals, fisheries officers, environmental NGOs, or even businesses. Their position allows them to hold information from a range of sources, respond early to threats and changes, and see new opportunities. Understanding brokerage relationships and their effect on governance outcomes (e.g. stakeholder participation) is a crucial step in navigating the complex socio-ecological systems of coral reefs and implementing successful management.

THE EVIDENCE

Interviews with reef resource users, NGOs, and government agencies were conducted in four countries (Barbados, St Kitts and Nevis, Belize and Honduras) to map information sharing networks and identify reef-related information brokers. Resource users' perceptions of information sharing and opportunities to participate in decisions made about reefs were also assessed.

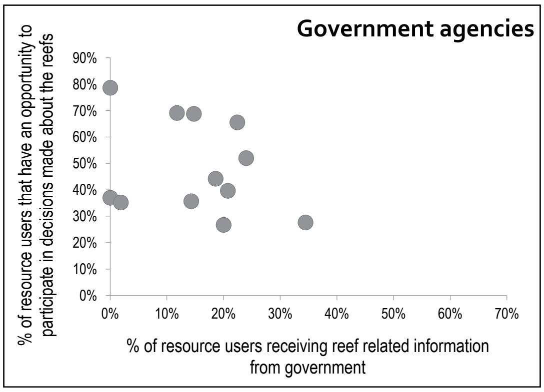
A broker is an actor (organisation or individual) that connects two otherwise unconnected actors. Brokers are sometimes known as bridging organisations.

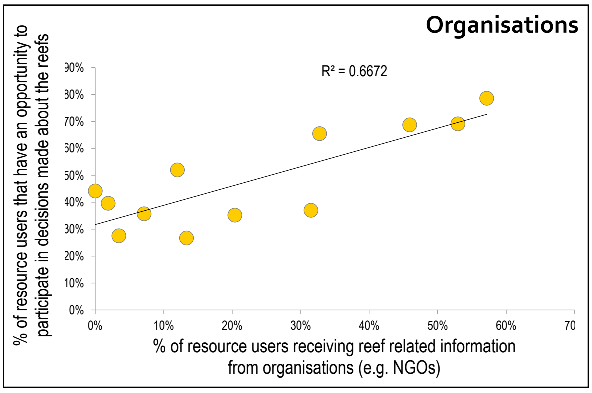
Social network analysis found that resource users were typically not well integrated into the information sharing networks. Local reef managers, environmental NGOs, or national fisheries agencies were most frequently found in positions to broker reef related information between resource users and other actors in the networks. However, these organisations and agencies were not always acting as effective brokers.

Evidence suggests that NGOs are more effective at sharing information with resource users. In communities where resource users were more likely to get information about reefs from an NGO, in particular NGOs that act as local reef managers, the users were more likely to feel like they have an opportunity to participate in decisions made about the reefs. Though government agencies were identified as brokers, they were less effective at reaching individual resource users.

Roatan Marine Park, Honduras.

Information received vs. opportunity to participate in reef decision-making. Points represent 12 study communities.





SIGNIFICANT BROKERS	GOVERNMENT AGENCIES e.g. fisheries, Coastal Zone Management	MIX OF GOVERNMENT AGENCIES AND ORGANISATIONS	ORGANISATIONS e.g. environmental or co-managing NGOs
MPA presence	No MPA or government managed MPA	Co-managed MPA	

The types of actors in significant roles brokering information to and from resource users in each study site corresponded with presence and management type of marine protected areas (MPAs). Significant brokers of reef-related information to/from resource users were identified for each of the study sites. The type of actor in these positions corresponded with the type of management present at the site.

Brokers can encourage participation

Over 78% of resource users from West End in the Bay Islands, Honduras stated that they had the opportunity to participate in decisions made about the reef. Roatan Marine Park (RMP), a community based NGO that co-manages the marine park, had a strong presence in West End. Signs from the marine park were frequent throughout the community informing users and visitors about the area. The dive shops in the community visibly supported the marine park and their endeavours. When asked who they received information from about the reefs, over 55% of resource users responded with the Roatan Marine Park. In addition to being an effective source of information for local resource users, the marine park was well linked to government agencies and other NGOs in the country.

MANAGEMENT IMPLICATIONS

The research highlighted here demonstrates the importance of organisations in brokering information to resource users. Information sharing, depending on the source(s) (e.g. NGO, government agencies) and the method(s) of interaction (e.g. community meetings, newsletters), is an important part of resource users feeling like they have an opportunity to participate in decision-making. Benefits from participation can include increased cooperation, higher perceptions of fairness of decision-making, increased compliance with regulations and reduced costs of management. It is important to recognise and support organisations and agencies that facilitate information exchange with resource users.

Many factors can affect the efficacy of a broker, a few points to consider are:

- The quality of information shared
- Method(s) of sharing; face-to-face interactions are more likely to lead to positive outcomes
- History of relationships between the broker and other actors
- Personal relationships (e.g. familial, friendship) of individuals within the brokering organisation and individuals in other groups
- Continuity and consistency of interactions

Brokers help to bridge gaps that may exist due to barriers such as language, geography, or social strata.

Assessing the proximate and ultimate drivers of reef health

THE ISSUE

Vibrant reef in Curaçao.

Caribbean reef health has declined rapidly in recent decades, with predicted impacts from climate change expected to put more stress on reefs over this century. At the same time, the demand for ecosystem services provided by reefs is increasing. Reef management is likely to be easier where people have a good understanding of the causes and consequences of changes in reef health and how they are affected by them.

It can be easier to manage a threat when it is well understood. Recognising both the proximate and ultimate drivers of change in Caribbean reef ecosystems will aid understanding. Research has largely focused on understanding the proximate causes of impacts to reefs, such as the lack of fish, nutrient levels, and so on. Studies of the ultimate drivers attempt to identify the ultimate – often social – reasons that these problems exist. Because these tend to involve people, this is where management can have an impact.

THE EVIDENCE

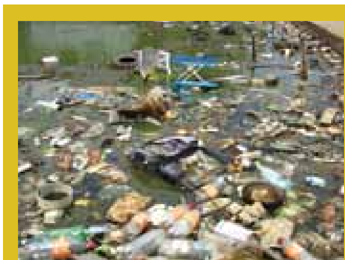
Interviews were conducted with a range of reef stakeholders in four countries (Barbados, St Kitts and Nevis, Honduras and Belize) to assess their perceptions of the drivers of reef health. These stakeholders included community households and 'key informants' such as local level community reef managers and national reef managers and policy makers.

A wide range of proximate and ultimate drivers to reef health were identified by interviewees. In total 39 proximate and 79 ultimate drivers were mentioned. The community interviewees mentioned 33 proximate and 48 ultimate drivers, compared with the key informants who collectively mentioned 37 proximate and 76 ultimate drivers.

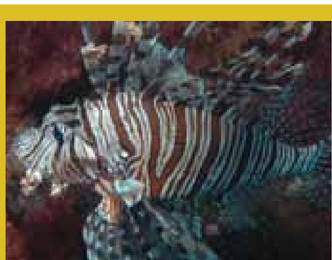
At the community level, people were most concerned with proximate drivers relating to pollution, rubbish and physical damage. Ultimate drivers relating to unsustainable tourism, snorkelling and diving, and coastal development were also commonly mentioned. In contrast, key informants were most concerned with ultimate drivers relating to non-compliance, enforcement, and resources and capacity, leading to ineffective reef management. Proximate issues relating to unsustainable fishing, pollution and physical damage were also commonly mentioned by key informants.

Snorkelling in Honduras.

Proximate drivers act directly on the reef, e.g. coral bleaching, pollution, and hurricane damage



Pollution



Invasive species

Coral bleaching

Top 30 proximate and ultimate drivers mentioned by community members.

Top 30 proximate and ultimate drivers mentioned by key informants

Larger text indicates constraints more frequently mentioned.

MANAGEMENT IMPLICATIONS

The research highlighted here demonstrates the complexity of impacts affecting coral reefs, and the importance of increasing our understanding of ultimate and proximate drivers of reef health. Reef management may be improved by taking two key issues into consideration:

- Identifying the ultimate drivers that act through proximate drivers can help address the underlying causes of reef degradation.
  Example *Sediment is one of the proximate drivers. One of the ultimate drivers might be poor coastal development practices that increase sediment on reefs. Hence improving coastal development regulations will help reduce sediment. Focusing only on the sediment (proximate driver) as the problem, e.g. trying to divert sediment flows away from the reef, might be useful but would not address the ultimate driver of increased sediment. Other ultimate drivers in this case might include lack of regulation, lack of political will to regulate and economic pressures to allow development.*

- Building a common understanding of drivers between the people that use the reefs and those that are responsible for managing them. If managers' and resource users' perceptions of the drivers of reef health are very different, it may lead to a lack of support for management measures as resource users may not perceive restrictions to be necessary. Identification of differences in perceptions may indicate important areas for potential awareness-raising and education.
  Example *If managers perceive fishing pressure to be a major driver of decline in reef health, but fishers attribute the decline to other causes such as pollution, attempts by the managers to regulate fishing may be met with resistance by the fishers.*


Tourism.


Fishing


Coastal development

Ultimate drivers may be physically seperated from the reef, e.g. overfishing, poverty, climate change, and poor governance.

Identifying and addressing governance constraints to reef management

THE ISSUE

Marine reserve patrol boat in Barbados.

The structures and processes that support decision making about the management of coral reefs can be described as reef governance. Good governance is considered important for effective management of coral reefs and other natural resources. Understanding the existing governance constraints can help managers identify the most appropriate management tool to plan for current and future changes.

Constraints could include a weak structure where organisations do not communicate with each other and are unaware of institutional arrangements related to reef management ('Governance architecture'). The lack of a governance process to facilitate effective communication and co-ordination (e.g. no clear leadership) is another constraint.

THE EVIDENCE

To explore perceptions of the current constraints to reef management, 117 'key informants', including reef managers and policy- makers at local and national levels, were interviewed during the FORCE project. Interviews were conducted in four countries (Barbados, St Kitts and Nevis, Honduras, and Belize) chosen to represent a gradient of governance structures, social and economic conditions, and levels of marine resource dependency in the Caribbean.

Interviewees identified a wide range of constraints to reef governance that were categorised under five themes that describe different aspects of the factors needed for good governance: influencing factors, system governability, governance architecture, governance process, and management.

Constraints in the 'Management' theme were most commonly mentioned. Over 80% of respondents reported challenges related to achieving effectiveness in enforcement, resources, capacity, and compliance.

Constraints relating to governance processes were also commonly mentioned, with four of the most frequently mentioned constraints falling under this category. These included a lack of education and awareness among reef users, which affected how people interact with reef resources; a lack of engagement of reef users and community members; a lack of cooperation and integration among groups and organisations involved in reef management; and a lack of information and research to support effective management of reefs.

Meeting with fishers.

Governance constraints mentioned by interviewees

- Influencing factors
- System governability
- Governance architecture
- Governance process
- Management

Larger text indicates constraints more frequently mentioned.

INFLUENCING FACTORS	SYSTEM GOVERNABILITY	GOVERNANCE ARCHITECTURE	GOVERNANCE PROCESS	MANAGEMENT
Factors external to the reef governance system that influence reef governance. E.g. socio-economic pressures, cultural factors, political will.	Inherent properties of the system to be managed that present challenges. E.g. complexity, scale, dynamics, diversity.	The structures or arrangements in place for reef governance. E.g. Institutional arrangements, legislation, regulations and policy.	Processes, procedures and principles that guide interactions, planning & decision-making. E.g. Leadership, engagement, transparency, connectivity.	Implementation of reef governance decisions and factors influencing capacity to manage. E.g. Resources & capacity, enforcement and implementation.

MANAGEMENT IMPLICATIONS

An understanding of the current governance constraints faced by reef managers can help improve reef management in two ways:

- It can help managers identify particular management tools that may be more successful under the current management constraints.
  Example *In cases where effective enforcement is perceived to be a constraint, management approaches that aim to increase stakeholder engagement, stewardship and voluntary compliance may be more effective than management tools that rely on enforcement of regulations.*

- It can help to identify appropriate and targeted interventions needed to improve governance which in turn can support more effective management of coral reefs.
  Example *Where a lack of cooperation and integration among reef managers is identified as a problem, efforts can be made to identify mechanisms to improve communication flows among different groups and organisations.*

Governance is the whole of public as well as private interactions taken to solve societal problems and create societal opportunities.

Exploring community futures for reef governance

THE ISSUE

Exploring future scenarios in St. Kitts and Nevis.

Coral reefs are part of complex social- ecological systems and sustainable management of these systems requires the integration of people that use and depend on the reefs for their livelihoods now, and their engagement with a future in which reefs remain important. Sustainability requires "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987) *and reef managers must try to incorporate such future needs.*

Structured techniques have been developed to encourage 'futures' thinking. Scenario work is one approach. To operate in an uncertain world, managers need to be able to question their assumptions about the way the world works. Decisions can be better informed, and strategies based on this knowledge and insight will be more likely to succeed. Scenarios describe plausible future worlds, but do not seek to predict the future.

THE EVIDENCE

Conducting scenario workshops with communities that use marine resources differently can highlight many differences in their ability to see and shape their own futures.

Future scenarios are possible views of the world. They provide a context for decision making. This process can help managers prepare for realistic future challenges.

Four scenarios are conventionally described, based on two axes designed around critical future uncertainties. This allows managers to see a divergent range of possible worlds. The process is structured to allow people to start 'consciously' thinking about the future. Data are less critical than the process: this should be creative and shared, allowing time for reflection about the future of the resource and dependent communities.

