Effective marine protected areas in the Caribbean

Good for the economy, good for the ecosystem

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Abstract
Marine protected areas (MPAs) are a popular tool used around the world in an attempt to protect and conserve ecosystems valuable to human well-being. Incentives can be created to protect ecological features by adding socio-economic value to the goods and services provided by ecosystems. It has recently been emerging that conservation efforts can be increased by having an ecosystem-based approach to protecting the environment, while also allowing the sustainable use of its resources. A basic assumption of the ecosystem-based approach to conservation is the notion that humans are also part of the ecosystem and need to be included in conservation plans concerning the use of MPAs. It is now possible to study design and management features which allow MPAs to have an increased level of ecological and socio-economic success, due to the large number of MPAs with highly variable design and management features being established in the last couple of decades. With the highest levels of biodiversity found on earth, countries throughout the Caribbean are also attempting to conserve their ecosystems for long-term sustainable use by forming regional networks of connected MPAs. Even though some Caribbean MPAs are having significant levels of success concerning the conservation of ecosystems and their associated goods and services, most of them do not. Caribbean nations are still a long ways from fully understanding how MPAs can be successfully implemented and run, and must cooperate with one another and keep drawing on lessons from the past in order to keep improving their understanding and use of MPAs.

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Introduction

Protection (minimising impact) and conservation (minimising loss) of biodiversity is of growing global concern due to the rapidly accelerating loss of species, alteration of habitats, and consequent ecosystem fragmentation (Ehrlich 1988). Changes in biodiversity can alter ecosystem processes which in turn can have profound consequences for services that humans derive from ecosystems (Chapin et al. 2000). There has been an international effort in the past decade to achieve conservation targets that were initially established at the 8th Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) in 2006. This initial global target was set out to protect 10% of the world's ecological regions. These spatial targets were updated in the Aichi Biodiversity Targets of COP 10. The update directed parties to conserve at least 17% of terrestrial and inland water, and 10% of coastal and marine areas. The conservation targets need to be accomplished via effectively and fairly managed, ecologically representative and well-connected protected area systems, especially in regions of particular importance for biodiversity and ecosystem services, by the year 2020 (COP 10 Decision 2010).

The CBD has given limited guidance in ways to measure management effectiveness of protected areas (De Santo 2013). Effectiveness is frequently described in conservation research as progress in achieving goals and objectives (Axford et al. 2008; Wells 2006). Goals and objectives are what define the establishment of protected areas. These can consist of general goals with more specific sub-goals and can relate to, e.g., human activities, social conditions, and ecological functions (Jentoft et al. 2011). The World Commission on Protected Areas (WCPA), which is part of the International Union for Conservation of Nature and Natural Resources (IUCN), developed six commonly used management categories with two subcategories: (a) areas managed primarily for biodiversity conservation (categories I and II) and (b) areas managed mainly for the sustainable use of resources (categories III–VI)(Dudley 2008). The IUCN also recognizes four broad types of governance of protected areas, any of which can be associated with any management objective. Governance can be categorized as: (a) privately owned and managed, (b) government owned and managed, (c) indigenous or local community owned and managed or (d) 'co-managed' – typically between governments or nongovernmental organizations (NGOs) and surrounding communities (Dudley 2008).

Marine protected areas (MPA) are sites in the ocean designated for the management of human activities in order to protect nature and conserve its associated ecosystem services and cultural values (Dudley 2008). MPAs have become a frequently used tool for protecting marine and coastal environments (Toropova et al. 2010). There are two common types of MPAs: No-take areas (NTAs) and multiple-use MPAs. NTAs, also known as "marine reserves", are fundamental to an effective MPA system, whether they are used as standalone MPAs or as zones within a multiple-use MPA. The vast majority of MPAs fall into the multiple-use category. They allow for a range of uses, and are often managed through zoning. An increasing number of multiple-use MPAs follow best practice in having a minimum of one NTA, buffered from edge effects by one or more surrounding zones allowing different uses (UNEP-WCMC 2008). A global review of studies found that that fish, invertebrates, and seaweeds had average increases inside marine reserves for: (a) biomass, or the mass of animals and plants, increased 446%, (b) density, or the number of plants or animals in a given area, increased 166%, (c) body size of animals increased 28%, (d) species diversity, or the number of species, increased 21% (Lester et al. 2009).

The wider Caribbean region comprises 38 diverse countries and states (Appendix 1). They include insular independent nations, overseas territories of the UK, France, USA and the Netherlands, and mainland countries in Central and South America extending as far south as Guyana. The participating countries are diverse in terms of e.g., development, geography, and population size (UNEP-WCMC 2008). Countries in the Caribbean are also attempting to achieve the Aichi Biodiversity Targets, but with even more ambitious targets. Nine Caribbean governments have agreed to effectively conserve and manage 20% of the marine environment by the year 2020 (Johnson et al. 2014). There are currently over 300 MPAs in the Wider Caribbean, protecting less than 10% of the coastal and marine resources of the region and with only 6% effectively meeting conservation objectives (Johnson et al. 2014). The objective stated most frequently in Caribbean MPA management policies, resulting from a survey of 31 MPAs throughout the wider Caribbean region, is to protect the ecosystem. Other common objectives include: providing general economic benefit, managing recreation, promoting effective management, preserving fisheries, and promoting education. Objectives stated less frequently in management policies are: having sustainable financing, serving as a model MPA, and having supporting science (Fig. 1)(Dalton et al. 2015). Appeldoorn & Lindeman (2003) compared 55 no-take reserves throughout the Caribbean region and found that half of the reserves offer potentially significant levels of protection. Unfortunately, most could be considered paper parks, which are officially designated areas that are not actively managed to achieve conservation goals. The Caribbean has one of the highest levels of biodiversity of all the world's regions (UNEP 2010). Its ecosystems have great economic value. In the year 2000, Caribbean coral reefs alone had an estimated annual net economic value of 3.1-4.6 billion US dollars provided by its goods and services (Burke & Maidens 2004). If properly designed and managed, MPAs have the potential to support conservation efforts through many ecological effects on the population, community, or ecosystem level (Appendix 2)(Pelletier et al. 2005; García-Charton et al. 2008). These ecological effects could then in turn benefit the economy by increasing the potential revenue of different practices related to marine environments, such as fishing and tourist recreation, which are important sources of income for many Caribbean countries (Geoghegan et al. 2001; Polomé et al. 2005).

