Review of the Benefits of No-take Zones

A Report to the Wildlife Conservation Society

By Craig Dahlgren, PhD
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Preface

This report was commissioned by the Wildlife Conservation Society to support a three-year project aimed at expanding the area of no-take, or replenishment, zones to at least 10% of the territorial sea of Belize by the end of 2015.

It is clear from ongoing efforts to expand Belize's no-take zones that securing support for additional fishery closures requires demonstrating to fishers and other stakeholders that such closures offer clear and specific benefits to fisheries – and to fishers.   Thus, an important component of the national expansion project has been to prepare a synthesis report of the performance of no-take zones, in Belize and elsewhere, in replenishing fisheries and conserving biodiversity, with the aim of providing positive examples, elucidating the factors contributing to positive results, and developing scientific arguments and data that can be used to generate and sustain stakeholder support for no-take expansion.

To this end, Dr. Craig Dahlgren, a recognized expert in marine protected areas and fisheries management, with broad experience in the Caribbean, including Belize, was contracted to prepare this synthesis report. The project involved an in-depth literature review of no-take areas and a visit to Belize to conduct consultations with staff of the Belize Fisheries Department, marine reserve managers, and fishermen, collect information and national data, and identify local examples of benefits of no-take areas.   In November 2013, Dr. Dahlgren presented his preliminary results to the Replenishment Zone Project Steering Committee, and he subsequently incorporated feedback received from Steering Committee members and WCS staff in this final report.

This synthesis report of the benefits of no-take zones to fisheries, biodiversity conservation, tourism, and enhanced resilience to climate change provides a valuable source of information from which to generate the messages for a communications campaign, the next step in the national expansion project.   It is also helping to guide the process of selecting the optimal areas for additional no-take designation, which is another integral part of this initiative.

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Executive Summary

Faced with overfishing, ecosystem phase shifts, and other declines in the condition or health of the marine environment, marine resource managers are increasingly turning to ecosystem-based approaches to management, including the use of marine protected areas (MPAs). MPAs are designated expanses of sea where some or all uses of marine resources are restricted to enhance the management or conservation of marine resources. MPAs may be created for a variety of purposes – fisheries management, biodiversity conservation, recreational uses, or to address the conservation needs of sensitive species or habitats. As such, they may be created and administered by a number of natural resource management authorities and under separate pieces of legislation in the same country and also under quite variable scenarios in different countries. MPAs worldwide have a wide range of restricted and permitted uses and are assigned a variety of different names – parks, sanctuaries, reserves, refuges – without much consistency in what management regimes actually apply in these areas. Increasingly, MPAs are divided into zones where different levels of protection are conferred. MPAs or zones within MPAs that have been shown to have the greatest positive impact on the resources within them are ones in which resource extraction, such as fishing, is prohibited. These areas go by many different names but are commonly referred to in the scientific literature as "no-take zones" or "fully protected" reserves.

Over the past 10-15 years, a tremendous number of studies have been conducted on the use of no-take zones for providing an abundance of benefits. The most commonly reported benefits from no-take zones around the world relate to their ability to conserve populations of exploited species. Evidence for these benefits is found in increases in the density, biomass per unit area, or individual sizes of various fishery species. In Belize and elsewhere in the Caribbean, there have been documented cases of improvements to conch, lobster and fish populations within no-take zones. Recovery of exploited species within no-take zones as opposed to fished areas may take as little as 1-6 years, but full recovery of populations to near-pristine levels may take decades.