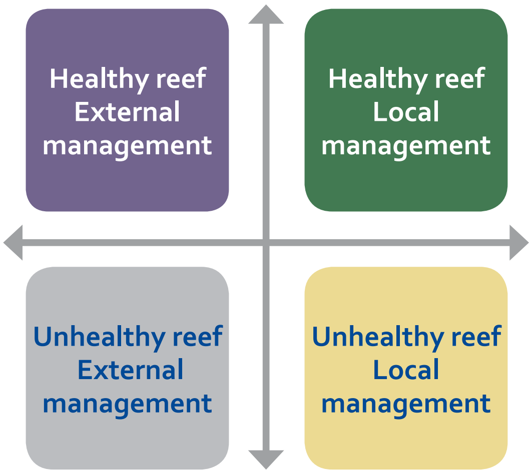
The following pages describe the futures process undertaken by the FORCE project. Examples of data generated by meeting participants in the Bay Islands of Honduras are then presented. The technique specifically aims to encourage discussion of 'extremes'. Narratives are polarized by design, but realistic glimpses of possible future worlds are visible within each.

A focal question was identified. "How can we best address threats to coral reef systems and the coastal communities that depend on them, and support coral reef management/governance in the future?"

Reef tourism.

Critical uncertainties were then defined as:
a) whether future decision making would be internal (i.e. local management) or external to the community, and b) the health of marine resources (healthy/ unhealthy reef); leading to a scenario matrix.

Community meetings were conducted. Members of each community were invited to discuss each of the four plausible futures in small groups. Workshops were planned for each study site. Ten communities (Barbados 3, Honduras 3, St. Kitts 2 and Belize 2) ultimately participated in the facilitated discussions.



Scenario matrix.

FISHING COMMUNITY	MIXED USE	TOURISM COMMUNITY

Visions of community futures in the Bay Islands of Honduras.

LOCAL MANAGEMENT

	Fishing community	Mixed use	Tourism community
Healthy reef Local management	Ecosystem dependent businesses flourishing, co-operatives ensure all benefit, positive feedbacks as tourist target species and ecosystems protected.	Cooperation creates high value island brand. Grants set fishers up with new professions, in diversified tourism industry (terrestrial takes pressure from marine). Lots of fish, impressed tourists, more work. Better education; everyone proud of healthy environment.	Culture shift – pride in all aspects of environment. High value reef – brings high value tourism; more jobs, more responsible cruise ships. People with more disposable income. Greater education.Marine park with more power and authority.
Unhealthy reef Local management	No tourism, no fishing, regulation means people can't live. Cays forgotten by government which allows resource depletion.	People live in poverty - islanders and mainlanders. No collaboration between communities. Low value tourism. Wholesale environmental damage – rubbish, pollution, reef damage – no one cares.	No resources, so no tourism. Locals resist government as taxes are taken and nothing is given back. Exodus of mainlanders and islanders – people seek work elsewhere. Increased crime, alcohol, drugs, corruption; decreased education/opportunity.

EXTERNAL MANAGEMENT

	Fishing community	Mixed use	Tourism community
Healthy reef External management	Government protect more and provide more projects to give people alternatives/ help people support their families. Lots of tourism, big taxes to government. More rules to protect marine species. People obey laws.	National marketing as a tourist destination. High employment. Support for local business, e.g. Microfinance. More alternative jobs and education so less fishing. Government regulate development -carrying capacity assessed. Stricter enforcement; population control. Equity of regulation and enforcement.	Increase in foreign investment, revenue generated for government, land in foreign hands, injustice and lack of equity for local people, increasing crime. Support for improving education and awareness, but jobs for local people limited to service level.
Unhealthy reef External management	Greater regulation, ecosystem based livelihoods abandoned, government support for new alternatives needed, communities supported by state.	Government abdicates responsibility for islands, no distribution of wealth. Corruption rife. No reef, no divers, no income. Resources exported. No incentives for businesses to stay, unemployment.	Big multinational companies in control, not government. More cruise ships, more damage, no corporate social responsibility. Resource deteriorates Tourism value drops, industry disintegrates.

HOW IS IT DONE?

By following a structured process, scenarios aim to capture four very different, but 'plausible', futures, including both good and bad aspects. These seek to maximise the diversity of futures imagined, to allow managers to plan proactively, developing policies that are robust against a wide variety of possible future events.

1) Find a venue. Invite community members who have attended interviews and project meetings.

2) Review project findings. Introduce thinking about the future on the basis of trend that community has previously identified.

3) Introduce structured scenario approach to thinking about the future, and explain the exercise.

4) Allocate a facilitator and a note taker to each group, to help with and record discussions.One person per group writes up main points for the wall.

5) Break into groups, ideally one group to discuss each scenario.

6) Facilitators stick main points onto the wall during the course of discussions, picking out the main themes as they go.

7) Until the full picture emerges.

8) The main themes emerging are discussed, and contributors have an opportunity to see the 'other' three scenarios.

9) Participants review all scenarios and are asked to vote on what aspect (across all worlds) they think most likely to actually happen in their community in the future.

10) Participants also vote on the element that they think would have the biggest impact if it did occur in their community.

11) Main events and weightings are then analysed to identify priorities for management. i.e. avoiding pathways that could lead to the 'greatest impacts'.

LOCAL MANAGEMENT: CAPACITY TO ACT

Fishing Community
Like the idea of this, but have little concept of the actions required to get there, still reliant on 'government' to help.

Mixed Use
Detailed vision of actions required to create a more positive environment, community will to achieve this.

Tourism Community
As fishing, but appear to perceive that they would have less control in any future as the multi-nationals already have a strong hold.

Fishing Community
Little concept of being able to take control without guidance.

Mixed Use
Scraping by in a deteriorating environment, knowledge that behaviour change is required to avoid this – community seems to have capacity to take action.

Tourism Community
Strong people with broader perspective of possibilities elsewhere - options to leave.

EXTERNAL MANAGEMENT: WILLINGNESS TO ENGAGE

MANAGEMENT IMPLICATIONS

Scenarios do not predict the future, but do illuminate drivers of change. Understanding them can help managers working with communities to develop successful conservation actions.
Example *If local populations are predicted to expand, proactive sustainable local development (housing) and food security (fishing vs. other protein sources) plans must be updated if coral reefs are to be adequately prioritised.*

The main value in the process is the development of shared views of the future. This can be used to create opportunities for groups with common aims to consider how they want to position themselves in those futures.
Example *Indigenous Garifuna people in Hopkins, Belize have developed cultural tourism in community groups to take pressure off declining reef tourism resources.*

FURTHER INFORMATION

Most major government departments around the world use foresight methods similar to those discussed here. Many resources are available, e.g:
www.bis.gov.uk/foresight, www.dlr.de/, www.ipcc.ch/

The Brundtland Report 'Our Common Future' – UN 1987
http://www.un-documents.net/our-common-future.pdf

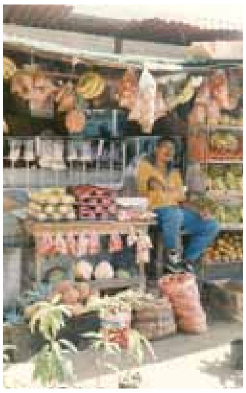
Livelihoods

Coral reefs not only play a critical role in ensuring the health of coastal and marine ecosystems, they also underpin many aspects of the lives of people who live in the Caribbean. Many of the livelihood activities of people in the Caribbean depend directly or indirectly on the services provided by coral reefs in the form of: fish for food and sale (provisioning services); the maintenance of overall ocean health and productivity (supporting services); coastal protection (regulatory service); and the provision of recreational and cultural activities (cultural services).

People's dependency on the reef has often led to an approach to managing coral reefs that has focused on controlling human activities that are seen as detrimental to reef health. However, undertaken in isolation, efforts to control or eliminate those human activities have often proved ineffective or damaging to people's livelihoods. This is frequently because of failure to fully understand how coral reef use (including unsustainable and destructive uses) interacts with the other activities that coral reef users undertake, the complexities and dynamics of the setting in which they live and the linkages between the different elements that make up the 'livelihoods' of coral reef users. The Caribbean reef livelihoods framework detailed here can be used to better understand the complexities of the interactions between people and reefs, and how livelihoods are affected as a result of these interactions.

Fisheries and tourism provide important livelihood opportunities in the Caribbean.

UNDERSTANDING LIVELIHOODS



Fruit stall in Jamaica.

To begin to understand the complexities of the interactions between reefs and reef-dependent people it is useful to apply the Sustainable Livelihoods Approach (SLA) to this interaction. The result has been the development of a Caribbean reef livelihood framework. This can be used to understand the interactions between people and reefs, to develop appropriate responses to reef livelihood dependency and to ensure sustainable reef-use. This is particularly important in the face of climate change which threatens to undermine many of the livelihood opportunities now available to coastal people.

The term 'livelihoods' has come to be increasingly associated with efforts to improve the management of coral reefs. In particular, coral reef management initiatives with 'alternative livelihoods' interventions are becoming more common. These generally aim to improve the effectiveness of coral reef management measures by providing alternative forms of income-generation to those

Local restaurant on the beach.

people who are negatively impacted by new management measures that may have deprived them of access to important resources on which they depend.

Detailed evaluations of alternative livelihoods initiatives have been rarely carried out, but there is a growing consensus that their effectiveness has been mixed (Haggblade et al 2002; IMM et al. 2005; GEF 2006). This failure to match expectations can be attributed to a lack of understanding of the complexity of livelihoods. Coral reef managers would benefit from a good grasp of these complexities if they are to incorporate human dimensions into their management plans.

Understanding of livelihoods, and the factors that are likely to make livelihoods sustainable in the face of change, need to take account of a broad range of factors and influences that may play a role at multiple levels. These levels range from the individual, to their immediate household, to the surrounding community, right up to policy and decision-making at the national and international levels, as well as at the level of society as a whole.

Defining 'Livelihoods'

"A livelihood comprises the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household".

Ellis F., 2000. Rural livelihoods and Diversity in Developing Countries. Oxford University Press.

"A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base".

Carney D. (ed) 1998. Sustainable Rural Livelihoods: What Contribution Can We Make? Papers presented at the DFID Natural Resources Advisors' Conference, July 1998. DFID.

CARIBBEAN LIVELIHOODS FRAMEWORK

First of all, livelihoods are not just about how people earn a living or produce food, but need to be understood holistically. Some of these key elements, and the relationships among them, are shown in the Caribbean Livelihoods Framework. In this framework, a key starting point for understanding livelihoods is placing **PEOPLE** at the centre of the analysis. Understanding people's diversity and their different characteristics as individuals **(WHO THEY ARE)** is key in attempting to understand their livelihoods. The livelihoods of men will usually be significantly different from the livelihoods of women; older people may have different relationships to different elements in the framework compared to younger people. Ethnicity, personal and family history, linguistic and cultural background, and relative ability or disability may all have a critical influence on how people are able to create a livelihood.

This focus on people is critical because different people have different levels of access to the assets or capital that they make use of to create a livelihood. Gender, age, ethnic group, socio-economic standing or personal history will all affect how people are able to access and use different types of natural, social, physical, financial and human assets **(WHAT THEY HAVE)**. For example, women may have different levels of access to education compared to men, which will affect their human assets, while older people may have very different social networks compared to younger people, affecting their social assets.

Livelihoods cannot only be understood by looking at the level of individuals or households, but need to include an understanding of the formal and informal institutions around them, policies that may affect them, and the processes going on in wider society that influence how they are able to pursue a particular livelihood. The Caribbean Livelihoods Framework focuses on three key areas of these policies, institutions and processes. These will often operate at different levels – the community that reef user households live in; the wider area or region where they are located; and nationally. Public and private service providers will often play a key role in affecting how people are able to access critical assets, including food to buy, equipment they need to produce food, services like transport and power, access to finance and credit, as well as to healthcare and education. In turn, the way these service providers function will be determined by policies, legislation and resources usually decided upon at higher levels by controllers or rule-makers. These include elected representatives whose task is to decide on legislation, policy-makers, civil servants, the judiciary, and all those who set the rules that determine what people are able to do to create a livelihood for themselves. More intangible influences from factors that may not be linked to specific organisations but which permeate society, such as power, communication, markets, norms and values, and culture or tradition, will often be as important as other more structured institutions.

The Caribbean Reef Livelihoods Framework aims to provide a lens through which the livelihoods of people living in the Caribbean and depending on coral reef resources, whether directly or indirectly, can be interpreted.

The influence of people's background on opportunities in the tourism industry

In many communities studied by the FORCE project there were strong perceptions that access to opportunities in tourism tended to be dominated by 'outsiders' – either foreigners or people from outside the local community – largely because they have better access to the capital required for investment in tourism facilities. Particularly where tourism has led to changes in access to beach areas and the use of the coast, this can affect local people's attitudes to tourism and to efforts to protect the reef areas which attract tourists. Age also plays an important role in people's perceptions of the opportunities that they can take advantage of in tourism. Older fishers often seem to have greater difficulty in adapting to changes in fishing access while younger people may find it easier to diversify their activities to take advantage of new opportunities in fishing.

Cleaning fish in Barbados.

Boats and fishing are an essential part of peoples livelihoods.

Reef managers need to be able to understand the relationships between people and their surrounding environment if they are to understand how people make decisions about their livelihoods. The way these linkages and relationships between people, service-providers, and rule-makers work are critical in establishing what sort of livelihood options are open to people.

Communication, transparency and fishers' perceptions of fisheries regulations

A recurring theme in discussions held with fishers was the lack of communication regarding new fisheries regulations prior to their introduction. Fishers in Barbados, Honduras and Belize all described how they often found themselves prevented from fishing, either in new protected areas or because of new licensing laws, without ever being informed or having a chance to comment on the new laws. Failure to take account of damage to fishers' livelihoods or to accommodate long-standing fishing traditions when formulating new regulations was a particularly sensitive issue. As a result, fishers often saw these regulations as an unfair imposition, even though they often agreed in principle with the need for controls on fishing activity. Others commented on how implementation of regulations was often uneven or influenced by family connections and preferences. As one fisher put it: "..if [they] don't like you they put you in jail but if they like you they leave you and let you go. That's the way it works...".

Sea urchin harvest in the past.