MPAs can benefit the economy and protect ecological features

A variety of goods and services are supplied by marine ecosystems, which provide direct and indirect contributions to human well-being. These include goods traded in markets, such as food and raw materials, as well as non-market goods and services, such as nutrient cycling, climate regulation, coastal protection, and opportunities for recreation (Appendix 3)(Schuhmann 2012). As stated in Wallace (2007), ecosystem services are increasingly being promoted as a means for documenting the values humans place on ecosystems and evaluating benefits derived from natural resources. In many Caribbean countries and coastal towns, tourism is the dominant industry, and commercial fishing is common. However, a long history of overfishing, as well as pollution and sedimentation from poor coastal development and agriculture practices, have had a negative impact on coral reefs, seagrass beds, mangroves and sandy beaches, along with their associated ecosystem goods and services throughout the region (Burke & Maidens 2004). MPAs are seen as a tool which can be used to protect the supply of ecosystem goods and services, and ultimately sustain or restore their socio-economic value (Geoghegan et al. 2001).

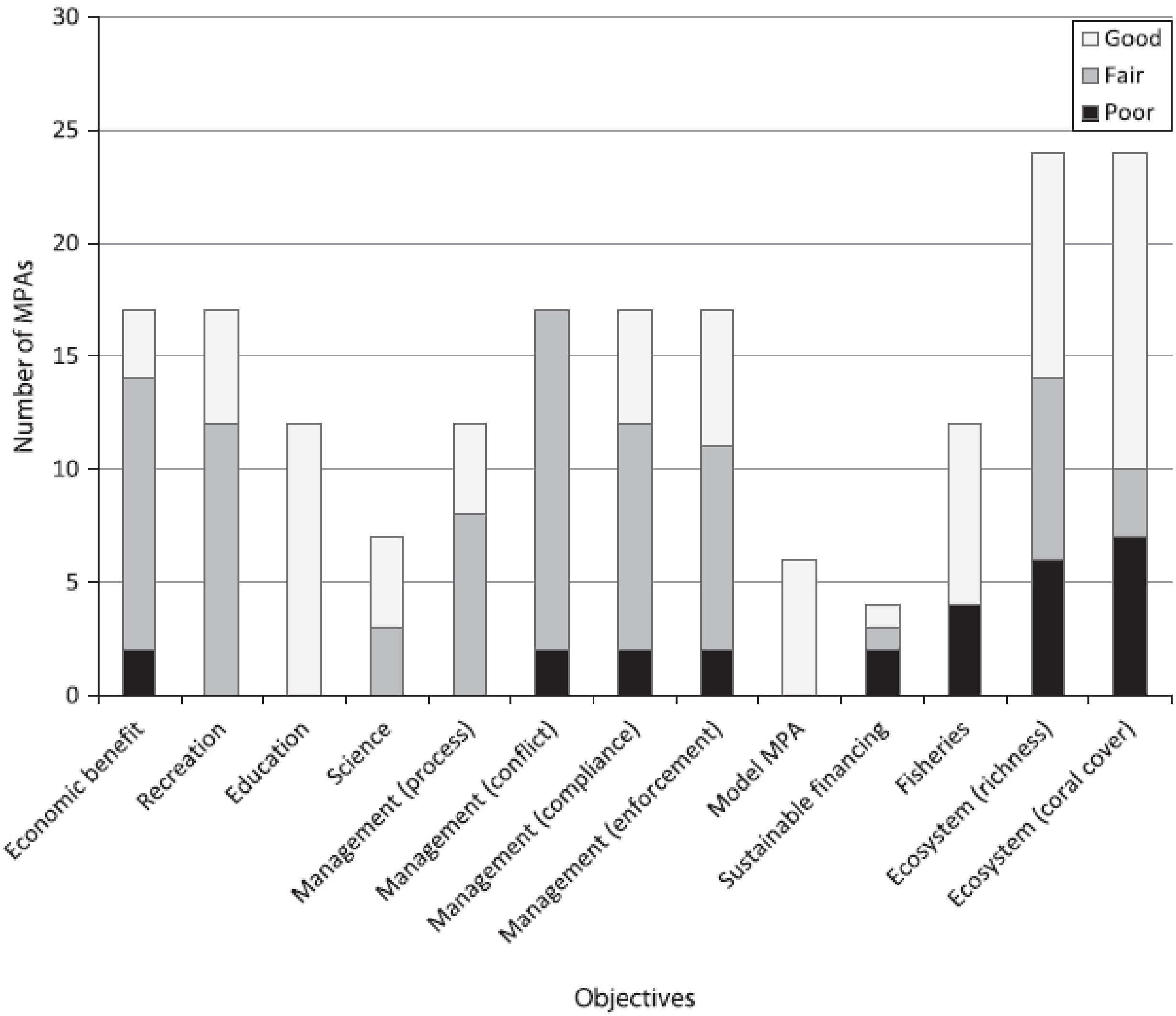

Fig. 1. Number of MPAs making progress (poor/fair/good) toward specific stated objectives.

Fishery revenue can benefit from MPAs through the exportation of exploited species biomass to non-protected areas (Sluka et al. 1997). There are two main mechanisms responsible for the export of biomass: (a) the “spill-over effect”, which is the net emigration of adult and large juvenile organisms, and (b) the export of pelagic eggs and larvae from restored spawning stocks inside the MPA (Appendix 4)(Rowley 1994; Mesnildrey et al. 2013). Emigration of adults and large juveniles from protected areas to fished areas is linked to the ability of exploited species to reach greater densities and larger sizes inside protected areas and to the movement patterns of individuals across protected area boundaries (Rowley 1994). Large fish and invertebrates contribute much more to the next generation than smaller ones, since they produce substantially more offspring. For example, a 60 cm gray snapper (*Lutjanus griseus*) produces 10 times more young than a 30 cm one (Lubchenco et al. 2007). Chiappone & Sealey (2000) showed how studies of queen conch (*Strombus gigas*), spiny lobster (*Panulirus argus*), and Nassau grouper (*Epinephelus striatus*) in the Exuma Cays Land and Sea Park (ECLSP, Bahamas) found greater adult size and densities inside the reserve when compared to fished areas in the region. They also suggested that benefits obtained from emigration are most likely to be on a local scale, based on the movement patterns of the studied organisms. Sluka et al. (1997) found densities of Nassau grouper at sites within 5 km of the ECLSP boundaries were more similar to densities inside the reserve than to those of areas further away. This decrease in density in further locations could be due to Nassau grouper movement from within the reserve, but also due to increased fishing pressure in surrounding areas. When scientists tagged Nassau groupers in the reserve, some of the fish were later caught up to 220 km away (Lubchenco et al. 2007). The increase in biomass obtained from protected areas is much harder to achieve for highly migratory species, such as sharks and sea turtles. However, many migratory species do have considerable site fidelity and well-defined habitats, which are prime areas for protection (Lascelles et al. 2014). The export of pelagic eggs and larvae from restored spawning stocks inside MPAs could enhance fisheries on a local and regional scale (Oracion et al. 2005; Butler et al. 2011). Larval behavior coupled with complex hydrodynamics of the Caribbean oceanographic environment may lead to self-recruitment, especially in regions under the influence of retentive oceanographic environments (Butler et al. 2011; Kough et al. 2013). Larvae that originate from populations located in strongly advective (i.e. horizontal movement of water) oceanographic environments could be dispersed 1000s of km downstream from their natal source and have much lower levels of self-recruitment (Butler et al. 2011). How far larvae can reach also depends on the pelagic larval duration, which can range from days to weeks for coral reef fish, to several months for species such as the Caribbean spiny lobster (Butler et al. 2011). Truelove et al. (2014) found high levels of connectivity among spiny lobster populations in MPAs in the Mesoamerican Barrier Reef (MBRS) of Central America. They also found that MPAs in the northern MBRS, which has more advective oceanographic environments, contained more individuals that were genetically determined outliers or migrants than southern MPAs dominated by retentive environments. A concern with MPAs, and especially no-take fisheries reserves, is the effect that closure of an area might have on the user groups and the surrounding environment due to the redistribution of fishing effort towards other zones. Closure could lead to congestion of fishing effort in zones that remain open to fishing, increasing pressure on the resource and causing ecological harm (Holland 2000). Redistribution of fishing effort can be minimized through programs that facilitate alternative livelihoods for local fishermen or provide compensation for lost rights (Ellis & Allison 2004).