These changes may have important implications for conserving populations of target species. For example, the number of eggs that female fish produce increases exponentially with size, so more abundant populations of larger fish within no-take zones can increase reproduction by orders of magnitude over unprotected areas. Similarly, because fish in no-take zones survive to older ages and larvae hatched from eggs spawned from older and larger individuals have a greater chance of survival and higher growth rates, fish spawned in no-take zones have a greater probability of reaching juvenile stages. Increases in the size of males can also increase reproductive output of crustaceans such as the Caribbean spiny lobster, as larger males are more likely to successfully reproduce and increase the number of fertilized eggs brooded by females. For fishes that change sex from female to

male, such as parrotfishes and many grouper species, the conservation benefits within no-take zones include preserving natural sex ratios that can become skewed towards females in fished populations and cause females to change to males at smaller sizes, potentially reducing reproductive output. Finally, because fishing selectively removes some of the more aggressive and faster-growing individuals from populations, characteristics that have a genetic component, fishing selectively removes some of the fittest individuals from the population and, in so doing, may exert selective pressures on the evolution of species. Preserving these beneficial traits within no-take zones may maintain the genetic diversity of species.

The recovery of populations in no-take zones has important implications for fisheries for target species outside of these zones. No-take zones can support fisheries in two ways. The first is called the "recruitment effect," whereby the increase in larvae spawned in no-take zones supports fisheries outside them, as larvae are carried by currents to fished areas where they recruit and replenish populations accessible to fishers. Recent advances in determining where larvae are spawned and where they recruit to juvenile populations indicate that no-take zones contribute a disproportionate amount of larvae to themselves (further increasing populations there) and fished zones. The extent to which this effect occurs in a location, however, depends on ocean currents, larval behavior and the time that larvae spend in the plankton.

The second manner in which no-take zones can support fisheries is through the "spillover effect," whereby juveniles or adults from a reserve leave the reserve in response to crowding, expanding home range size as they grow, or other factors. This effect has been demonstrated in several ways and may be evident as a density gradient in populations where densities decrease with distance away from no-take zones; a gradient in catch per unit effort or catch per unit area that decreases with distance from a no-take zone; or tagging fish within a no-take zone and examining catches outside the no-take zone. The spatial extent of the spillover effect may depend on factors that influence movement (e.g., how home range size varies with size and density, agonistic behavior) of key species and the location of no-take zone boundaries within a seascape, but it generally occurs over distances of less than a kilometer from no-take zone boundaries.

The recovery of target species within no-take zones also has significant implications for various ecosystem properties. Because many target species are becoming scarce in fished areas, the recovery of their populations in no-take zones can enhance biodiversity of a marine ecosystem. No-take zones also eliminate bycatch within their boundaries, preserving stocks of many non-target species and preventing habitat damage from fishing gears. Increases in populations of target and bycatch species can also have cascading effects throughout the ecosystem through trophic or competitive interactions. Because many target species play an important ecological role as predators or grazers, increases in their numbers impact populations of their prey species, and even the species that these prey feed on. As a result, whole food webs can be affected. This can be particularly important in coral reef systems where the delicate balance between corals and macroalgae can be influenced by key grazers like parrotfish and urchins. Studies have shown that ecosystem processes responsible for maintaining healthy reefs may be increased in no-take

zones, leading to less macroalgae, more coral recruitment, and healthier reefs. This may improve the resilience of reef ecosystems to impacts such as climate change and possibly the spread of invasive species such as lionfish. Further research is needed, however, to gain a better understanding of the roles of no-take zones in addressing these impacts.

From the human side of no-take zones, both the spillover and recruitment effects can benefit fisheries by promoting sustainable yields, buffering against the uncertainty that plagues traditional fisheries management, and increasing fishery yields and profits in many cases. No-take zones may also benefit recreational anglers by supporting trophy fisheries, as larger fish from the no-take zone spill over into fished areas. No-take zones can also support tourism, particularly for snorkelers and divers who are willing to pay more to visit healthier reefs with more abundant and larger fish and other sea life. No-take zones may also be used to reduce conflicts among fishers, dive operators, and other user groups whose use of resources may not be compatible. Because of their potential to reduce impacts towards a "pristine" marine ecosystem, no-take zones also have value for research and education and provide opportunities that are not available elsewhere. While there may be short-term costs to creating no-take zones, the long-term benefits to fisheries, tourism, and other activities can be significant.