For example, rules may have been established about reef access and use at the national, policy-making level. However, if they are not effectively communicated to people who make use of those resources, or if they have been determined with limited consultation of the people directly involved, they may be perceived negatively, or ignored. Similarly, even if rule-makers have communicated with the service providers (such as Fisheries Officers or Park Managers) who are responsible for enforcing them, if they have not also provided the resources necessary to carry out enforcement, the rules may never be put into effect. In turn, the effectiveness of enforcement will often be determined by the relationships between enforcers (service providers) and reef users. If there is limited communication and consultation between the two, and if local institutions and leaders are not involved in the process of enforcement, regulations may be ignored or opposed by resource users.

Thinking about the quality of these relationships is therefore important. These 'qualities' include, for example, the extent to which there is effective communication in these relationships (e.g. Do rule-makers and service providers listen to what resource users are saying? Is there effective communication between the people who make rules and regulations and the service providers who have to enforce them?) Transparency and accountability in these relationships is also an important quality This might mean that the people who make rules and laws be held accountable for their decisions and the process of decision-making is made clear to everyone. Service providers should also be held accountable for the quality of their services, both by people on the ground and rule-makers. Often working to improve these relationships, such as by increasing accountability and transparency or creating opportunities for participation and communication from both sides in these relationships, can be more important for people's livelihoods than simply providing them with new sets of assets or training them in a new type of activity.

The ways in which people interact with service providers and rule-makers are also affected by wider processes in society: factors like politics, power relations, dominant values, markets forces, and the ways in which people's rights are recognised and upheld. Clearly, many of these factors are difficult to change in the short term, but the ways in which they influence people and institutions need to be understood and taken into account.

As shown in the framework, all these complex interacting factors operate within a broader context of external challenges. These are factors over which it may be very difficult to exert any direct influence. These external elements include shocks like hurricanes or earthquakes, cyclical changes like seasonality, or very long-term processes such as rising populations or climate change. These external factors may be very difficult to avoid, but the extent to which people can respond and be resilient in the face of these factors will depend very much on how effectively the relationships at the centre of the framework function: if decision-makers and service providers are supportive of people in their attempts to create a viable livelihood and the linkages between them are strong, people's resilience and capacity to adapt to external changes is likely to be better.

For the people at the centre of this framework, their choices regarding their livelihoods, and the way they respond to different changes in the many elements that make up their livelihoods, are determined by how all of this fits together. Reef managers need to recognise that often their interventions represent just one part of this more complex picture - their focus may be on improving the sustainability of one particular set of natural resources that people regard as a livelihood asset, e.g. fisheries. The way people respond is likely to take into account a very wide range of different influences. These will determine people's hopes and aspirations for the future, their perceptions of what constitutes an opportunity or a threat and, eventually, the choices they make and the actions they take to ensure a livelihood for themselves and their families.

Reef managers should ideally see their work in this context to help face the challenge of understanding how their actions are likely to lead to a change in the options open to a range of different people within this complex, dynamic picture of livelihoods.

Local politics, power relations and social networks influencing enforcement of fisheries regulations – for better and for worse

On small Islands in the Caribbean, the small population size and close relationships between resource users and resource managers often influence the regulation of the fishery. Enforcement of regulations is perceived to be difficult as perpetrators of violations may often be friends or family of enforcement officers. Family connections, private interests and political factors affect how the fishery is managed and the access of individuals or groups to resources (Korda et al. 2008). *These influences can work both ways: in Jamaica, local rangers were able to encourage family and friends to voluntarily comply with regulations by appointing community leaders as enforcement officers to create 'community policing'. These individuals have been able to prevail upon others not to embarrass them by violating the rules* (Espeut 2002).

Dealing with the impacts of economic trends

Tourism, as an industry, is strongly affected by world-wide economic trends and market forces over which those employed in the industry have little direct influence. The economic downturn experienced in the US and Europe during 2008-2009 directly impacted on tourist arrivals in the Caribbean and a decline in employment opportunities affected people who had taken up jobs in hotels and services for tourism. Respondents in St.Kitts and Nevis noted that "..experience has taught us that this industry (tourism) is very fragile and you never know" and that "..tourism is a fickle industry…". It was seen as important to have other livelihood options available in order to deal with the periodic downturns that the industry experienced.

Steve Box

Centro de Estudios Marinos

RESEARCH

We are looking into improving the management of key reef fish species, specifically yellowtail snapper so as to help protect other ecologically important species such as parrotfish and commercially important species such larger-bodied groupers which have seen big declines in the abundance and diversity. Yellowtail snapper is at a really crucial point because it is one of the last commercially important species before fishers switch gear types to very unselective gears. The whole research works to provide tools for the region so that we can rebuild fish populations on reefs and have sustainable fisheries at the same time.

it's not too late for these proactive steps ...

Seen evidence of change on Caribbean coral reefs? Yes and no actually. Yes, there have been very widely documented declines that we all read about. Then in a local context, we've seen declines in diversity and abundance of fish. We do see these issues and there's been a lot of comments from fishers that we work with that it's getting harder to fish. They have to go further; the fish they are catching are getting smaller. They are shifting species; they are putting more effort in and getting less return. So we see that a lot; we hear that a lot and that's important because there's this kind of word-of-mouth - problems that it's really touching people's day-to-day lives.

In terms of the quality of reefs, we're losing coral cover. Visibility in the water's going down. Things you can really notice. But, as well there are some success stories. There are some areas where things are still very, very good and I think it's very easy to focus on the negative side and we do need to be aware of it, but it's not all doom and gloom. There are positive stories and I think it's very important that the work we do can make people change; can make positive change to the ecosystems and it's not too late for these proactive steps. It is not pristine; it is not in a wonderful state but it's not the end of the world. We can manage it.

BRIEFS

LIVELIHOODS

1
Coral reef dependency and change: implications for the future

2
Livelihood enhancement and diversification to support adaption to changes in coral reefs

Coral reef dependency and change: implications for the future

THE ISSUE

Fresh catch on the fish market in Dieppe Bay, St. Kittts and Nevis.

Throughout the Caribbean, people depend on coral reefs in many ways. This dependence makes them sensitive to changes in the availability of or access to the resources and services coral reefs provide. Such changes may take place seasonally, suddenly, or over generations. Understanding the sensitivity of livelihoods to these changes and the implications on people's livelihoods and their vulnerability is critical for informing policy and management decisions which affects access to coral reef resources.

THE EVIDENCE

Households in eight coastal communities across four countries (Barbados, St Kitts and Nevis, Honduras and Belize) were interviewed with the aim of understanding how people depend on coral reefs and how they have responded to change.

Coral reef dependency

For many people coral reef dependence is directly or indirectly associated with either fisheries or tourism activities, or a combination of the two. These activities provide a source of income and employment and in the case of fisheries, provide food and have cultural significance.

The variability of dependency

The nature of coral reef dependency varies from one household to the next. In certain locations, where the local economy offers few alternatives, coral reef dependency may be high. Dependency can vary throughout the year according to seasonal changes in accessibility and availability of fisheries resources and fluctuations in tourist arrivals. In addition, dependency varies unpredictably, with households suddenly relying heavily on coral reef fisheries as a safety net following unemployment in other sectors.

Many activities dependent on coral reefs are sensitive to sudden changes such as the hazards associated with fishing (e.g. bad weather, decompression sickness in lobster divers), the unpredictable nature of the tourism economy, or the impact of hurricanes. These are changes which households have little control over and can lead to the sudden loss of access to coral reef resources and related employment and income.

Long-term changes in dependency - for many households, declining fisheries availability and access has undermined their dependence, making livelihoods more insecure and less viable. In some cases, livelihoods have been criminalised, where fisheries or conservation restrictions have limited access to coral reef resources, and households are unable, or unwilling, to access alternatives.

At the same time, a growing tourism economy has led to increasing dependence on coral reef associated tourism, through a range of employment opportunities. The growth of tourism is also, in some cases, a driver of continued fisheries dependence, offering a lucrative market for fish products with high returns for fishers. The demand for fish from tourist restaurants and hotels can divert fish supplies away from local markets, potentially reducing food security for local people.

Dive school in Utila, Honduras.

Coral reefs as a safety net

The accessibility of near shore coral reef resources often means people turn to them during sudden periods of hardship. In St Kitts and Nevis, case studies revealed households which had been forced to depend heavily on coral reef fisheries following loss of employment in the construction industry. Likewise, on the island of Utila in Honduras, mainland Honduran migrants were reported to fall back on the near shore coral reef fisheries when they found themselves out of work.

Changing fishing practices

Across all countries studied, fisher households have been attempting to cope with the declining availability of fisheries by modifying their fishing practices. This may mean increasing the time spent fishing, travelling to new or more distant fishing grounds, or making use of new technologies. However, for many fishers rising fuel prices have limited the success of these changing practices, and they continue to face declining returns.

Coping with changing dependency

Households adopt a range of different strategies to respond and cope with changing access to and availability of coral reefs. These strategies include modification of existing activities, diversification or substitution of activities, and even migration. Diversification presents a key strategy, helping households cope with seasonal, sudden and long term changes by providing income sources from different sectors, such as tourism, farming and construction.

The growth of tourism has presented many opportunities for diversification, but the finance and skills required are not always easily accessible to local people and some tourism activities, such as SCUBA diving, are often dominated by outsiders with more resources. Tourism opportunities have allowed many households to diversify and improve their livelihoods, alleviating the insecurities of fisheries dependence in the short term. However, these new opportunities are still vulnerable to degradation of the coral reef and the uncertainties of wider economic and political changes.

MANAGEMENT IMPLICATIONS

Factoring coral reef dependency into decision making
Any management intervention that limits access to coral reef resources, such as no-take marine reserves, will have social and economic impacts on people who depend on coral reef resources for their livelihoods. Policy and management decisions should ideally factor in an understanding of the varied nature of dependency on coral reefs, recognising the seasonality of this dependency, as well as the role of coral reefs as a safety net for households.

Help people adapt and build resilience
Acknowledging that change and uncertainty are a central and continuing part of people's lives, it is important to help build people's resilience and capacity to adapt to future changes and not just in relation to current conditions. People's on-going experiences of responding to change needs to be central in this effort, building on their existing capabilities and their visions for the future. To succeed in supporting households build resilience for an uncertain future, policy decisions are best if they are adaptive and integrated across sectors, recognising that people's livelihoods draw upon multiple sectors, from fisheries and tourism to farming and construction.

Livelihood enhancement and diversification to support adaptation to changes in coral reefs

THE ISSUE

Fruit stall in St. Kitts and Nevis.

When people's ability to make use of coral reefs and the services that reefs provide changes, their livelihoods are impacted. The way people use these resources to obtain food and income and their social and cultural activities can all be affected. This is true whether the changes take place because of declining reef health, or whether they are a side-effect of measures introduced to protect coral reefs by limiting people's access and use, e.g. marine reserves.

Encouraging people to take up new, or 'alternative', livelihood activities is often regarded as an important means of reducing human pressure on reef resources. However establishing genuinely sustainable alternative livelihood activities that respond to people's aspirations in the long-term has often proved challenging.

THE EVIDENCE

A series of interviews and workshops with individuals, households and key informants were conducted in 8 communities across four countries (Barbados, St Kitts and Nevis, Honduras, and Belize). Questions and discussions focused on understanding people's responses to changes to help identify key guidance for supporting future livelihood change. Additionally, a workshop brought together people from around the Caribbean with experience in supporting livelihoods change.

KEY FINDINGS

Adaptation to change is a way of life

People in the Caribbean already constantly adapt and respond to changes such as seasonal changes in weather, sudden shocks from hurricanes, changes in the demand for tourism services and wider economic fluctuations, and new measures (e.g. MPAs) that restrict access to coral reefs. Climate change is making adaption even more challenging.

Matching skills, existing capacity and market demand

In Honduras, skills training provided to households through a poverty alleviation fund had relatively limited success in supporting long-term livelihood change. The skills provided did not match or build on existing capabilities or market demand and training was not supported by measures to assist people to start up new businesses to make use of the skills they had acquired.

Appropriate and adaptable support

Having access to the right kind of institutional support in order to identify and take advantage of new opportunities is also important. This includes access to credit or grants and training in new skills, as well as access to information about livelihood opportunities, new markets and the experiences of others. People often draw on support from a range of organizations and institutions in order to obtain these.

Livelihood adaptation

The timeframes involved in building more adaptable and resilient livelihoods are long, often involving generations.

Building on skills and networks

To adapt, people draw on their existing skills, knowledge and resources, enhancing existing activities and diversifying into related activities, e.g. for fishers in Belize, shifting over to guiding tourists visiting coral reefs enabled them to make use of their existing knowledge of the marine environment. Social networks of family, friends and connections are a key source of support. Remittances from family members abroad are playing an increasingly crucial role.

Cruiseship and dive boat in St. Kitts and Nevis.

Boys with cast seine net.

Drawing on diversified support for livelihood change

People draw on diverse sources of support to successfully change their livelihoods. A food vendor in St.Kitts started her business by combining existing skills with a compensatory financial package provided when she lost her job at a local resort. A seaweed farming initiative by a local cooperative in Belize built on experience in wild seaweed collection among the members as well as support from local institutions. Local organizations also played an important role in another Belizean initiative to develop cultural tourism driven and owned by indigenous garifuna people.

Seaweed farming.

MANAGEMENT IMPLICATIONS

Allow time for livelihood change

Some of the best cases of successful support for livelihood adaptation come from longer-term interventions, particularly where local organizations rooted in the community have taken the lead.

Empowering people to make their own decisions about livelihood change

Empowered individuals and communities are more likely to develop viable strategies for the future than those who have been provided with ready-made, 'off-the-shelf' solutions by outside agencies. In a dynamic environment, where no single livelihood option is likely to remain viable for long, developing people's capacity to adapt now, and in the future is important.

Building adaptive capacity

More attention needs to be given to building people's capacity to make changes in their livelihoods before changing circumstances reduce their capacity to respond. For example, where reef management measures are being introduced that will restrict people's access to reef resources, the reef users' capacity to adapt to new restrictions needs to be built before those measures are introduced, so that they are in a better position to take changes in their stride.