MPAs tend to attract tourists (UNEP-WCMC 2008). The protection of aesthetically pleasing marine ecosystems, such as highly productive coral reefs, can increase revenue from tourist recreation activities, such as diving and snorkeling (Oracion et al. 2005). Sandy beach recreation can also benefit from the protection of entire ecosystems. Coastal protection, provided by intact coral reefs and mangroves, is a natural way to attenuate wave and storm surge, reduce beach erosion, and ultimately maintain the coastal profile (Spalding et al. 2014). Pristine beaches are not often a direct source of economic income, although aesthetically pleasing beaches can attract more tourists which could indirectly lead to increased economic benefits (Polomé et al. 2005). MPAs have the potential to conserve habitats through the restoration or maintenance of trophic structures and functional diversity (Gjertsen 2005; Campbell & Hewitt 2006). For example, live coral recruitment and balanced coral-algal competition, two important aspects of coral reef health, can be maintained through proper composition and presence of herbivorous fish and their associated bio-eroding and grazing activities (Ledlie et al. 2007). On the other hand, live coral and structural complexity is critical for the health and abundance of adult reef fish and has been directly linked to the survivorship and replenishment of juvenile reef fish (Jones et al. 2004; Wilson et al. 2006). These examples illustrate the mutualistic nature between living habitat structures and the organisms that inhabit them. Protecting such ecosystem features can help towards the conservation of the ecosystem. Rioja-Nieto & Sheppard (2008) showed how some management regulations and strategies are having a positive effect on habitat integrity inside Cozumel Reefs National Park (CRNP, Mexico). They also found higher levels of habitat diversity when comparing an area inside the MPA to an adjacent unmanaged site with uncontrolled use. The regulations that had the most influence on habitat integrity in CRNP were those preventing physical damage to the benthic substrates (e.g. restricted use of anchors or reducing vessels draft). Preventing physical damage to benthic substrates is just one of many possible management regulation features that can be implemented in MPAs. Another study, performed in Cozumel, by Alvarez-Filip et al. (2011) explored the influence of reef structure on fish assemblages, by comparing the size and trophic structure of reef fish, along a 20 km-long 15-reef gradient of coral cover, coral species dominance and structural complexity. Their results show that reefs with high structural complexity, in particular those dominated by robust *Montastraea* corals, supported fish assemblages with larger numbers of individuals in the smallest size classes (<20 cm) and longer food chains (higher mean trophic levels). The greater abundance of both small fish and the key early life stages of larger fish on more complex reefs suggest that the structural complexity present in Cozumel may influence entire reef fish assemblages. This shows how protecting key reef-building corals such as *Montastraea* is likely to be important for maintaining fish communities, prevent loss of fish recruitment, and prevent truncated food chains.

Caribbean MPA design

It has recently become possible to better understand MPA design, due to the large amounts of marine reserves and multiple-use MPAs being established around the world, with highly variable design features (Edgar et al. 2014). When wanting to increase conservation efforts through the use of MPAs, it is essential to design them according to appropriate goals regarding ecology. Those goals can revolve, as seen in previous paragraphs, around different levels of biological organization, which can range from populations to entire ecosystems (Appendix 2)(Pelletier et al. 2005; Pomeroy et al. 2005). However, ecological goals are often viewed as not being compatible with some social and economic goals. Therefore, there should not be a choice between environmental and economic goals, but rather between short-term gain and long-term prosperity. Long-term gains depend directly on healthy and resilient ecosystems, enabling them to provide ecosystem services on a sustainable basis by minimizing disruption of human uses of the ocean (Halpern et al. 2010). There is no single design feature that will ensure the success of an MPA. Edgar et al. (2014) found by comparing 87 MPAs worldwide, that the biomass and species richness of prey and predatory fish increased exponentially with the accumulation of five selected features relating to design and management. The five MPA features they selected were: age, size, isolated by deep water or sand, level of fishing pressure, and level of enforcement. They also found that most (59%) of the studied MPAs only had one or two of the aforementioned features and were not ecologically distinguishable from unprotected sites. There are many managerial reasons (e.g. lack of funding or conflicts of interest between stakeholders) why it is not always possible to implement all the necessary design features into an MPA, which will be discussed in the next paragraph (Leverington et al. 2010; Kusumawati & Huang 2015). Common questions about designing MPAs involve issues relating to their location, size, number of MPAs in a given area, and spacing between MPAs (Gaines et al. 2010). The ecological and commercial benefits of MPAs vary according to species, habitats, their degree of exploitation, and the characteristics of the protected area. Some design features relating to ecological traits are emerging as crucial factors that need to be considered which can influence the effectiveness MPAs; whether the goals are to, e.g. protect commercially important fish species, conserve habitats, or maintain biodiversity (Foley et al. 2010; Mesnildrey et al. 2013).