Whether catch-and-release fishing should be permitted in no-take zones is the subject of much debate. A review of the literature on catch-and-release fishing shows that, while the majority of fish may be released alive, post-release survival is variable, depending on the type of fishing (e.g., flats fishing versus bottom fishing), angling and handling practices, tackle used, and the presence of predators likely to feed on released fish. Furthermore, injuries and stress resulting from catch-and-release angling may alter behavior and inhibit growth and reproduction of fish. Reviews specifically addressing whether catch-and-release angling should be allowed in no-take zones agree that this form of fishing can have negative impacts on populations, and that more research is needed to understand these impacts; however, they arrive at different conclusions as to whether or not the practice should be allowed. Based on all considerations, it is suggested here that well-regulated catch-and-release angling could be allowed in some, but not all, no-take zones in Belize, based on certain conditions, and that regulations should restrict the number of permits issued for an area, and set requirements on gear types and use and best practices for landing, handling and releasing fish.

While no-take zones can provide a wide range of benefits for conservation, fisheries, tourism, research and education, and ecosystem protection, specific benefits generated may vary among no-take zones. This variability can result from differences in the size, shape, configuration within a seascape, and proximity to other no-take zones, as well as the characteristics of the species being protected, characteristics of the fishery outside of no-take zones, and the level of compliance with no-take zone restrictions. Basic design principles can be followed, however, to produce an effective network of no-take zones, and some benefits may be increased by incorporating specific design characteristics. Regardless of the design, however, the rules and regulations of the no-take zone must be respected. Voluntary compliance can be increased through engagement of stakeholders in the designation process and implementation of no-take zones, as well as clearly marking

the zone boundaries and communicating rules and regulations. Effective enforcement is also necessary.

Belize is currently in the process of expanding its national network of no-take zones from a total of approximately 3% of its marine territory to 10%. Because terms such as "no-take zone" or "fully protected area" may have a negative connotation for resources users concerned about being restricted from these areas, and in order to better reflect the overall objective of enhancing benefits to fisheries and biodiversity, these areas are being referred to as "replenishment zones."

In taking lessons from the examples presented in this report, Belize's expanded no-take, or "replenishment," zone network should provide increased benefits for the conservation of target species, fisheries management, preservation of ecosystem function, as well as to the livelihoods and well-being of Belizeans.

1. Overview

1.1 Status of the World's Oceans

Around the world we are seeing changes throughout our oceans. Many of the world's great fishery resources that were once viewed as inexhaustible have crashed or are teetering on the brink of collapse. Global marine fisheries landings in 2010 were reported at 77.4 million metric tons – down from a peak of 86.4 million metric tons in 1996 – and over 57% of marine fisheries in 2009 were considered overexploited (FAO 2012).   As worrisome as these statistics are, they are likely to underestimate the severity of the problem, due to a range of issues in data reporting (Pauly and Froese 2012). Furthermore, habitats have been altered, and ecosystem function has been affected. Ecosystems that have withstood thousands of years of hurricanes and other natural disasters have undergone ecological phase shifts (e.g., from coral-dominated reef systems to reefs covered in macroalgae), such that they are barely recognizable and no longer function as they once did. Key species and overall diversity have been lost from marine ecosystems to the point where these systems are unstable and unable to maintain themselves. While these problems are occurring in various marine ecosystems around the world, nowhere are they more pervasive than on coral reefs (e.g., Pandolfi et al. 2003, Côté et al. 2005, Pandolfi et al. 2005).

As these changes occur, human communities that rely on the sea are forced to adapt. It is getting harder and harder for fishers to make a living as the resources that they rely on dwindle (e.g., Cinner et al. 2009); they often are driven to exert greater fishing effort, such as traveling farther to fish, or to switch to species of lesser value as stocks of higher-valued species disappear (e.g., Pauly et al. 1998, Pauly and Palomares 2005, Cinner et al. 2011). In some cases, traditional livelihoods that rely on fishing are lost, or communities that were once dependent on the sea for food become increasingly dependent on food brought in from elsewhere (e.g.,Atta-Mills et al. 2004, Cinner et al. 2011).