Creating supportive networks

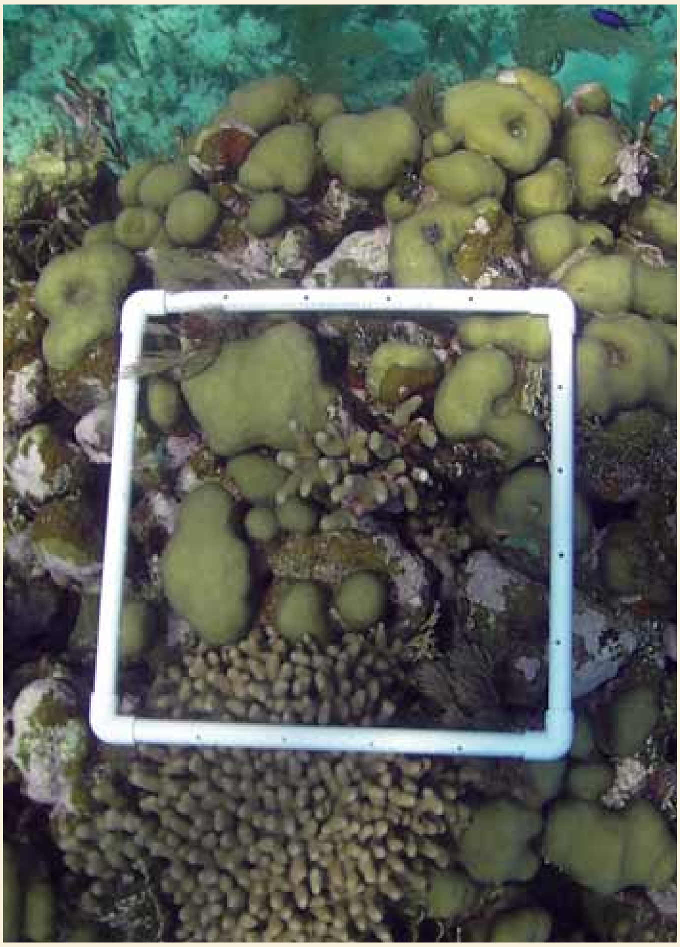
To support long-term processes of livelihoods change, and to make those processes sustainable, the focus should be on establishing supportive networks that ensure that people have access to the information, skills, resources and technical support that they need. Supportive networks need to be adaptable, capable of providing long-term support, and involve a range of agencies that can respond to people's diverse needs.

Reef Monitoring for Management

Monitoring the state of the reef is often a fundamental part of any reef management programme. Many different methods, such as AGRRA and CARICOMP, are used to survey reefs, but collecting data is only useful if the trends observed can be interpreted.

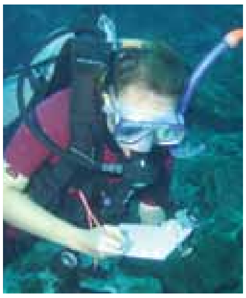
Frequently asked questions include:
Are some trends OK whereas others are a cause for concern? What does a particular trend tell me?
What kinds of management measures should I consider in light of certain patterns?
Are there any threshold values of say, coral cover that I should be worried about crossing?

We try to answer these to the best of our ability, drawing on the wider scientific evidence to date.



Benthic photo quadrats are commonly used in reef monitoring.

WHY MONITOR REEFS?



Recording reef fish on a survey in Tobago.

Most reef management programmes need to conduct some form of monitoring. The objectives of each monitoring programme may vary, but most attempt to determine the current health of the reef as characterised by variables such as coral cover and fish biomass. The core objectives of monitoring usually include:

- To provide an early warning system of stressors on the reef system
- To help diagnose potential causes of reef degradation and identify appropriate management methods to combat the causes
- Determine if reef management measures, such as MPAs and restrictions on tourist activities, are having an effect.

Reef monitoring is not the only reason to undertake reef surveys; rapid assessment of reefs is frequently carried out to compare the vulnerability of reefs or to prioritise sites for conservation activities. Although rapid assessment uses snapshot surveys rather than repeated sampling over time (monitoring), many of the same techniques and principles apply.

This following information is not intended to provide a step by step guide for reef monitoring, particularly given that many texts exist on methods. Instead we focus on three areas that we hope will be of use to reef managers:

1. Overview of current reef survey methods and programmes available
2. Practical advice on which methods to use and key considerations on implementing them
3. Detailed guidance on interpreting results gained from reef monitoring.

Protocol (purpose)	Community surveyed	Method	Number of transects and dimensions	Detail recorded	Data analysis methods included?	Methods available freely online?
AGRRA (structural and functional attribute of reef, fisheries independent data)	Benthic	Point intercept transect	6 x 10m transects, 10cm intervals	Benthic species or category, including coral state (bleached, newly dead)	No. But rationale given for each included species and method. Data to be sent to AGRRA database.	Yes: www.agrra.org Manual, data entry sheets and training materials all available online.
				Macroalgae (cyanobacteria and turf) height		
		Quadrats	5 x 25cm x 25cm on each transect	Coral recruits (<2cm)		
				Predominant substrate type		
		Belt transect	6 x 10m x 1m	Diadema, spiny lobster, queen conch, lionfish, rubbish		
				Predominant algae		
	Coral	Belt transect	2 x 10m x 1m	Corals >4cm species, state, dimensions, % mortality/ bleaching		
	Fish	Belt transect	10 x 30m x 2m	AGRRA fish species in binned size categories (ecologically and economically important species)		
			6 points on each transect	Rugosity – max. relief		
CARICOMP (productivity structure and function)	Benthic	Chain transect (laid below 10m taut transect line)	10 x 10m permanent transects, measured once a year	Benthic species or category, coral growth form	No. Data to be sent to CARICOMP.	No. But manual can be requested through CARICOMP.
	Gorgonians	Belt transect	As above	Gorgonian species and growth form		
	Diadema	Belt transect	As above x 1m	Diadema count (+ other urchins)		
	Fish	As AGRRA				
Reef Check (community engagement and volunteer coral reef monitoring)	Benthic	Point intercept transect	20m, 0.5m interval	Substrate categories (x 10)	Yes – integrated into Excel spreadsheet. Data sent back to Reefcheck.	No. Training through Reef Check trainers
	Fish	Belt transect	4 x 20m x 5m	Commercially important species abundance of families, groupers and Nassau grouper in size classes		
	Invertebrate	Belt transect	As above	Few indicator species + bleaching, coral damage impacts		

continued on next page

METHODS FOR SURVEYING CORAL REEFS

Several different methods exist for surveying coral reefs. Programmes such as AGRRA (Atlantic and Gulf Rapid Reef Assessment) and CARICOMP (Caribbean Coastal Marine Productivity) have issued manuals which provide full descriptions of the methods used. Other manuals exist which provide details of a selection of methods and offer some advice on how best to conduct reef surveys, e.g. English et al. 1997 and Rogers et al. 1994. Some points to note regarding these manuals and programmes are:

- Rogers et al 1994: Very useful overview of methods available and Caribbean-focused examples
- English et al 1997: Comprehensive, though strong focus on Indo-Pacific reefs and methods. Includes methods for monitoring of mangroves, seagrasses, soft-bottom communities and coastal fisheries.
- CARICOMP: Very detailed methods, particularly use of chain transects, which are time consuming and not widely used for assessment (though still used for monitoring in places). Includes methods for monitoring mangroves and seagrass communities.
- AGRRA: Excellent set of techniques and you can pick and choose which to include. Basic and advanced versions allow for tailoring of methods to the expertise of the people doing the surveys.
- Reef Check: OK for basic data on fish abundance and benthos and for engaging community, but not designed as a monitoring tool.

For an in depth review of coral reef monitoring methods see 'Methods for ecological monitoring of coral reefs' by Hill and Wilkinson, available free online via the IUCN library system: https://portals.iucn.org/library/dir/publications-list

Laying out a transect line.

Protocol (purpose)	Community surveyed	Method	Number of transects and dimensions	Detail recorded	Data analysis methods included?	Methods available freely online?
English et al. 1997 (baseline assessment methods)	Benthic	Manta tow	Large scale (entire islands)	% cover of major categories (e.g. coral, sand, COTS)	Yes. Full rationale given for each method and data analysis suggested methods. Section on sampling and database design.	No.
		Line intercept transect	5 x 20m at shallow and deep	Benthic categories and species		
		Permanent quadrat (photo) + sediment trap	2m x 2m quadrat (in conjunction with LIT) at 3m depth	Detailed change in coral colonies and coral recruitment, measurements of coral colonies taken (tagged colonies)		
	Fish	Belt transect	3 x 50m x 5m transects, 2 depths	Selected fish species (fishery target, indicators, etc.), abundances binned, size estimation discussed		
	Coral	Recruitment tiles	12cm x 12cm tiles on wire rack, 20 -30 per site, multiple times per year	Coral recruits abundance, species		
	Reef fish recruitment	Belt transect	3 x 50m x 2m transects at each site	Reef fish recruits (only conspicuous, abundant juveniles surveyed)		
Van Woesik et al. 2009 (repeated measures of process and state variables)	Benthic	Transects and quadrats (both photo)	5 x 50m transects at each station; 3 x 4m x 4m quadrats at each station	Benthic composition and coral demography: size measurements, partial mortality	Some. Only instructions for photo quadrat analysis provided.	Yes: www.gefcoral.org
	Coral	Quadrats and tiles	Quadrats as above	Coral recruits abundance, size and species		
		Belt transect and tagged colonies	3 x 10m x 2m transect at each station	Coral disease prevalence, progression		
	Fish	Belt transect	5 x 30m x 4m	Reef fish (adults)		
		Belt transect	8 x 40m x 1m x1m	Reef fish (recruits)		

State variables and process variables

- State variables, as the name suggests, give you information on the current state of the reef, such as coral cover, abundance of fishes, macroalgal cover.
- Process variables provide information on the ecological processes that drive the state variables. Key process variables that might be measured include recruitment rates, growth and survival rates and herbivory. Measurement of process variables can be important for diagnosing the potential causes of reef change and can provide information on the future trajectory of the reef.

Stratification of habitat

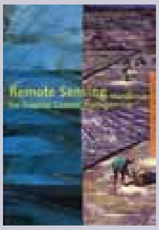
What is referred to as coral reef is made up of several different habitats, such as gorgonian plains, patch reefs and *Orbicella* dominated forereefs. The physical, biological and chemical processes that drive the ecology of these habitats can be quite different. Stratifying surveys according to habitat as well as other factors, such as wave exposure and proximity to river outflows is important to avoid comparing results from reefs that are fundamentally different. For example, healthy *Orbicella* dominated forereefs should have high hard coral cover, whereas healthy gorgonian plain habitats naturally have very low hard coral cover. Averaging data from both these habitats would result in a misleadingly low value for coral cover, because only one habitat has significant coral in its natural state. It is particularly important to discriminate flat featureless gorgonian plains from degraded examples of true 'coral reef' habitats that have lost their complexity. Typically gorgonian habitats are found in more exposed environments and have fine layer of sand sitting above the hard substratum.

Classification of reef habitats is generally based on their physical and biological features including the dominant species and reef geomorphology. One example of a classification scheme, describes the eleven common reef and lagoon habitat types found in the Bahamas (Table p.149). Although this classification scheme does not cover all habitats found in the Caribbean, it does provide a starting point for managers wishing to form their own classification scheme.

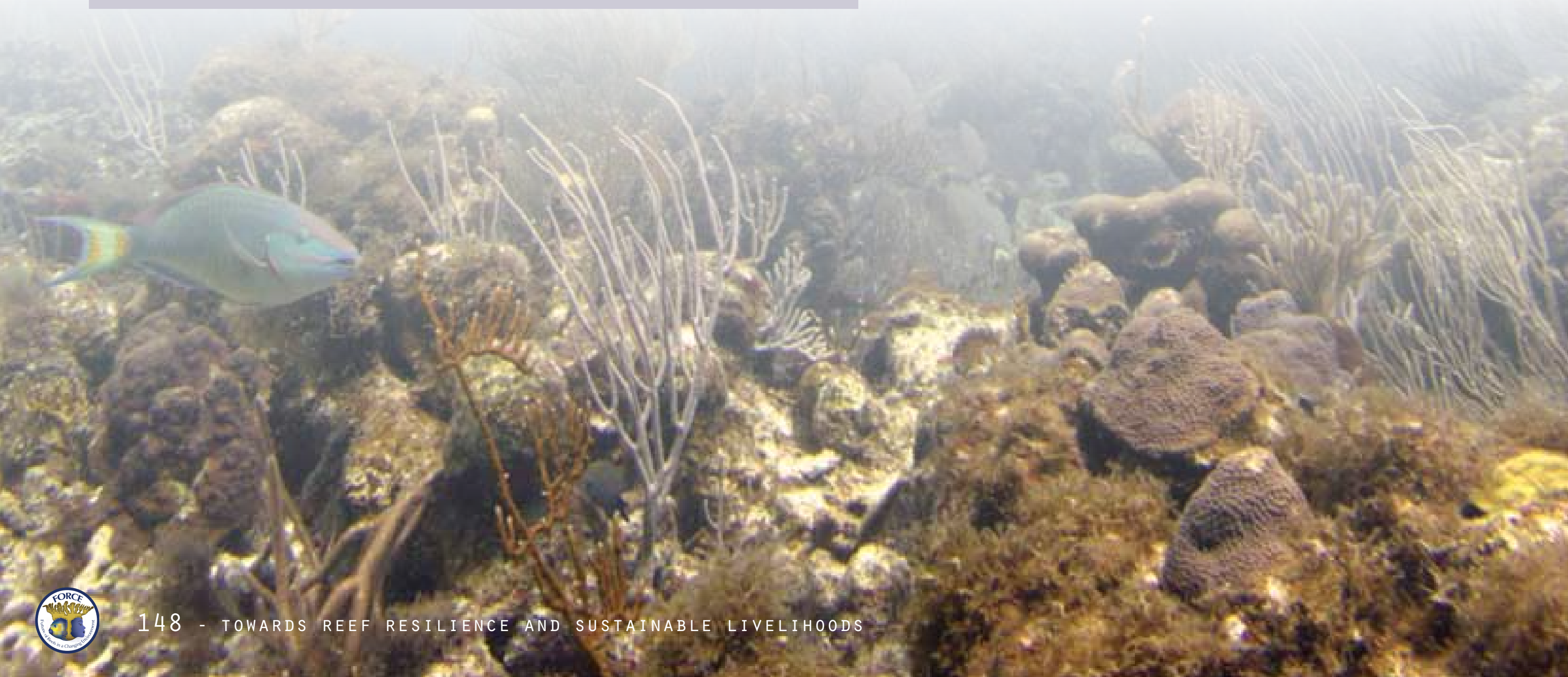
Habitats can be mapped using a combination of remote sensing methodologies. Direct mapping is often carried out using high resolution satellite imagery. Distinguishing areas of forereef that are dominated by gorgonians versus coral reef habitat (*Orbicella* reef) can be carried out cheaply and reliably using the simple relationship described by Chollett and Mumby (2012) and wave exposure data available via the FORCE WebGIS, link available through: http://force-project.eu

A complete map of the physical environments of the Caribbean Sea is also available (Biogeography Brief 1 p.22), which can also be used to help stratify monitoring sites.