First of all, MPAs require many years after establishment before they can achieve the goals they were intended for (Claudet et al. 2008). The time taken to observe ecological effect depends on many different criteria. Time can vary according to biological characteristics of species, such as spawning biomass, age at maturity, growth rate, fertility, and lifecycle (Mesnildrey et al. 2013). Fast growing species, like scallops, can reproduce at an early age and produce a large quantity of eggs. These animals can rapidly increase in abundance after a few years. On the other hand, species like predatory fish grow slowly and reproduce later, meaning that their increase in abundance in protected areas occurs many years after its establishment (Lubchenco et al. 2007). Inside a marine reserve at Glover's Reef (Belize), the total lobster biomass was 45 times greater when compared to outside areas after only a couple of years, while at the Jardines de la Reina marine reserve (Cuba), slower growing large predatory fish (e.g. sharks and large groupers) had 10 times greater biomass inside the reserve than outside after several years (Lubchenco et al. 2007). The time for effects to take place in MPAs can also depend on interactions between species (i.e. trophic interactions). While some individual fish and invertebrate species may become more abundant in numbers, others may decline or not change. In general, species subject to fishing in unprotected waters tend to become more plentiful in protected areas (Sale et al. 2005). A worldwide analysis by (Micheli et al. 2004) found that 61% of fish species were more abundant inside reserves than outside, while 39% of species were more abundant outside reserves than inside. Some fish and invertebrate species become less abundant in an area after it is designated as a marine reserve due to species interactions such as larger numbers of predators eating more of their prey. For example, sea urchins may decline if a key predator, lobster, increases inside a marine reserve. It could take several years before a new balance in predator-prey abundances is achieved (Shears & Babcock 2002; Shears & Babcock 2003). Habitat restoration is another complex process, with components relating to predator-prey interactions, and can also take decades to accomplish (García-Charton et al. 2008; Shears & Babcock 2003). Mumby et al. (2006) found large increases in the biomass of top predators and fish herbivores after 2 decades of protection in the ECLSP, Bahamas. Macroalgal cover was dramatically reduced due to the increase in grazing pressure inside the reserve. The reduction in competition from macroalgal species can have important restorative effects on vulnerable coral species by allowing better survivorship and recruitment (Hughes et al. 2007).

Determining spatial (i.e. size and location) and temporal (i.e. seasonal operation) features of marine reserves and multiple-use MPAs also depends on biological characteristics and life history traits of the species of interest. Interspecies differences make it very difficult to have universal specifications for all MPA design (Gaines et al. 2010). It is important to choose locations that have low levels of degrading areas surrounding them. The most obvious example is the damaging impact toxic pollution from distant locations can have on the species and ecosystems inside an MPA when it drifts into the MPA boundaries. Equally likely are other impacts, such as noise pollution and eutrophication effects (Agardy et al. 2011).

From an ecological perspective, larger protected areas with lower degrees of exploitation and anthropogenic threats should be better at increasing the abundances of different species when compared to their smaller counterparts, as they can protect more space for the dispersal of larvae as well as habitat necessary for early life stages (e.g. nursery habitats), which would make the populations largely self-sustaining (Walters 2000). However, the designation of large MPAs often poses significant long-term monitoring and enforcement challenges, such as the prevention of illegal fishing activities (De Santo 2013). Furthermore, MPAs often have the purpose of enhancing fish stocks and increasing biodiversity in non-marine reserves for commercial purposes. As well as being large enough to contain and protect a population of adequate size, marine reserves need to be small enough to be able to complement production effectively of surrounding populations in areas with higher degrees of exploitation (Murawski et al. 2000; Botsford et al. 2001). Smaller MPAs, in some cases, can fairly easily result in conservation benefits due to the fact that many coastal demersal fish are relatively sedentary. A large number of coral reef species require living spaces smaller than one km^2 (Kramer & Chapman 1999). On the other hand, many long lived and slow to mature coastal fishery species such as cod, groupers, and snappers, tend to be highly mobile and require much larger living spaces (Reynolds et al. 2002). Smaller MPAs could still be beneficial for such species if the MPA was placed in areas where vulnerable moments in their life history occur, such as the locations where feeding and spawning aggregations take place. Such aggregations often occur at highly predictable times and locations, and are extremely vulnerable to high levels of fishing pressure (e.g. trawling with large nets). Cubera snappers (*Lutjanus cyanopterus*) for example are an important fishery species found throughout the Caribbean that forms predictable seasonal spawning aggregations in relation to location, photoperiod, water temperature and lunar cycle. Heyman et al. (2005) found that Cubera snappers in Belize aggregate to spawn near the continental shelf edge. Their spawning aggregations typically formed 2 days before to 12 days after full moon from March to September within a 45.000 m^2 reef area. Peak abundance of 4000 to 10.000 individuals was observed between April and July each year (between 1998 and 2003), while actual spawning was most frequently observed in May. Spawning was observed consistently from 40 min. before to 10 min. after sunset within a confined area smaller than 1000 m^2. Protecting such aggregations by having small MPAs in the right places at the right times can effectively maintain greater stock abundances and has the potential to further increase the conservation of highly mobile marine species (Roberts & Sargant 2002).

Many marine fish and invertebrates have diel and/or ontogenetic migrations between habitat types during their lifetime, making them vulnerable to human activities in different environments. Gray snappers for example, another important fishery species found throughout the Caribbean, are a species that uses more than one habitat. Luo et al. (2009) examined the spatial and temporal dynamics of Gray snapper movement among neighboring mangrove, seagrass, and coral reef habitats in the northern Florida Keys, USA. They found a distinct diel migration pattern, whereby shallow seagrass beds are visited nocturnally and mangroves and other habitats with complex structure are occupied diurnally. They also found bay-to-ocean movement which occurred during the known spawning season of Gray snappers in this region. Lubchenco et al. (2007) described the ontogenetic habitat shifts of Gray snappers. Their life cycle starts when adult Gray snappers gather at the seaward edge of reefs to release eggs into the water, which then hatch into larvae. These larvae may drift in ocean currents for up to 30 days and can be found swimming near the surface of the ocean as far as 480 km. offshore. Most young gray snapper travel to shallower areas inshore as they age and are often found at depths of 1-5 meters when they are 4-6 weeks old. They favor mangrove areas with good places to hide at this point in their lives. As they age, gray snappers move into seagrass beds and nearby patch reefs, which are in slightly deeper water a little further from shore. The oldest, largest gray snapper move even further offshore onto deeper coral reefs. In summation, to thrive from birth through old age, gray snappers need open ocean, inshore mangrove areas, seagrass beds and patch reefs, and deeper offshore coral reefs (Appendix 5). Conservation benefits can be increased by creating a network of small, properly connected MPAs, that protect the different habitats and migration routes necessary for diel and ontogenetic migrations (Roberts et al. 2014). The distance between different protected habitats necessary for proper connectivity requires an understanding of the biology (e.g. larval duration), swimming/dispersal capabilities of different life stages, and physical transport properties of different water masses over time (Shanks 2009; Caldwell & Gergel 2013).