Many may think of these changes as only occurring in areas that are overpopulated or have industrial fishing fleets, but declines in fisheries and ecosystems have been observed around the world, from the polar regions to the tropics and from highly industrialized countries with huge commercial fishing fleets to those where populations still live in small villages and rely on the sea for subsistence. Even sportfishing plays a role in these declines (e.g., Eggleston and Dahlgren 2001, Cooke and Cowx 2004, Lewin et al. 2006, Arlinghaus et al. 2007).

1.2 State of Marine Fisheries and Ecosystems in Belize

Belize harbors some of the most extensive and diverse nearshore marine systems in the Caribbean. Vast mangrove systems, a wide lagoon with seagrass and patch reefs, the largest barrier reef system in the Western Hemisphere, and several offshore atolls have provided

Belize with a bounty of marine resources. Even here, however, various human impacts have taken their toll.

The fisheries of Belize have reduced populations of exploited species. Three of the most important fishery species in Belize are the queen conch (*Lobatus gigas*, formerly *Strombus gigas*), Caribbean spiny lobster (*Panulirus argus*) and Nassau grouper (*Epinephelus striatus*), and each of these species has experienced sharp declines in numbers. Already by 2001, for example, approximately one third of Nassau grouper spawning aggregations in Belize had disappeared due to overfishing, and remaining spawning aggregations had declined in abundance by up to 80% (Sala et al. 2001). A recent study of fisheries on Glover's Reef atoll has indicated that Nassau grouper and snapper species targeted by spearfishers are overfished, although other target species, such as parrotfish (which are now protected by law), angelfish, and hogfish are probably not overfished (Babcock et al. 2013).

Belize's queen conch landings first peaked in the 1970s and were followed by a peak in lobster landings in the mid-1980s as fishers switched from conch to lobster (Gillet 2003). By 2005, the majority of fishermen interviewed at landing sites in Belize City (including local markets and fishing co-operatives) and Caye Caulker reported fewer conch and lobster (Huitric 2005). Recent trends in the conch fishery, however, have shown an increase in landings since 2000 (Gongora 2012), reaching levels similar to those of the mid-1970s by 2011. Conch levels in most fished areas are now below reproductive thresholds, and the Belize conch fishery, along with the conch fisheries throughout the species' range, have come under scrutiny from CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (the species was listed on the treaty's Appendix II in 1992), owing to concerns about the adequacy of the non-detriment findings that are required by the treaty as the basis for issuing CITES export permits (Acosta 2006, Smith et al. 2008).

Over the past six years, conch densities in national surveys have increased from 106 conch per ha. in 2006 to 337 conch per ha. in 2012 (Gongora 2012). Mean shell size has also increased during this time, but the majority of the population (72%) is below the legal size limit (Gongra 2012). These recent improvements in conch populations are believed to result from improved management, including through MPAs (Gongora 2012). Although spiny lobster landings may have stabilized since the 1980's, fishers must now travel farther to fish than they did 30-50 years ago, and the number of traps fished per lobster fisher has increased by an order of magnitude since then (Huitric 2005).

Belize's reefs are also in decline, having suffered many natural and human impacts from which they have not been able to recover (e.g., Mcclanahan and Muthiga 1998, Aronson et al. 2000, McField 2000, Aronson et al. 2002a, Aronson et al. 2002b). A recent study of the Mesoamerican Reef found that only 11% of reefs were in good to very good condition, while the majority of reefs surveyed (64%) were in poor to critical condition; in the Belize portion of the reef, no reefs were found to be in very good condition, while only 5% were in good condition, and a full 73% were in poor to critical condition (Healthy Reefs Initiative 2012).