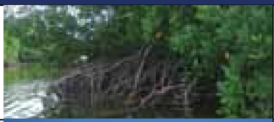
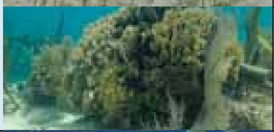
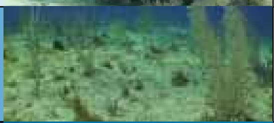
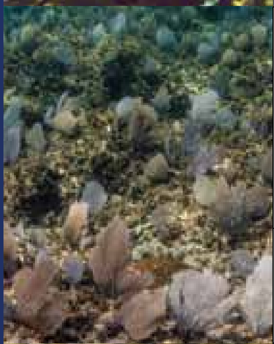
Free resources to help map coral reef habitats



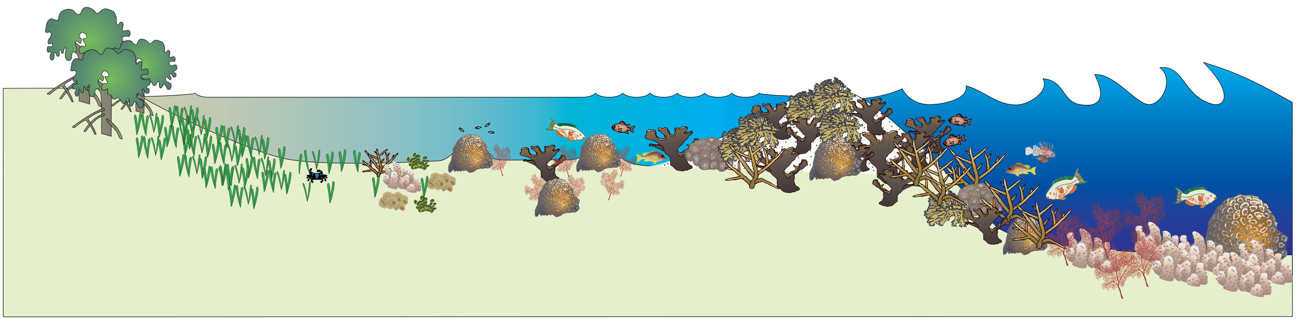
- The 'Remote Sensing Handbook for Tropical Coastal Management' is available for free download through the FORCE website or by contacting Prof Peter Mumby (p.j.mumby@uq.edu.au).
- Free and excellent software for remote sensing is available online together with specific training modules for coral reef management applications. See Bilko for Windows http://www.learn-eo.org/software.php
- An online directory of remote sensing applications and toolkits for coral reefs is available from www.gefcoral.org (see remote sensing publications).



COMMON REEF AND LAGOON HABITATS

Habitat type			Description	Examples of ecological functions
Land-sea edge		Fringing Mangrove	Outer edge of red mangrove stands. Found along shorelines, tidal creeks, offshore islands.	Habitat for spiny lobster, Nassau grouper, and invertebrate-eating fishes. Moderate contributions to primary productivity.
Lagoon		Dense Seagrass	Dominated by turtle grass but may contain manatee grass.	Converts atmospheric nitrogen into biologically useable form (nitrogen fixation). Habitat for spiny lobster, queen conch, and invertebrate-eating fishes.
		Medium-density Seagrass	Dominated by turtle grass but may contain manatee grass and shoal grass.	Converts atmospheric nitrogen into biologically useable form (nitrogen fixation). Habitat for spiny lobster, queen conch, invertebrate-eating fishes, and *Euchema* seaweed.
		Sparse Seagrass	Dominated by manatee grass and shoal grass.	Habitat for queen conch and Euchema seaweed
		Sand and Sparse Algae	Sand with sparse algal community.	Habitat for queen conch
		Patch Reef	Dominated by massive corals and dense sea fans (gorgonians).	Habitat for surgeonfishes, long-spined sea urchin, stoplight parrotfish, threespot damselfish, young coral, invertebrate-eating fishes, and spiny lobster.
Lagoon & Outer Reef		Seaweed Plain	Relatively smooth, rocky bottom with seaweeds and few sea fans (gorgonians).	Habitat for spiny lobster and Nassau grouper. Fuels food web through primary productivity. Converts atmospheric nitrogen into biologically usable form (nitrogen fixation).
Outer Reef		Elkhorn Coral	Reef-crest areas between depths of 1-5 meters.	Fuels food web through primary productivity. Habitat for surgeonfishes, long-spined sea urchin, and stoplight parrotfish. Forms reef structure (calcification). Converts atmospheric nitrogen into biologically usable form (nitrogen fixation).
		Dense Gorgonians	Densely covered with sea rods, fans, and other gorgonians with little hard coral. More than 10 gorgonians per square meter. Often just seaward of elkhorn coral reef; also in shallow, wave-swept areas.	Fuels food web through moderate levels of primary productivity. Habitat for spiny lobsters, Nassau grouper, reef-grazing organisms, plankton-eating fishes, and invertebrate-eating fishes. Moderately vulnerable to bleaching and disease.
		Gorgonian Plain	Sparse sea rods, fans, and other gorgonians on hard, rocky bottom with some seaweed.	Habitat for Nassau grouper, surgeonfishes,long-spined sea urchin, and invertebrate-eating fishes. Vulnerable to disease.
		Orbicella reef	Dominated by star coral. High structural relief. Typically in areas relatively sheltered from waves.	Habitat for stoplight parrotfish, threespot damselfish, surgeonfishes, invertebrate-eating fishes, young coral, long-spined sea urchin, spiny lobster, and Nassau grouper. Forms reef structure (calcification). Converts atmospheric nitrogen into biologically usable form (nitrogen fixation).

Eleven habitat types that are common in the shallow coral reefs and lagoons of The Bahamas.



How to measure?

Quadrats

- Usually 1 m² with 10 cm nylon grid.
- Typically 20+ per site.
- Can be photographed for later analysis or percentage cover can be estimated *in situ*
- In addition, measure the canopy heights of major forms of algae using a ruler (3 measurements per quadrat).
- For juvenile corals use 25 cm x 25 cm quadrat, ten per site, placed only on hard substrate, free of living adult coral.

Line intercept transects

- An alternative to quadrats.
- Typically 10 m length weighted transect tape with marks every 10 cm.
- Usually 3-4 transects per site.
- Benthic cover recorded directly below tape and composition of each 10 cm segment recorded.
- Measure algal canopy and height several times along transect.

Software for analysis of photo quadrats or video frames

Analysis of photo quadrats or video frames can be easily done using the following software packages:

- **VidAna** – simple, free software for quantifying percentage cover by drawing around different benthic categories: http://www.marinespatialecologylab.org/resources/vidana/
- **ImageJ** – another free software package that can be used to quantify percentage cover by drawing shapes around benthic organisms and substrate, but requires slightly more technical knowledge: http://imagej.nih.gov/ij/
- **Coral Point Count** with Excel extensions – specifically designed for determining benthic cover from reef transect photos. Software generates random points over photo and the user then identifies the features under these points: http://www.nova.edu/ocean/cpce/

Video transect

- An alternative to quadrats or line intercepts transects but not great for small corals.
- Video of a swath of reef taken adjacent to a transect line.
- Distance of camera from reef varies the width of transect: short distance (15 – 20 cm) recommended for detailed surveys (i.e. species level ID), larger distance (40 – 50 cm) for larger scale surveys (e.g. effects of bleaching).
- Typically five 50 m transects or ten 10 m transects per site.
- Video broken into non-overlapping photo frames for analysis.

Rugosity

- Use a 5 m chain and planar transect tape to measure the horizontal distance which the chain has covered.
- Calculate rugosity as length covered by taut transect tape divided by distance covered by chain, e.g. 5 m chain may fit to the substrate and cover only 2.5 m horizontal distance ("as the crow flies"); rugosity = 5/2.5 = 2.
- Use at least 4-5 random transect measurements per site.

It really does not matter much whether you choose quadrats or line transects. Photo and video transects provide a permanent record. However, it is important to remember that analysis of videos and photos can be time consuming. Photo and video transects/ quadrats also have the advantage that more in-detail analysis can be done at a later date (e.g. if initial analysis of a video transect only recorded a single category for hard coral cover, later analysis could still be done to distinguish cover of individual species).

Permanent sample units?

If a one-off reef assessment is being done, then there is no need to implement permanent quadrats or transects. For monitoring, there are advantages to fixing the corners of quadrats and ends of transects because this provides greater statistical power for the same number of samples, i.e., it's more likely you'll detect a trend in the data. Plastic or stainless steel pegs are best used to mark quadrats or transects as iron pegs or rebar can rust, causing localised algal blooms that can distort the data.

What to measure?

This will depend on the objective of the monitoring programme or assessment, however core measurements include:

- Coral cover - ideally by species
- Cover of major algal groups - crustose corallines, turf, fleshy macroalgae, *Lobophora*, *Dictyota* spp, articulated corallines (e.g., *Halimeda*).
- Canopy heights of algal turfs, fleshy macroalgae, *Dictyota*, *Lobophora* and articulated corallines – average height can be calculated and multiplied by the cover to obtain a volumetric index of algal abundance that is more likely to be insightful than cover alone.
- Sponge cover – especially *Clionaids* (Resilience Brief 7 p.46)
- There really is not much need to include sand/ sediment but if you do include them ensure that their cover is excluded from the calculation of percent coral and algal cover because this substrate is not available for reef colonisation and is therefore of little relevance.
- Urchin density – typically within ½ m either side of a 10 m transect line. Separate *Diadema* and *Echinometra*.
- Rugosity (see How to measure? p.150)
- Juvenile coral density – count juveniles (corals up to 2 cm diameter). For density calculation only include the percentage of space available for recruitment, i.e. exclude live coral cover.
- Diseases - it is more useful to monitor the incidence (percentage of new infections per year) and fate (probability coral survives) of disease rather than simply prevalence (percentage of corals that have a disease whenever a survey is done). Taking an extreme example, imagine that 5% of corals get infected by the disease a year and then die quickly. The prevalence might remain stable for a while (5%) but there'd be no corals left after a number of years. Alternatively, 5% of corals might have the disease and manage to cope without dying. The incidence of new diseases could be virtually zero, which is a far better state of affairs. But in these contrasting cases the prevalence would be the same and not alert you to a major problem. Incidence can be studied by tagging a random number of corals and following their fate over time.
- Coral bleaching - observations of bleaching are important but remember than many corals completely recover when the bleaching event has past, particularly if the stress was minor or shortlived. It's useful, therefore, to tag a bunch of random colonies (e.g., 50 per site bleached or not) and track whether they survive or not, or how much coral is lost (partial mortality).

Physical factors

Sediment

If a sediment problem is suspected it is useful to set up sediment traps. Sediment traps are frequently misused, providing misleading data on sedimentation rates. Storlazzi et al. (2011) provides more information on using sediment traps on coral reefs, including nine basic protocols to follow.

Nutrients

Where raised nutrient levels are suspected as an issue on a reef, analysis of algae samples can help in the diagnosis. Samples should be taken along a gradient: from areas which are believed to be highest in nutrients to those that are the 'cleanest'. The species of algae to be sampled will depend on what is available at the sites, but where there are algal blooms, it would be most logical to sample the most abundant species. Only small samples (less than 1g) are required for analysis, but at least 5 samples per site for each species should be taken. The apical section (growing tip) of the algae is the place to sample. Samples should be air or oven dried, then ground to a powder. In most cases, samples will have to be sent to a laboratory for nutrient content analysis, so it is best to confirm with the lab how they prefer the samples to be prepared. This analysis should be contrasted with analysis of dissolved nutrients in the water.

Isotope analysis of algae samples can help identify the source of nutrients, e.g. fertiliser run-off, sewage, factory effluent, and therefore target where management measures would be best focused.

Hogfish.

Tiger grouper.

Rainbow runners.

Trumpetfish.

Who will measure?

There are enormous differences in data between observers even if they are experienced and using the same technique. This occurs because people swim at different speeds and differ in their decisions over whether to include a fast-moving fish passing across the transect ahead of them. So, if possible, try to use the same person for all fish surveys – or at least all surveys of a particular fish group.

How to measure?

There are two main quantitative methods available – stationary sampling of fish within a cyclinder around the diver (Bohnsack and Bannerot 1986) or the laying of belt transects. Either are fine although transects have become more widely used so might be easier to make comparisons with other datasets. We focus here more on transects.

Transect size and number

We generally find it most effective to scale the size of the transect to the habitat and abundance of the fish group. For example, damselfish and wrasses are found in high densities and can be adequately surveyed using 30 m x 2 m transects (n=4+). Parrotfish and grunts can be surveyed using wider transects (we use 30 m x 4 m, n=10), whereas grouper, snapper and jacks are better censused using 50 m x 4 m transects (n=5+). If a single person is conducting the census then consider using a 30 m transect and surveying the widely-roving and rarer species within a 4 m swath and then return along the transect and sample the high-density, small species along a narrower 2 m swath.