Having a regional ecosystem-based approach to determining spatial and temporal MPA features has recently been emerging as a way to further assist conservation efforts on a national and regional scale. The regional ecosystem-based approach to MPA design is expected to increase the stability and resilience of ecosystems for sustainable use and economic benefit. Researchers have indicated that MPAs following an ecosystem-based approach are more likely to achieve social and ecological success and it seems that several Caribbean countries are aiming to develop a regional network of ecosystem-based MPAs throughout the Caribbean (Foley et al. 2010; Johnson et al. 2014; Dalton et al. 2015). There are four basic ecosystem principles that need to be considered when designing ecosystem-based MPA networks with the purpose of sustaining valuable ecosystem function and services. Ecosystem-based MPA networks are required to maintain or restore: (a) native species diversity, (b) habitat diversity and heterogeneity, (c) key species, and (d) connectivity (Foley et al. 2010).

Native species diversity, composition, and functional redundancy (e.g. the degree to which multiple species perform similar ecological functions) is essential for sustaining productive and resilient ecosystems. Species diversity can affect many ecosystem functions, such as stable food web dynamics, and resistance to or recovery from environmental disturbances (Dulvy et al. 2004; Palumbi et al. 2008). Native species diversity is mentioned here explicitly because even though exotic species can potentially perform the same essential functional roles as native species, they can also have unpredictable and highly harmful ecological impacts. For example, the exotic Indian Ocean seagrass (*Halophila stipulacea*) can support equal or even higher abundances of different trophic groups relative to seagrass native to the Eastern Caribbean (Willette & Ambrose 2012), while invasive lionfish (*Pterois volitans*) are having harmful impacts on Caribbean coral reef food-webs (Arias-González et al. 2011).

Habitat diversity (i.e. the number of different habitat types within a given area) and habitat heterogeneity (i.e. the spatial arrangement and relationships among habitat patches across the seascape) are also essential for sustaining properly functioning ecosystems. Diverse habitats promote species diversity by safeguarding different species from competition and predation, and providing multiple sources of prey and settlement conditions (Rodríguez-Zaragoza & Arias-González 2008). Habitat heterogeneity influences connectivity among habitats and facilitates the successful movement of individuals among multiple habitats throughout their lifetime (Caldwell & Gergel 2013).

There are four types of key species (keystone species, foundation species, basal prey, and top predators) which are particularly important drivers of community structure and functioning, and decline of their populations below functional thresholds will result in significant losses of ecosystem services (Paine 1980; Duffy 2009). Keystone species have community-level effects that are often disproportionate to their biomass (Paine 1995). Top predators such as sharks can function as keystone species by driving community changes through trophic cascades, as was observed in the Bahamas by Mumby et al. (2006). Foundation species are important because they create habitat and refuge for a large numbers of other species as is the case with *Montastraea* corals in Cozumel (Alvarez-Filip et al. 2011). Basal prey species, such as microbes, certain phytoplankton, macroscopic algae, krill, and small pelagic fish such as anchovies and sardines, form important prey for higher consumers in the food chain (Menge et al. 2002)

Connectivity among habitats and populations in marine ecosystems is critical for population and species persistence. As was mentioned earlier, connectivity can occur through the movement of individuals (larvae or adults) across habitat boundaries. Connectivity also involves the movement of materials (e.g. nutrients and detritus). Large and small-scale dispersal dynamics throughout a species' life history determine national and regional metapopulation and metacommunity dynamics. Due to retentive and advective ocean circulation dynamics present in the Caribbean, some locations may act as larval source populations, while others may be larval sinks that depend entirely on recruitment and migration from other sites for population persistence (Butler et al. 2011). Placing MPAs in larval source locations can potentially enhance activities, such as fishing, in larval sink locations.

Ecosystems and ecosystem processes throughout the world involve complex interactions and non-linear dynamics that are not yet fully understood, resulting in uncertainty regarding future responses to disturbances and even management interventions (Bennett & Dearden 2014). Uncertainty about ecosystem dynamics and responses to different anthropogenic uses should be reduced but is unlikely to ever be eliminated due to the interactive effects of multiple stressors in marine ecosystems and by the varying levels of vulnerability of different habitat types to the same threats (Halpern et al. 2007). It is therefore critical to build redundancies (especially among key species and drivers of ecosystem structure) so that ecosystem functioning and services will be protected (Crowder & Norse 2008). Furthermore, the inherent uncertainty of anthropogenic effects on the ecology of the ocean makes it necessary to monitor changing climate, ecosystem states, and key ecosystem characteristics so that adaptive management can be practiced to improve the effectiveness of MPAs and MPA networks (Francini-Filho et al. 2013).

Caribbean MPA management

It is becoming a global norm that MPAs can and should lead to beneficial outcomes for conservation and development, by satisfying the needs of conservationists, governments, fishers, tourism operators, and local communities. MPAs therefore need to be associated with local social, cultural, economic, political, and environmental context. They also need to be associated with macro level contextual factors, such as history, politics, policies, global-economics, environmental shocks, climate change, demographic shifts, and technology. These contextual factors need to be incorporated into MPA design and management. Although some may be difficult or even impossible to predict, control, or change. This is particularly true for macro level factors, such as climate change (Bennett & Dearden 2014). MPAs require an adaptive management system (i.e. scientific monitoring and evaluation system) based on experience and outcomes with goals, objectives, and indicators relating to ecological, local development, management, and governance outcomes (Appendix 6, 7, and 8). Having an adaptive management system allows for, e.g. reflection on goals and objectives, identification of necessary improvements, encouragement of accountability, and justification of human and financial resource reallocation (Pomeroy et al. 2005; Francini-Filho et al. 2013; Bennett & Dearden 2014).

Most of the Caribbean MPAs are owned and managed by government agencies, and only in a few of them are non-government organizations and local groups involved in management, which is considered to be one of the main factors needed for MPA success. Effectiveness is compromised in MPAs where local communities are not involved and lack the social or economic incentives to comply with MPA regulations (Pollnac et al. 2010). Due to the fickle nature of government agencies, MPAs need to have financial and administrative independence. The Hol Chan Marine Reserve in Belize managed to obtain financial independence primarily due to the user-fee collection system, which allows the management authority to charge visitors. The revenue collected is also managed by the same authority. Hol Chan Marine Reserve does not receive any direct government funding other than occasional grants for special projects. A user-fee system is another important factor affecting the success of most MPAs in the region as governments are not able to provide the necessary resources for the MPAs to operate. The management scheme that makes the Hol Chan Marine Reserve a model MPA in the Caribbean comprises a long list of tools (Appendix 9)(Bustamante et al. 2014).