1.3 Marine Resource Management

While declines in marine fisheries and coral reef ecosystem health around the world have been severe in many cases, scientists suggest that these declines can be reversed with improved management and ocean policy (Bellwood et al. 2004, Hughes et al. 2005, Hughes et al. 2007a, Mumby and Steneck 2008, Keller et al. 2009, Steneck et al. 2009, Worm et al. 2009). Such improvements include increasing or expanding the use of ecosystem-based management tools, including no-take zones and other marine protected areas (MPAs), as well as catch limits, such as through catch shares or similar restricted-access systems, or other measures (e.g., Costello et al. 2008). As these changes occur, marine resource managers are forced to adapt their thinking to maintain stocks and preserve ecosystem function. Traditional fisheries management, which focuses on trying to achieve maximum sustainable catches of species, has often failed because of uncertainty in stock assessment or variability in populations, coupled with a failure to adequately control landings at target or precautionary catch levels (e.g., Lauck et al. 1998) or to account for ecosystem processes that interact with target species (e.g., Murawski 2000, Jackson et al. 2001).

Over the past 20 years, there has been an increasing call to incorporate ecosystem-based approaches to management of marine resources (FAO 1995, 2011). One of the more popular management tools within an ecosystem-based approach is MPAs, a catch-all term that refers to designated expanses of sea that are conferred protection from various uses or impacts. This protection covers a wide range of areas, management regimes, and nomenclature and includes: spatial or seasonal closures; areas where some types of extraction are prohibited but other types of fishing are allowed (e.g., gear restrictions); areas where most types of fishing are prohibited and/or landings are restricted; and areas where all extractive uses are prohibited; and even areas where access is restricted altogether. The FAO Code of Conduct for Responsible Fisheries (FAO 1995) emphasizes the importance of spatial management, such as MPAs, for conservation and rehabilitation of critical habitats against pollution and degradation, as well as minimization of waste, discards, catch by lost or abandoned gear, catch of non-target species, and negative impacts to endangered species. According to MPA Global, the most comprehensive database of the world's MPAs, there are now over 6,000 MPAs around the world, spanning nearly 250 countries and territories (www.mpaglobal.org). Recent estimates of the proportion of the world's oceans that are in MPAs are on the order of 1.6 percent, but estimates may vary depending upon how they are calculated (*MPA News* 2012).

1.4 What's in a name: MPA Nomenclature

Around the world, MPAs are assigned different names based on the uses that they allow or restrict and the legislation or management authority under which they are created. MPAs are variably referred to as parks, sanctuaries, refuges, reserves, preserves, and other terms. Importantly, there is no standardization of terms across countries nor often even among different management authorities within a country. In the Florida Keys (USA), for example, MPAs include a National Marine Sanctuary managed by the National Oceanic and Atmospheric Administration, three National Parks managed by U.S. Park Service, three National Wildlife Refuges managed by the U.S. Fish and Wildlife Service, a State Park

managed by the State of Florida, and two Aquatic Preserves also managed by the State of Florida.

Because terminology is not standardized, a marine sanctuary in one part of the world may have very different management goals and permitted uses from those in a sanctuary in another part of the world. Scientists, for example, frequently refer to areas where extractive uses of all living and non-living marine resources are prohibited as no-take areas or marine reserves, but areas designated as marine reserves in some places, such as Belize, are often multiple-use MPAs.

In an attempt at rationalization, IUCN, the International Union for the Conservation of Nature, has developed a classification scheme for all protected areas (marine and terrestrial), which is based on the management objectives of the area (Table 1). While this framework is widely accepted and useful for categorizing protected areas, it may conflict with local terminology. The IUCN classification scheme also uses a mix of criteria that include the intent or goals of the area, the state or condition of the area, and some aspect of the management regime that may apply. Some areas may be difficult to classify into one of these categories as they might have characteristics of several different categories. Furthermore, the IUCN classification system is based on the premise that protected areas are being created for the conservation of nature. However, in many instances, MPAs are not specifically established for this purpose (Govan and Jupiter 2013) but, instead, for example to support sustainability of specific fisheries or other human uses.