Abundance of rare species

The density and biomass of those species that tend to be very rare, such as large groupers and sharks, are often not well represented using standard transect or cylinder methods. There are two solutions to this. One is to use timed swims, such as 5 minute long swims at a particular depth, recording everything you see. The other is to just record whether you see these species (and their size, etc) when doing regular transects. In other words, they might not appear on the transect but you might observe them during the dive. The advantage of the latter approach is that it standardises the area surveyed and time quite well. The data are then used to estimate the probability of seeing the species per survey (e.g., per hour of fish census) rather than an actual density. For example, if you saw a shark on 2 out of 20 surveys, then the probability of occurrence / encounter is 10%. You can test for significant trends over time using the binomial distribution (see examples in Mumby et al. 2004; Mumby et al. 2012).

For these rare species, fixed video cameras can be used as they can be left running for extended periods of time (4 hrs +). This is possible even with limited funds thanks to the availability of cheap, high quality cameras such as GoPros. It is important to remember that all footage will need processing!

Fish biomass

It is important to estimate the size of fish so that trends can be tracked (e.g., is fishing pressure so high that average fish size is getting smaller?) and biomass can be estimated. Biomass is the usual currency for assessing patterns in reef fish assemblages. Several protocols suggest that fish sizes are placed in bins (e.g., 1-5 cm, 6-10 cm, etc). This is an unnecessary simplification and weakens the data analysis because it is not straightforward to interpret a trend in the number of fish in a size class (e.g., size could be decreasing within a class but this would be undetected). Better to attempt to estimate size to the nearest centimetre and use a T-bar to help scale observations when in the field. If necessary, actual measurements of size can be regrouped into bins at a later date for comparisons to datasets where bins are used. Lengths can be converted to biomass using a simple equation that requires two parameters per species (Bohnsack and Harper 1988, Fishbase.org).

What to measure?

This depends on the objectives of the monitoring programme, but the following is a minimal list to consider:

- Commercially important species – groupers, snappers, barracudas, large-bodied jacks, large wrasses such as Hogfish
- Ecologically important species – parrotfishes (preferably distinguishing between terminal and initial phases), surgeonfishes, damselfishes, triggerfishes, porgies, trumpetfishes, smaller groupers, lionfishes.

TIPS FOR SURVEY METHODS - SHELLFISH

Spiny lobster *(Panulirus argus)*

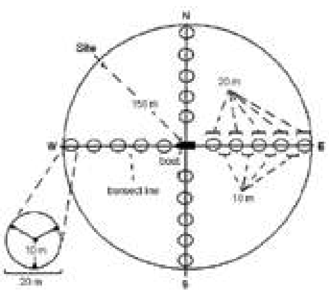
As with conch, lobsters are often recorded as part of standard benthic survey protocols. However, for lobster-specific censuses the survey methodology must take into account the fact that lobsters are nocturnal, remaining hidden under ledges and in crevices in the reef during the day. As such, belt transects or timed searches by SCUBA divers are most commonly used but require careful inspection of shelter habitat. Manmade aggregating shelter devices or baited traps may also be deployed for fishery independent lobster surveys. Apart from the number of lobsters encountered, surveys may also record size (e.g. carapace length), sex and the reproductive status of females (e.g. whether berried with eggs or carrying a sperm filled tar spot). Sites are normally stratified by habitat and depth. For deep water, traps are the only practical option for obtaining an index of abundance.

Belt transects

Vary in size, but can be between 50 and 150 m long depending on habitat and up to 10 m wide (Smith & van Nierop 1986; Acosta & Robertson 2003).

Timed search

Commonly 3 x 1 hr searches per site (Bertelsen & Matthews 2001; Cox & Hunt 2005), timed searches yield relative abundance (number of lobsters per unit time) compared to belt transects which yield density estimates (lobsters per unit area). As lobsters are gregarious and their distribution is often patchy, timed searches are often the better method of surveying (Cox & Hunt 2005).



Layout of circular transects used for surveying conch.

Queen Conch *(Strombus gigas)*

Conch are often recorded in standard reef monitoring programmes as part of the benthic survey protocol, e.g. AGRRA. For specific conch surveys, typically either belt or circular transects are used depending upon conditions. The number of conch, habitat type and depth of observations are typically recorded on all surveys. Other attributes such as shell length, lip thickness and spawning behaviour may also be recorded on surveys which allow the surveyor to stop (i.e. not towed or scooter surveys).

Belt transects

If a large shallow sandy area is to be covered and it is relatively calm with good visibility, then belt transects are typical and are usually done by towed free diver. If deeper, but still relatively calm, then towed SCUBA diver or a SCUBA diver left to swim the benthic transects with underwater scooter (for examples see Tewfik et al. 2001) or unassisted (for examples see Stoner and Ray 1996) may be used. For water deeper than safe diving depth (e.g. > 30 m) remotely operated underwater vehicles (ROVs) may be used. Transects vary in length and width depending on the size of area to be covered; however they are generally 2 – 5 m wide.

Circular transects

If areas are smaller, or have complex topography (e.g. reef), or highly variable depths, then circular surveys work much better. This is also a good method if sea conditions are rough and you don't want divers scattering in all directions from the support vessel! For this method you have a central marker and a rope (or tape) attached to it, and you swim in circles moving further away from the centre. This allows a much more detailed search. Circle radius has varied among studies from 7 to 20 m. This method has been used in Jamaica (Tewfik & Appeldoorn 1998), Bahamas (Stoner et al. 2012) and around Barbados (Valles & Oxenford 2012).

For deep water, an underwater drop video camera can be used.

For a good description of sampling design for conch surveys see 'Conch (*Strombus gigas*) stock assessment manual' by Erhardt and Valle-Esquivel, available via the Caribbean Fishery Management Council website: http://caribbeanfmc.com

There are two aspects to interpreting monitoring data. The first is simply how the data should be analysed. We do not cover this here as there are many resources available on this topic. A particularly good text is: 'Practical statistics for field biology' by Jim Fowler and Lou Cohen.

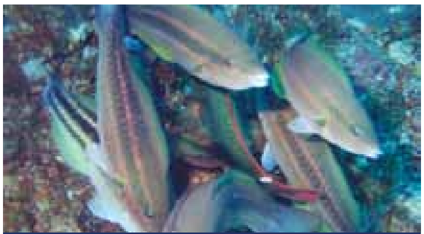
The second issue is how to interpret the trends found in the data. We have attempted to provide some guidance on this issue for the most widely-used monitoring variables. For each variable, we considered how to interpret changes in variables, what other variables could be looked at to provide more information and the ecological implications of the change.

Acute decrease/ increase – normally greater than 10% in a year
Chronic increase/ decrease – few % per year

FISH/SHELLFISH

Groupers and snappers biomass

What is the trend?
Decrease
Possible main interpretation
Overfishing.
Other variables to look at
Abundance and size data, fisheries data.
Ecological implications
Loss of top predators; trophic cascade effects.

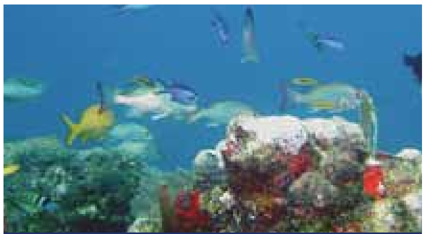


Total fish abundance

What is the trend?
Decrease
Possible main interpretation
Difficult to interpret change, check length data, possibly: increase in fishing pressure (reduction in abundance of large fish) or loss of habitat (reduction in abundance of all size classes).
Other variables to look at
Fisheries data, species level length data, rugosity (has it declined?).
Ecological implications
General loss of reproductive capacity and fisheries productivity.

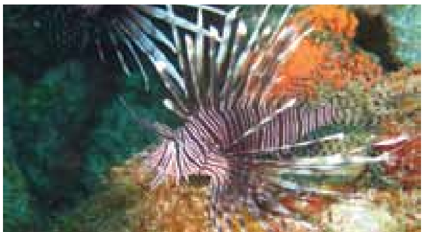
Total fish biomass

What is the trend?
Decrease
Possible main interpretation
Decrease in average fish size and/ or abundance due to: increasing fishing pressure (reduction in abundance of large fish) or loss of habitat (reduction in abundance of all size classes).
Other variables to look at
Fisheries data, species level length data, rugosity.
Ecological implications
General loss of reproductive capacity and fisheries productivity.



Fish diversity (species richness)

What is the trend?
Decrease
Possible main interpretation
Loss of species, possibly due to habitat loss.
Other variables to look at
Species level biomass data.
Ecological implications
Loss of functional redundancy in specific groups which could reduce resilience as fish feed less extensively.



Lionfish density

What is the trend?
Increase
Possible main interpretation
Lionfish population has not reached maximum density.
Note that a decrease can occur even in the absence of control measures because the population might exceed its carrying capacity – effectively running out of food (though not yet described for lionfish).
Ecological implications
Reduction in biomass of prey species (small fish species and juveniles), possible reduction in reef resilience if prey upon herbivores.

Supporting references on page 159.

Grunt biomass

What is the trend?
Decrease (when they are not a targeted fishery species or caught as bycatch in traps). If they are fished, then fishing can be a driver of decline.
Possible main interpretation
Loss of nursery habitat (mangroves and seagrass) and/ or foraging grounds (seagrass and sand flats).
Other variables to look at
Fisheries data (check for absence of grunts in catch), habitat survey data.
Ecological implications
May indicate loss of mangrove/ seagrass habitat which both play important functional roles.

Damselfish density
(three-spot, longfin and dusky)

What is the trend?
Increase or decrease
Possible main interpretation
Decrease can follow an increase in abundance of their predators (mainly mesopredators) due to fishing down the food web. Loss of preferred habitat could also be a factor (e.g., loss of living *Acropora cervicornis*). Increase in damselfish abundance might occur if predators decline.
Other variables to look at
Biomass of mesopredators, coral species composition.
Ecological implications
An increase in these damselfish can result in an increase in algal turfs – can have negative impacts on coral recruitment.

Parrotfish biomass

What is the trend?

Increase

Possible main interpretation

Unless fishing recently declined, an increase is usually attributed to a large loss of coral and increase in algal food.

Other variables to look at

Coral cover, trends in fishing.

Ecological implications

Helps compensate for the loss of coral in reducing potential algal bloom.

Trigger fish and porgies biomass

What is the trend?

Increase or Decrease

Possible main interpretation

Increase implies overfishing of predators in a system where triggerfish and porgies are not heavily targeted.

A decrease implies direct fishing effects.

Other variables to look at

Biomass of predators, turf/macroalgal cover.

Ecological implications

A reduction in their biomass could lead to increased *Diadema* densities and vice versa.

Barracuda and jacks biomass

What is the trend?

Decrease

Possible main interpretation

Overfishing most likely explanation.

Other variables to look at

Abundance and size data, fisheries data.

Ecological implications

Loss of top predators; possible trophic cascade effects.

Parrotfish biomass (genus: Sparisoma: stoplight, redband, yellowtail, redtail)

What is the trend?

Decrease

Possible main interpretation

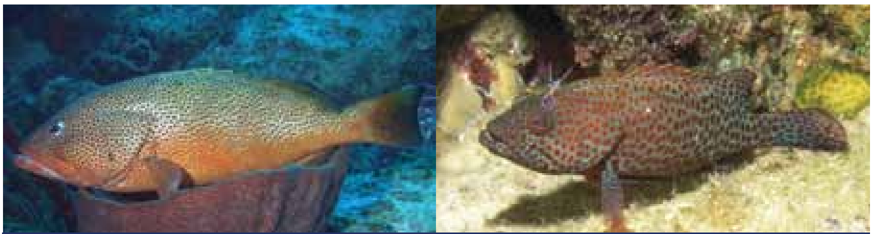
Overfishing (fishing down the food web) and/ or loss of habitat.

Other variables to look at

Macroalgal cover (preferably by species), turf algal cover and canopy height, rugosity.

Ecological implications

Loss of important macroalgal and turf grazers – increases in turf height and macroalgal cover/ height, loss of reef resilience.



Mesopredators biomass
(hinds, graysbys, coneys, small snappers, trumpetfishes)

What is the trend?

Increase

Possible main interpretation

Top trophic level (mostly large-bodied grouper) overfished – leading to an escape from predation

Other variables to look at

Abundance and size data for top predators (large groupers and snappers, barracuda), fisheries data.

Ecological implications

Possible trophic cascade effects – decrease in biomass of damselfish and other mesopredator prey items.

What is the trend?

Decrease

(with no increase in top predators)

Possible main interpretation

Fishing through the food web (at all level simultaneously)– overfishing.

Other variables to look at

Abundance and size data for top predators (large groupers and snappers, barracuda), fisheries data.

Ecological implications

Loss of functional role of top predators; increase in damselfish abundance which may result in more algal growth.

Parrotfish biomass
(genus Scarus: queen, striped, princess)

What is the trend?

Decrease

Possible main interpretation

If only in smaller parrotfish species (e.g. *Scarus iseri*), possible increase in abundance of mesopredators or habitat loss.

Other variables to look at

Turf algal cover and canopy height, rugosity, mesopredator biomass.

Ecological implications

Loss of herbivores with highest grazing rate – increase in turf height, loss of reef resilience.

Conch density

What is the trend?

Decrease

Possible main interpretation

Increase in fishing pressure (overfishing), loss of habitat.

Other variables to look at

Fisheries data.

Ecological implications

Loss of conch fisheries productivity, population may be unable to sustain itself if less than 47 individuals ha-1.

Lobster density

What is the trend?

Decrease

Possible main interpretation

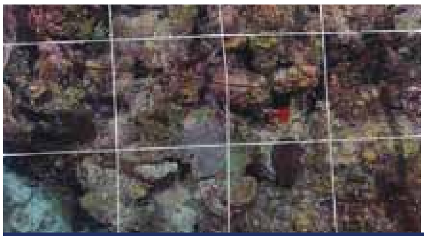
Increase in fishing pressure (overfishing), loss of habitat, disease outbreak.