The failure of MPAs is often attributed to factors relating to their design and operation. A large amount of effort has been directed towards adapting their functions and associated rules and regulations in order to improve their performance (Pomeroy et al. 2005). However, not all failures can be remedied by reorganization and enhancing capacity in monitoring and enforcement. Lack of success can also be found in the process that leads up to their establishment, i.e. the initial stage when the idea was conceived, communicated, and discussed among stakeholders (Chuenpagdee et al. 2013). The implementation of MPAs can be viewed as a process where stakeholders representing governments, markets, and the general public participate in the discussion about what the MPAs are for, why they are needed, where they should be located, and how they should operate (Kooiman et al. 2005). Different stakeholders often have different interests and desired goals for the MPA. Conflict between stakeholders can already exist or arise when their interests do not match. This can drastically affect the outcomes of an MPA (Jentoft et al. 2011). MPAs are always introduced in places already struggling with political conflict and in social environments that are not always conducive to their establishment (Bavinck 2005; Chuenpagdee et al. 2013). The objectives of the MPA may change during the inception process depending on how the balance of power shifts between different stakeholders with different levels of influence (Christie 2004). Furthermore, the inception process can be prolonged, even up to several years, by certain stakeholders until they are able to secure their positions. In the meantime, other stakeholders can get frustrated and lose interest. Thus, power relations shift. Those who are active at the beginning may be pacified in the process, as other stakeholders discover what is going on and realize that their interests may be threatened, and decide to jump on board (Chuenpagdee et al. 2013). It has recently been emerging that the successful establishment of an MPA can potentially be achieved by educating the local community on conservation issues regarding their local environment, then having them take part in the implementation process, and in the end allowing them to also benefit from the established MPA (Charles & Wilson 2009; Bustamante et al. 2014).

Regional cooperation is a way to help improve conservation efforts and management effectiveness. Over the past 40 years, Regional Seas Conventions and Action Plans (RSCAPs) have been working all over the world towards the protection and sustainable management of marine and coastal environments (Johnson et al. 2014). They are mandated by their member states and strengthened by a United Nations Environment Program (UNEP) Governing Council Decision (Decision 22/2 III A). The Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region, or Cartagena Convention, was adopted in 1983 and provides the legal framework for the protection and development of the Caribbean marine environment (UNEP-WCMC 2008). On a national and regional scale, the Cartagena Convention contributes to setting objectives and working towards agreed targets and actions for establishing and ensuring the effectiveness of marine conservation efforts in the Caribbean (Johnson et al. 2014). This includes, for example, the facilitation of regional cooperation for the establishment of MPA networks, or strengthening the formal relationships and collaboration with bodies, such as Regional Fisheries Management Organizations, by looking for common objectives between conservation and fisheries management (Rice et al. 2012). The Cartagena Convention also contributes to the enforcement of measures and best use practices for resources and has enabled leveraging of funding, bringing together stakeholders, capitalizing on skills and tools, jointly addressing common pressures and threats in order to solve common challenges. It provides a framework for institutional sustainability and facilitates the regional cooperation needed for long-term sustainable MPA network development and implementation in the Caribbean (Johnson et al. 2014). Initiatives started by regional politicians and/or members of the community, such as the Caribbean Challenge Initiative, also help to further advance and support the work of UNEP's Cartagena Convention and its regional program in the Caribbean (CCI 2014). Another way of improving conservation efforts is through the formation of a managers' network. The Caribbean Marine Protected Area Management Network and Forum (CaMPAM) was created in 1997 by 50 MPA managers for the purpose of addressing conservation gaps and strengthening existing MPAs. CaMPAM is under the guidance of UNEP's Caribbean Environment Program (CEP) and its regional biodiversity-related treaty, the SPAW Protocol (UNEP CEP 2015). CaMPAM enhances management effectiveness through a variety of tools, such as a capacity building program that provides training through regional intensive 2-week annual courses followed by local training activities. Other capacity building tools include learning exchanges between sites, sponsoring attendance of managers to scientific conferences, an active Internet List and Forum, a regional MPA database, and the provision of technical expertise. Furthermore, CaMPAM's Small Grants mechanism provides financial assistance to MPAs in order to address specific management and operational needs (Johnson et al. 2014).

Conclusion

Even though there is a large number of MPAs being established in the Caribbean, most of them are unsuccessful in realizing their conservation goals and objectives. However, due to regional collaboration efforts and the establishment of scientific frameworks allowing for the adaptive management of MPAs, Caribbean nations seem to be heading in a positive direction towards achieving long-term sustainable usage and conservation of their valuable ecosystems.

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Appendix 1

Figure 2: The Wider Caribbean Region

Appendix 2

Table 1: Expected ecological effects of MPAs. List modified from Pelletier et al. 2005

Population level	1. Protecting critical spawning stock biomass of species from fishery-related depletion 2. Rehabilitating population structure 3. Increasing fecundity and production of eggs and larvae 4. Density-dependent changes in life history traits and parasitism 5. Protection of recruitment
Community and habitat level	6. Restoration of/changes in assemblage structure 7. Protection of biodiversity 8. Indirect effects on algae and invertebrates 9. Increasing ecosystem stability and resilience 10. Detrimental effects due to non-exploitative uses

Appendix 3

Table 2: Ecosystem services (Schuhmann 2012)

Supportive Services	**Regulating Services**
Nutrient Cycling	Gas Regulation
Net Primary Production	Climate Regulation
Pollination and Seed Dispersal	Hazard Protection/
Habitat	Disturbance Regulation
Hydrological Cycle	Biological Regulation
	Water Regulation
	Soil Retention
	Waste Regulation
	Nutrient Regulation
Provisioning Services	**Cultural Services**
Water Supply	Recreation
Food	Aesthetics
Raw Materials	Science and Education
Genetic Resources	Spiritual and Historic
Medicinal Resources	
Ornamental Resources	

Appendix 4

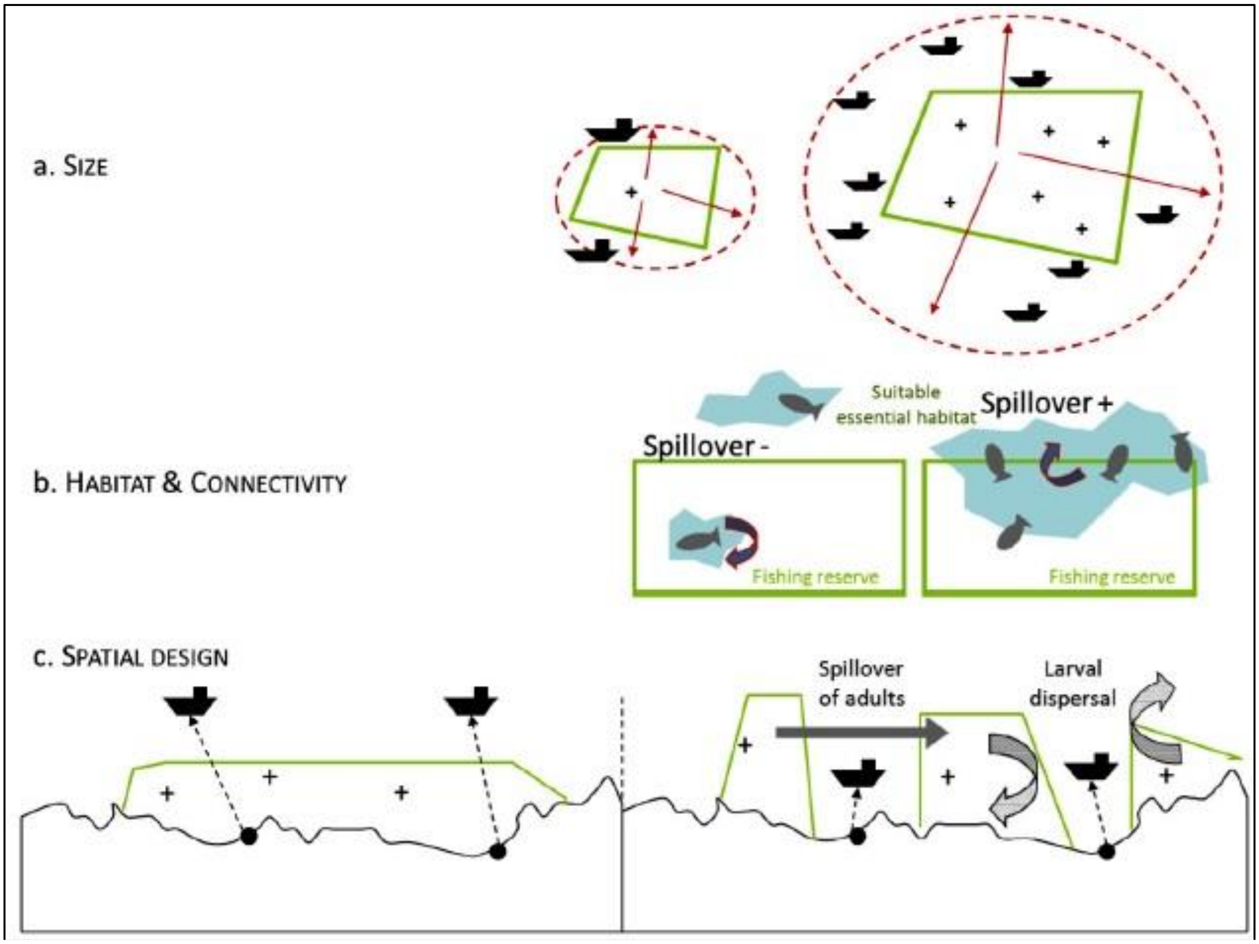
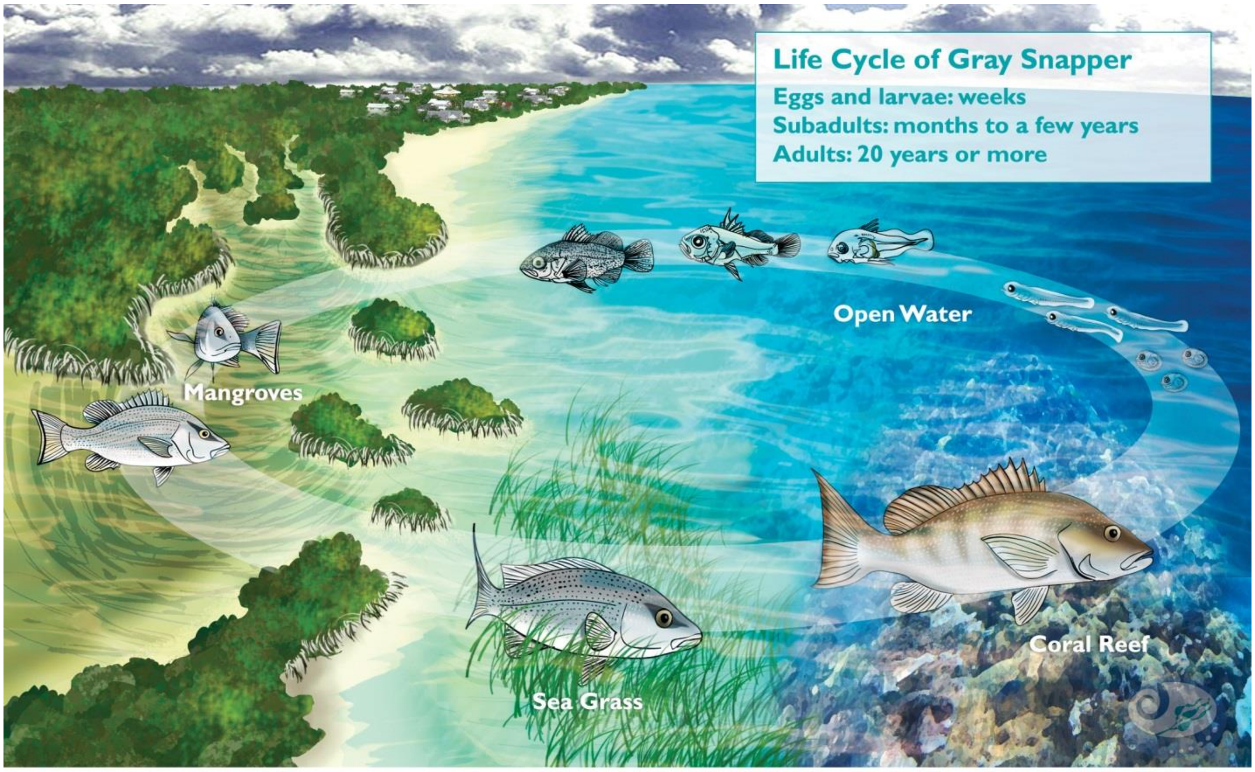


Figure 3: Factors influencing effectiveness. (a) Fishing reserves have positive effects on protected communities, even when they are small. Nevertheless, the scale of these impacts is greater if a reserve is larger. (b) Reserve network has to include the habitats essential for it to accomplish its life cycle and these must be sufficiently connected via animal movements. (c) One of the major socioeconomic advantages of marine reserve networks compared with a single large reserve is the possibility to fish between the reserves rather than of being excluded from a wide zone (Mesnildrey et al. 2013).