Other variables to look at

Fisheries data, size classes (largest sizes removed by fishing).

Ecological implications

Loss of lobster fishery productivity, reduced spawning potential.



Coral cover

What is the trend?

Acute decrease

Possible main interpretation

- Reef impacted by major disturbance causing high coral mortality, e.g. hurricanes, ship groundings, mass coral bleaching, disease outbreak, coral blasting.
- Look at coral cover by species to determine potential disturbance.

Other variables to look at

Coral cover by species, rugosity.

Ecological implications

Increase in other benthic organisms, potential decrease in substrate suitable for coral recruitment, loss of rugosity, sudden reduction in grazing intensity could allow algal bloom.

What is the trend?

Chronic decrease

Possible main interpretation

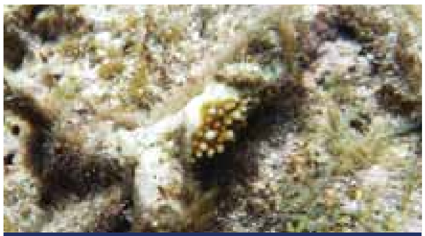
- Continuous stressor on reef preventing adequate coral recruitment, causing coral mortality or both e.g. thick algal turfs, disease at low incidence.
- Look at coral cover by species to determine potential disturbance.

Other variables to look at

Coral recruitment, juvenile coral density, coral cover by species, rugosity.

Ecological implications

Chronic loss of resilience. Either insufficient recruitment or rates of background coral mortality have increased recently.



Density of juvenile corals

What is the trend?

Decrease or low level

Possible main interpretation

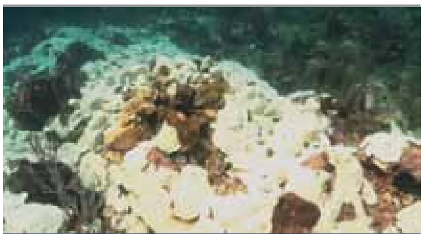
Most likely because of a reduction in the quality of the settlement habitat, brought on by thicker algal turfs and/ or macroalgae. Could also result from a decrease in the availability of larvae though this has rarely been demonstrated.

Other variables to look at

Recruitment onto settlement tiles. Coral cover by reproductive type (brooders/ spawners), algal cover by functional group (CCA, turf, EAM, MA, bare), herbivore biomass (fish) and density (urchins).

Ecological implications

Losing supply of new individuals for population maintenance and recovery, loss of genetic diversity.



Coral bleaching

What is the trend?

Presence

Possible main interpretation

- The expulsion of zooxanthellae (Symbiodinium) from corals due to external factors/stressors.
- Mostly likely caused by exceptionally high temperature or an exceptionally high level of sunlight (e.g., if calm conditions reduce the sediment load in a lagoon). At high latitudes, bleaching can also be associated with low temperature or salinity stress.
- Note: corals do not necessarily die after bleaching.

Other variables to look at

Coral cover by species, permanent quadrats to monitor individual colonies; oceanographic data, coral disease prevalence.

Ecological implications

Coral mortality (decrease in live coral cover), coral cover by species, reduce reproductive potential, decrease in net rates of calcium carbonate accretion and primary productivity, increase in other benthic organisms, loss of rugosity.

Coral cover by growth form or species

What is the trend?

Decrease

Possible main interpretation

- Different growth forms (massive, branching, etc.) vary in their response to disturbance.
- Agaricids (e.g., leaf corals) are highly susceptible to both bleaching and overgrowth by macroalgae.
- *Acropora cervicornis* is easily fragmented by storms. *A. palmata* can become infested by *Drupella* especially if the coral is not that abundant.
- Large star corals (*Orbicella* spp.) bleach easily but tend to be relatively resistant to bleaching-induced mortailty. However, these corals can be among the most susceptible to diseases, including those that follow bleaching. *Acropora* is usually the most resistant to bleaching.

Other variables to look at

Coral cover by species, rugosity

Ecological implications

Decrease in coral cover, increase in other benthic organisms, potential decrease in substrate suitable for coral recruitment, loss of rugosity.

Coral disease prevalence

What is the trend?

Increase

Possible main interpretation

- Presence of bacteria/viruses and/or external stressors and/or favourable environmental conditions such as extreme temperatures, sedimentation, excess nutrients and toxins that cause disease. A commonly observed triggering factor is water temperature increase.
- To find out whether corals are dying, recovering or staying diseased, set permanent quadrats to monitor individual colonies.
- Different corals species are susceptible to different coral diseases. Injured colonies are most susceptible to infection when in contact with a diseased colony.

Other variables to look at

Tag colonies to obtain data on rates of disease incidence, recovery, and mortality; oceanographic data (temperature, nutrients), proximity to sources of nutrients.

Ecological implications

Coral mortality increase in other benthic organisms, disease transmission between colonies (further decrease in coral cover/ increase disease prevalence).

Supporting references on page 159.

Sponge cover

What is the trend?
Increase
Possible main interpretation
Reef impacted by decreased water quality due to changes in land use, increased runoff or sewage input.
Other variables to look at
Coral cover, macroalgae cover, turf height, cover of other benthic heterotrophic feeders.
Ecological implications
Increase in bioerosion, competitive exclusion and decrease substrate available for recruitment of other benthic organisms.

Rubble cover

What is the trend?
Acute increase
Possible main interpretation
Reef impacted by major mechanical disturbance (e.g: hurricanes, ship groundings) causing coral mortality and fragmentation in situ or in neighboring reefs. Ship groundings usually obvious and small in scale.
Other variables to look at
Coral cover, rugosity.
Ecological implications
Substrate instability and low recruit survival, likely increase in bioerosion.

Rugosity

What is the trend?
Decrease
Possible main interpretation
Rapid declines expected after major storm or disease of *Acropora*. But if rapid decline in the absence of these impacts, it implies that bioersion is extremely high (e.g. due to sponge bioerosion or overabundance of urchins).
Other variables to look at
Coral cover and community species composition.
Ecological implications
Increase in bioerosion, decrease in structural complexity, decrease in fish recruitment and overall abundance; reduced fisheries productivity.

Sea urchin (*Diadema*) density

What is the trend?
Decrease
Possible main interpretation
Urchin disease outbreak and/or increase of predator populations.
Other variables to look at
Urchin disease prevalence, predator biomass.
Ecological implications
Increase in macroalgal cover. Functionally non-existent below 1 m-^{2}.

What is the trend?
Increase
Possible main interpretation
Increase in recruitment and/or reduction of predator populations.
Other variables to look at
Urchin recruitment, predator biomass.
Ecological implications
Decrease in macroalgal cover, increase in bioerosion. Potential overabundance when density greater than approx. 5 m-^{2}.

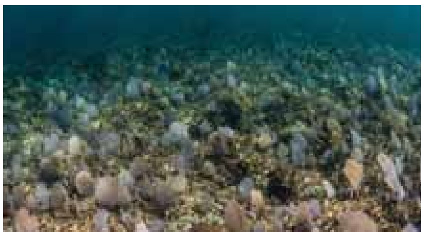
Cover of sand and bare rock

What is the trend?
Increase
Possible main interpretation
- Reef impacted by storm which redistributed sand on the reef or exposed bare rock.
- Reef impacted by major mechanical disturbance (e.g: hurricanes, ship groundings, coral blasting) causing coral fragmentation and disintegration and the formation of new sand.

Other variables to look at
Coral cover, rugosity, abundance of bioeroders.
Ecological implications
- If increases in sand: possible increase in bioerosion, decrease of substrate available for recruitment.
- If increases in bare rock: increase of substrate available for recruitment.

Cover of other living (e.g. Corallimorphs, Zoanthids)

What is the trend?
Increase
Possible main interpretation
Reef possibly impacted by decreased water quality due to changes in land use, increased runoff or sewage input.
Other variables to look at
Coral cover, macroalgal cover, turf height, cover of other benthic heterotrophic feeders.
Ecological implications
Increase in bioerosion, competitive exclusion and decreased substrate available for recruitment of other benthic organisms.



Octocoral density

What is the trend?
Decrease
Possible main interpretation
Octocoral disease outbreak; might link to terrestrial runoff.
Other variables to look at
- Octocoral disease prevalence.
- Macroalgal cover, turf height, cover of benthic heterotrophic feeders.

Ecological implications
Decrease in structural complexity.

CCA cover

What is the trend?

Decrease

Possible main interpretation

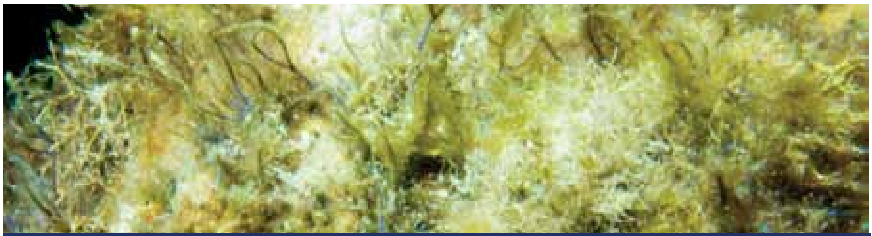
- Increase in thick algal turfs, particularly if sediments present.
- Possible diseases of CCAs.

Other variables to look at

- Algal turf canopy height.
- Survey of disease prevalence.
- Sedimentation.

Ecological implications

- Decrease in carbonate production, reef accretion and stability. Increase in reef erosion.
- Reduce settlement cues for coral larvae.
- Reduce overall reef resilience.



Turf cover

What is the trend?

Acute increase

Possible main interpretation

- Increase in substrate availability due to coral mortality from acute disturbance.
- Sudden increase in nutrient inputs after storms. Not necessarily a problem.

Other variables to look at

- Coral cover
- Algal canopy height

Ecological implications

Only likely to be a problem if accompanied by an increase in turf canopy height.

What is the trend?

Chronic increase

Possible main interpretation

- Overfishing of herbivores and/or the predators of urchins.
- Increase in nutrient availability and pollutants (e.g.from terrestrial runoff).
- Changes in environmental conditions (e.g. rainfall, river flow, light, water temp).
- Could indicate an increase in the abundance of garden-forming damselfish.

Other variables to look at

- Herbivore biomass, density.
- Water quality (nutrients, turbidity).
- Trends in damselfish density.

Ecological implications

- Only likely to be a problem if accompanied by an increase in turf canopy height.

Macroalgal cover by growth form and species

What is the trend?

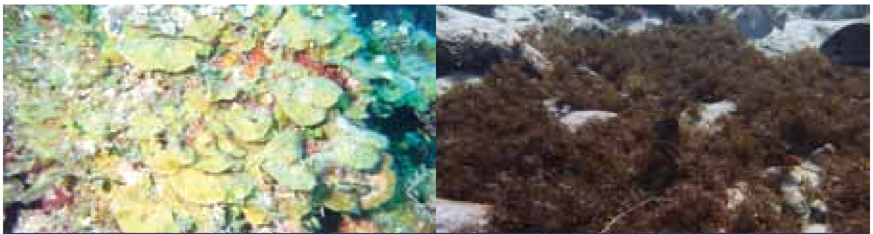
Increase

Possible main interpretation

- Lots of important variability. Some of the most common fleshy macroalgae on reefs suggest the following insights:
- *Lobophora* – tends to have limited seasonality and not strongly influenced by wave exposure. But one of the most problematic algae for other organisms such as coral and sponges (i.e., very strong competitor).
- *Dicyota* spp. – Can have very erratic dynamics including summer blooms. Note that blooms can change under upwelling conditions. Difficult to interpret a change in this group unless it persists over time.
- *Halimeda* spp – An increase in microhabitats that are usually intensively grazed, such as the tops of (dead) coral heads, suggests that grazing is chronically low.

Other variables to look at

Shift in algal species composition.



Macroalgal cover (and/or volume)

What is the trend?

Acute increase

Possible main interpretation

- Increase in substrate availability due to coral mortality after reef is impacted by physical disturbance (e.g. tropical storms).
- Sudden increase in nutrients due to increased runoff or sewage input.
- Possible seasonal variation if historical data in that season not available to confirm natural patterns. For example, *Dictyota* blooms in summer in many places. Reefs associated with large banks – e.g,. Bahamas, Turks and Caicos – tend to have natural seasonal blooms of *Microdictyon* in summer.
- Disease of *Diadema.*

Other variables to look at

- Changes in coral cover
- Algal species composition
- Water quality (nutrients and sediment loading).
- Herbivore density and biomass.

Ecological implications

- Overgrowth of corals. If herbivory is low, a phase shift to macroalgal-dominated reefs and decrease in carbonate production.
- Changes in species composition, competitive exclusion, losses or shifts in diversity and ecological roles

What is the trend?

Chronic increase

Possible main interpretation

- Overfishing of herbivores.
- Changes in environmental conditions (e.g. regional rainfall, river flow) leading to increase of nutrient inputs and a reduction in water clarity.

Other variables to look at

- Water quality (e.g. nutrients, sediment loading, turbidity),
- Changes in fish size structure, fish biomass or fishing pressure data.
- Changes in coral cover,
- Shift in algal species composition.

Ecological implications

- Reduction in coral recruitment and recovery.
- If herbivory is low, a phase shift to macroalgal-dominated reefs and decrease in carbonate production.
- Loss in diversity and decrease in structural complexity.

Supporting references on page 159.

Turf canopy height

What is the trend?

Increase

Possible main interpretation

Reduction in grazing intensity that can occur for several complementary reasons:

- Rapid increase in dead coral (substrate available for herbivore feeding).
- Decrease in herbivore size, biomass, density.
- Increased nutrient supply
- Increase in density of damselfish that defend algal gardens (e.g., *Stegastes planifrons*).

Other variables to look at

- Herbivore biomass
- *Diadema* density
- Water quality
- Coral cover
- Damselfish density

Ecological implications

- Indicator of a possible shift towards increased macroalgae and likely to result in reduced coral recruitment.
- Healthy system 2mm or less. Greater or equal than 5mm shutdown in coral recruitment.

Cyanobacteria cover

What is the trend?