Appendix 5



The gray snapper uses many habitats throughout its life. Open water, mangroves, sea grass, and coral reef are important for growth and survival during different life stages of this fish. *Art by Ryan Kleiner*

Appendix 6

Table 3: Framework for analyzing marine protected area Governance inputs (Bennett & Dearden 2014)

Indicator	Corresponding question
Governance category	
Clear and enabling policies and norms	Are laws, policies and local norms clear, enabling and consistent?
Clear targets and actions	Are conservation targets clearly identified and actions being taken to achieve them?
Planning process	Is there a clearly articulated MPA planning process?
Fit to social and ecological context	Is the MPA type and format chosen contextualized to fit the ecological and social context?
Appropriate co-management	Are collaborative management arrangements contextually appropriate, inclusive, efficacious, equitable and representative?
Integrated in broader scale management	Is the MPA integrated within a broader scale system of management (e.g., EBM, ICZM)?
MPA network	Is the MPA part of a representative and connected network of MPAs?
Participation and relationships	Was the MPA implemented in a manner that was participatory and encouraged trust and relationship building?
Transparency	Are decisions made in a transparent manner?
Legitimacy of governors	Are MPA managers appointed in a manner that is deemed legitimate by stakeholders?
Accountability	Are governors and managers held accountable for their actions?
Coordinated organizational network	Is there a cooperative and coordinated network of organizations supporting the MPA?
Incorporates local governance	Are local and informal governance systems incorporated into management structures and processes?
Adequate capacity for participation	Is adequate human and financial capacity provided to facilitate participatory processes?
Mechanisms to adapt governance	Are there institutionalized mechanisms to monitor and adapt governance institutions, structures and processes?
Social capital	Are there forums and networking opportunities for building relationships and sharing learning?
Tenure and rights	Are rights and land tenure arrangements clearly articulated?

Appendix 7

Table 4: Framework for analyzing marine protected area Management inputs (Bennett & Dearden 2014)

Indicator	Corresponding question
Management category	
Management plan	Is there a complete and accessible management plan that states MPA objectives and specific measures to achieve them?
Financial resources	Are there adequate financial resources to support management?
Site specific management strategies	Are there site specific management strategies being taken to mitigate against and adapt to threats within and around the MPA?
Marked Boundaries	Are the boundaries of the MPA marked and accepted by local stakeholders?
Multiple use zones	Have zones for different uses been established and marked?
No take areas	Are "no-take" areas an integral part of the MPA and adequate to achieve conservation targets?
Outreach and education	Is there an effective program of outreach, education and awareness building?
Communications	Is there a communications strategy?
Clear rules and regulations	Are rules and regulations clearly defined and communicated?
Graduated sanctions	Is there a system of graduated sanctions that are legally supported?
Enforcement	Are rules and regulations equitably and consistently enforced?
Conflict resolution	Is there a process for resolving conflicts?
Management capacity	Is there sufficient capacity – people and equipment – to carry out management?
Capacity building	Is there a program of capacity building for staff?
Monitoring and evaluation	Is there a program for monitoring ecological outcomes and evaluating management actions? Is there baseline ecological data?
Adaptive management	Is there a means to adapt management based on new information and changing conditions?
Knowledge and information	Is there sufficient knowledge of the ecology of the area and of the species or habitats that the MPA aims to protect?
Diverse knowledges	Are scientific and local/traditional knowledge integrated into management?
Standards and carrying capacity	Is park-related use and development being managed through establishing standards and carrying capacity?
Monitoring and surveillance	Is there an adequate program of monitoring and surveillance?
External threats	Do managers work with stakeholders outside the MPA to ensure that external threats are minimized?
Incentives	Are there appropriate and effective incentives in place to increase local compliance?
Cultural and historical values	Are there systems in place to articulate and safeguard cultural and historical features, resources and values?
Visitor facilities and services	Are there adequate facilities and services for visitors?

Appendix 8

Table 5: Framework for analyzing marine protected area Local Development inputs (Bennett & Dearden 2014)

Indicator	Corresponding question
Local development category	
Mechanisms to ensure local benefit	Are there mechanisms to ensure benefits of conservation accrue to local people?
Contextualized interventions	Do development interventions consider the social and cultural context?
Equitable benefits	Are there mechanisms to ensure equitable outcomes for disenfranchised groups?
Financing	Is there a means to finance alternative livelihood programs?
Capacity building	Is there a program of capacity building to develop the skills of local people?
Livelihood infrastructure	Is there sufficient infrastructure to support existing and alternative livelihood options?
Participation	Is the process of development participatory?
Adaptive development	Is there a means to adapt the development program based on experience and outcomes?
Development professionals and partnerships	Do conservation organizations include dedicated community development professionals or maintain partnerships with development organizations?
Monitoring and evaluation of development	Is there a program for monitoring socio-economic outcomes and evaluating local development programs?
Enhanced and diversified livelihoods	Are livelihoods being enhanced and diversified to include both natural resource-based and non resource-based livelihoods?
Connected to markets	Are alternative livelihood programs connected to viable markets?
Long-term commitment	Is there a long-term commitment to partnering on developing alternative livelihoods?
Leadership	Is there an individual or group that is taking the lead in advocating for local development?

Appendix 9

List of tools that make the Hol Chan Marine Reserve a model MPA in the Caribbean

1. Revenue generation scheme administered by the Reserve based on the collection of entrance/user fees paid through tour guides and dive shops operators
2. Sound financial plan
3. Enforcement of fisheries regulations, no-take areas, fishing and flora and fauna collection/ harvesting restrictions with the involvement of stakeholders
4. Exclusive fishing rights for local traditional fishers
5. Fundraising program to support education and monitoring projects
6. Institutional arrangements with the Navy, NGOs, etc.
7. Operational mooring buoys
8. Contingency plan for natural damage restoration (hurricanes)
9. Habitat restoration programs
10. Board of Trustees with financial and advisory responsibilities
11. Co-management scheme between the Advisory Committee and the Fisheries Dept.
12. Education/outreach program for school kids, the general public and visitors
13. Enforcement capability (rangers, patrols, etc.)
14. Navigational restrictions
15. Qualified on-site professional staff (manager, biologists, wardens, educators)
16. Permitting program (to license uses such as fishing, snorkeling, diving) that generate income
17. Research facilities in collaboration with academic institutions, NGOs
18. Signage and boundaries demarcation
19. Zoning scheme based on habitat distribution and uses
20. Tourism regulations
21. Visitor center
22. Volunteer program (with rules to avoid staff overloading)
23. Implementation of a ‘managed access’ fisheries tool