Increase

Possible main interpretation

- Terrestrial inputs
- Nutrient increase

Other variables to look at

Shift in algal species composition.

Ecological implications

Changes in chemical microhabitats for coral recruitment.

Reef monitoring - supporting references

Fish

Appeldoorn et al. 2011; Arnold et al. 2010; Behringer et al. 2009; Bozec et al. 2013; Burke 1995; Burkepile & Hay 2008; Ehrhardt et al. 2011; Ferrari et al. 2012; Graham et al. 2005; Graham & Nash 2012; Green et al. 2012; Harborne et al. 2009; Micheli et al. 2014; Morris & Akins 2009; Mumby et al. 2005; Mumby 2006; Mumby, Hastings, et al. 2007; Mumby et al. 2012; Rogers et al. 2014; Stoner et al. 2012; Williams & Polunin 2001; Wynne & Côté 2007

Coral

Arnold et al. 2010; Brown 1997a; Brown 1997b; Done 1999; Douglas 2003; Eakin et al. 2010; Glynn 1996; Harvell et al. 2007; Hoegh-Guldberg 1999; Jones et al. 2009; McCook et al. 2001; Muller et al. 2008; Mumby, Harborne, et al. 2007; Peters 1997; Randall & Szmant 2009; Rogers 1990; Scoffin 1993; Smith & Buddemeier 1992; Szmant & Gassman 1990; Vega Thurber et al. 2014; Weil et al. 2006; Wilkinson 1999; Williams & Bunkley-Williams 1990

Other Benthic

Alvarez-Filip, Côté, et al. 2011; Alvarez-Filip, Dulvy, et al. 2011; Carpenter 1984; Carpenter & Edmunds 2006; Cooper et al. 2008; Cooper et al. 2009; Fabricius 2005; Glynn 1997; Harvell et al. 2007; Hernandez-Munoz et al. 2008; Kuguru et al. 2004; Lapointe et al. 2010; Lessios 1988; Lessios et al. 1984; López-Victoria et al. 2006; Mah & Stearn 1986; Rasser & Riegl 2002; Ward-Paige et al. 2005; Webster 2007

Algae

Arnold et al. 2010; Arnold & Steneck 2011; Davies et al. 2014; Diaz-Pulido 2002; Díaz-Pulido et al. 2012; Diaz-Pulido & McCook 2004; Kuffner et al. 2006; Kuffner et al. 2008; Mumby et al. 2005; Paul et al. 2005; Renken 2008; Renken et al. 2010; Vermeij et al. 2010; Webster et al. 2010

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OUR RESEARCH

Our research focuses on delivering science to improve the management of coral reefs. We carry out empirical ecological studies at scales ranging from millimetres (algal patch dynamics) to thousands of kilometres (gene flow in Caribbean corals) in an effort to plug gaps in our understanding of reef processes. Empirical data are then used to develop ecosystem models from which we can investigate the effectiveness of conservation measures in mitigating disturbance on reefs including climate change.

we need a governance framework that allows common stakeholders and public to influence the decision-making process...

When I started working on coral reef management in 1992, there was not much science available to guide decision-making. But while scientists always talk about the need to know more – which is their job after all – there is now a wealth of information from which to base and justify decisions.

Natural science justifies the need to control pollution, control fishing, and reduce local damage to reefs. Social sciences tells us the principles of good governance. Yet, despite progressive action on management throughout the region, each step forward seems to be met with one step back, particularly in meeting the challenge of development, be it cruise ship terminals or land clearance for housing.

To me, turning of the tide will require renewed commitment of the public to see a change of beneficiaries. All too often the beneficiaries are large international companies and local people experience the cost of a degraded and dwindling environment. Science can play a role here in trying to illuminate the real costs and benefits of development, making it transparent for all to see. This goes beyond hard economics and considers the ways in which peoples' quality of life is influenced by a clean, healthy, and safe environment. But having the science is only part of the answer; we need a governance framework that allows common stakeholders and public to influence the decision-making process. And it is here that government and managers can make a start.

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accretion
The process of growth or enlargement either by a) organic growth: continued development from within, or b) increase by external addition or accumulation

acidification
The process by which acids are added to a water body, leading to a significant decrease in pH that may lead to the water body becoming acidic. This is a common form of water pollution.

anthropogenic
Applied to substances, processes, etc. of human origin, or that result from human activity.

aragonite
A colourless mineral, the stable form of calcium carbonate. It is different from calcite, the more common form of calcium carbonate, by its greater hardness. Aragonite is the mineral normally found in pearls and mollusc shells are formed of aragonite crystals.

assemblage
A group of plants and/or animals that is indicative of a particular environment.

benthic algae
Algae that live attached to the sea bottom.

benthic communities
Life attached, moving or occurring at the base of bodies of water.

bioerosion
Erosion or decay caused by living organisms such as mollusks, sponges, crustaceans, either by boring, drilling, rasping, or scraping.

bioindicator
An organism used as an indicator of the quality of an ecosystem, especially in terms of pollution.

biomass
The total quantity or weight of organisms in a given area or volume.

broadcast spawner
Coral that releases eggs and sperm directly into the sea for external fertilization.

brooder
Coral that harbours or broods developing larvae within its polyps.

calcium carbonate
A white solid chemical compound that is found as chalk, limestone, or marble, and in animal shells and bone.

calcification
The process by which corals and calcareous algae extract calcium from seawater and produce it as calcium carbonate to form skeletons in corals and the shells of molluscs.

carbon
Extracted from carbon dioxide by plants during photosynthesis, is incorporated in living matter, and when organic matter decomposes its carbon is combined chemically with oxygen and returned to the atmosphere as carbon dioxide.

carbon budget
A record or estimation of carbon in an area or system, and the flux into and out of this system.

carbon cycle
One of the major cycles of chemical elements in the environment. Carbon (as carbon dioxide) is taken up from the atmosphere and incorporated into the tissues of plants in photosynthesis. It may then pass into the bodies of animals as the plants are eaten (food chain). During the respiration of plants, animals, and organisms that cause decomposition, carbon dioxide is returned to the atmosphere. The combustion of fossil fuels (e.g. coal) also releases carbon dioxide into the atmosphere.

coralline algae
A branching pink/reddish seaweed with a calcium carbonate jointed stem.

corallivory
The act of eating coral polyps by some marine organisms.

Cost–Benefit Analysis (CBA)
A primary tool that economists use to determine whether a particular policy promotes economic efficiency. CBA is an aggregator of all impacts, to all affected parties, at all points in time. The impacts, both positive and negative, are converted into a common monetary unit, and the cost–benefit measure is simply a test of whether the benefits exceed the costs.

crustose coralline algae
Red algae that cement and bind the reef together. Crustose corallines resemble pink or purple pavement. They can range from smooth and flat, to rough and knobby, or even leafy

cyanobacteria
Often called blue-green algae, these photosynthetic aquatic bacteria have no relationship to algae.

marine dissolved organic matter
Marine dissolved organic matter is a complex mixture of molecules of diverse origins found in seawater. It affects the penetration of light, the exchange of gases at the sea surface and the availability of trace metals and other nutrients to the community. Phytoplankton, including photosynthetic algae and bacteria, are the primary source of marine dissolved organic matter.

eutrophication
Excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land, which causes a dense growth of plant life limiting the oxygen needed for animal life.

excavating sponges
Also called boring sponges, marine sponge which bores passages in mollusks, shells, corals, limestone, and other calcium carbonate matter.

fix
Biology (Of a plant or microorganism) absorb (nitrogen or carbon dioxide) by forming a non-gaseous compound.

fragmentation
A method of asexual reproduction, occurring in some invertebrate animals, in which parts of the organism break off and develop into new individuals.

food web
A series of interconnected and overlapping food chains in an ecosystem.

fore reef
A talus or straight slope on the seaward side of a reef, constantly under attack by waves and currents.

gamete
Reproductive sex cell that joins with another sex cell to form a new organism Female gametes (ova) are usually motionless; male gametes (sperm) often have a tail (flagellum).

hedonic pricing
A technique used to investigate how environmental quality affects the prices of other goods and services. It is widely used to explain variations in house prices in terms of variations in environmental quality (such as air pollution, water pollution, or noise) and environmental amenities (such as attractive views or access to recreational sites).

herbivore
An animal that feeds on plants.

hermatypic corals
Refers to 'stony corals' which are reef-building corals.

Institutions
Institutions can be thought of as the 'rules of the game' in any society, and the formal or informal structures, mechanisms and processes that establish those rules.

macroalgae
Another name for seaweed.

matrices
A rectangular array of quantities or expressions in rows and columns that is treated as a single entity and manipulated according to particular rules.

mesopredator
A medium-sized predator which often increases in abundance when larger predators are eliminated.

metapopulation
A set of partially isolated populations that belong to the same species, between which individuals can freely migrate.

microbial degradation
Processes of decomposition and breakdown of materials by the action of micro-organisms, principally bacteria and fungi.

microsatellites
Regions within DNA sequences where short sequences are repeated one right after the other. They are widely used in the population studies and conservation biology to detect sudden changes in population, effects of population fragmentation, and interaction of different populations.

mitochondrial DNA
DNA that is found in mitochondria in most cells, in which the biochemical processes of respiration and energy production occur. It is entirely independent of nuclear DNA and, with very few exceptions, is transmitted from females to their offspring.

multi-criteria analysis (MCA)
In a MCA, you quantify your criteria in different units or qualitative terms, using a ranking or rating format. By determining the relative importance of the criteria it is possible to compare different alternatives based on these criteria.

multiple driver effects
Drivers are factors which bring about a situation that is observed to exist or happen. Such factors include fishing, sedimentation, grazing, predation and recruitment; the effects are the changes which are a result or consequence of those factors.

nitrogen
A colourless, tasteless, odourless gas, that exists in the atmosphere or as a dissolved gas in water; is a nutrient for plants. It is produced in septic systems, animal feed lots, agricultural fertilizers, industrial wastewaters and garbage dumps.

pathogen
An organism (bacterium, virus or other microorganisms) which causes a disease within another organism.

phosphorus
An element essential for the growth of organisms Phosphorus is also released into the environment by fertilizers and detergents where they act as a nutrient pollutant in water.

physicochemical
Relating to physics and chemistry or to physical chemistry.

phytoplankton
Microscopic plant-like organisms that live in the ocean and are the foundation of the marine food chain.

photosynthetic
Green plants that go through the process of photosynthesis which is the combining of carbon dioxide and water, by using energy from light, to produce their own food.

plankton
Plankton is made up of animals and plants that either float passively in the water, or with limited powers of swimming are carried from place to place by the currents.

polyp
A small tube-like marine animal which lives in warm, clear seas and grows attached to the sea-bed, to rocks, or to other polyps. On the other end is a mouth surrounded by finger-like, stinging tentacles. Live coral is made of polyps.

proximate drivers
Causes of reef decline that include coral bleaching, ocean acidification, hurricane damage, algal blooms, coral disease, sedimentation, invasive species and disease of sea urchin, *Diadema antillarum*.

proxy
Substitute or surrogate.

recruitment
The addition of new members into a population by reproduction or immigration.

saturation states
Surface tropical seawaters are generally supersaturated with respect to the carbonate minerals (e.g. calcite, aragonite) from which marine organisms construct their shells and frameworks. We refer to the degree to which seawater is saturated with respect to these minerals as 'saturation state'.

senescence
The condition or process of deterioration with age.

sessile
(Of an organism, e.g. a barnacle) fixed in one place; immobile.

sink
A body or process which acts to absorb or remove energy or a particular component from a system.

spatiotemporal
Of, relating to, or existing in both space and time.

substrate
The surface or material on or from which an organism lives, grows, or obtains its nourishment.

symbiont
An organism living in a mutually beneficial relationship with another organism from a different species.

symbiosis
Association of two different organisms (usually two plants, or an animal and a plant) which live attached to each other, or one as a tenant of the other, and contribute to each other's support.

Total economic value (TEV)
The overall economic value of a particular natural resource, taking into account both use and non-use values. The sum of these ecosystem services is defined as the TEV of that ecosystem and is normally expressed as a yearly value.

trophic
Of or pertaining to the feeding habits of, and the food relationship between, different types of organisms in the food-cycle.

trophic cascade
An ecological phenomenon triggered by the addition or removal of top predators changes the relative populations of predator and prey through a food chain, which often results in dramatic changes in ecosystem structure and nutrient cycling.

trophic transfer
Energy or nutritional transfer within a food web.

trophic structure
The organisation of the links within an ecosystem based on communities of organisms (species) and their feeding habits.

turf algae
densely packed algae with thread-like strands which rise less than one centimeter above the substratum where they are growing.

ultimate drivers
Causes of reef decline that include rising atmospheric carbon dioxide, rising sea temperature, overpopulation, poor governance, inappropriate coastal development, destructive fishing practices, overfishing, agricultural fertilisers and pesticides, elevated watersheds, inadequate environmental education.

zooxanthellae
Photosynthetic algae that live in the tissues of most reef-building corals. They have a mutualistic relationship with coral. The coral provides the algae with a protected environment and compounds they need for photosynthesis. In return, the algae produce oxygen and help the coral to remove wastes.

IMAGE CREDITS

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Keep Our Islands Green
and Our Reefs Clean

This handbook aims to provide reef managers with tools, information and recommendations on management of coral reef ecosystems.

The handbook sections range from ecological history and biogeography, resilience as well as climate change issues to fisheries, governance and the monitoring of coral reef ecosystems. Within each section are practical stand-alone 'briefs'. These briefs offer concise information on particular reef-related issues, utilising some of the most recent scientific research to inform management actions. Each of the briefings are a unique grab-and-go resource.

The accessible format also provides a useful resource for students, researchers, policy-makers and anyone interested in the future of Caribbean coral reefs.

The Future of Reefs in a Changing Environment (FORCE) project partners a multi-disciplinary team of researchers from the Caribbean, Europe, USA and Australia to enhance the scientific basis for managing coral reefs in an era of rapid climate change and unprecedented human pressure on coastal and coral reef resources.

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