Zoning within a MPA is often used to regulate different uses, reduce conflicts among different user groups, and provide increased levels of protection for key areas within the MPA. While zoning for different uses further complicates classification within the IUCN protected area classification system, it enables managers to deploy a range of management tools to address important marine conservation and fisheries management issues. In the Florida Keys (USA) example, several of the MPA management units, particularly the National Marine Sanctuary, are zoned for different uses, with some areas designated as Sanctuary Preservation Areas, Ecological Reserves, and research-only areas. Each of these zones allows or prohibits specific uses to address different management objectives (e.g., fisheries management, habitat protection, etc.).

Some of the most effective MPAs for conservation and fisheries management are highly protected areas that prohibit extraction of living and non-living marine resources; these are commonly referred to as "no-take zones" or "fully protected areas." While 1.6% of the world's oceans may be included in MPAs of some form, only 0.08% of the world's oceans or 0.2% of the total marine area under national jurisdiction were included in no-take zones as of 2008 (Wood et al. 2008). While the terms "no-take" and "fully protected" accurately reflect the restrictions applied within these areas, it defines the zones based on their exclusion of human activities. This often leaves people with the impression that they will not benefit from the creation of these areas. Many argue that referring to these areas as being "no-take" has a negative connotation and increases resistance to their designation from fishers and other stakeholders. For this reason, many designations of no-take zones use terminology that does not reflect the uses that they prohibit, but, instead, the overall

goals or benefits the zones are expected to provide, such as Preservation Areas or Ecological Reserves. Even these terms may be contentious, however. For example, during zoning of the Florida Keys National Marine Sanctuary, the term No-take Reserve was replaced with Ecological Reserve for a large no-take zone in the Tortugas area because some stakeholders contended that this area may not meet the goal of replenishing fished populations outside its boundaries (Suman et al. 1999).

Table 1. IUCN Categories of Protected Areas
IUCN protected area management categories classify protected areas according to their management objectives. The categories are recognized by international bodies such as the United Nations and by many national governments as the global standard for defining and recording protected areas and as such are increasingly being incorporated into government legislation (Table adapted from Day et al. 2012).

Ia Strict Nature Reserve
> Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphical features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.

Ib Wilderness Area
> Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.

II National Park
> Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.

III Natural Monument or Feature
> Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.

IV Habitat/Species Management Area
> Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.

V Protected Landscape/ Seascape
> A protected area where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.

VI Protected area with sustainable use of natural resources
> Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

1.5 MPAs In Belize

In Belize, MPAs have been created by several different management authorities under separate pieces of legislation (Gibson et al. 2004). MPAs in Belize may be designated as Marine Reserves under the responsibility of the Fisheries Department, or National Parks, Sanctuaries, or Monuments under the responsibility of the Forest Department (Table 2). In addition, there are Marine and Forest Reserves under the authority of both the Fisheries and Forest Departments. Within each of these areas, various uses are restricted, often within zones allowing different types of use. Zones may vary from one MPA to the next but typically include General Use Zones, limited-use zones (e.g. Conservation Zones) and no-take zones (e.g., some Conservation Zones and Preservation Zones). General Use Zones typically have minimal restrictions on human activities and allow common fishing practices to be conducted. Conservation Zones and Preservation Zones or Wilderness Zones typically have more restrictive management (Table 3). The one exception to the "standardized" zoning scheme presented in Table 3 is that of the Hol Chan Marine Reserve, which has different zones designated based on habitats and uses that are prohibited or permitted, including No-take Zones and Recreational Areas; seagrass, mangrove and reef zones; as well as zones that allow sportfishing.

1.6 Overview of the Benefits of No-Take Areas

Regardless of its name, how a MPA functions to produce benefits for conservation and sustainable use of marine resources depends to a great extent on the level of protection that it confers on marine resources, including water quality, habitat, and species assemblages that utilize the area. Several theoretical and empirical studies have suggested numerous benefits that may be provided by no-take areas. Sobel and Dahlgren (2004) provide a comprehensive summary of the potential benefits of no-take reserves, which they group into four general categories:

- Improving fisheries
- Protecting ecosystem structure, function and integrity
- Enhancing non-consumptive opportunities
- Expanding knowledge and understanding of marine systems

Angulo-Valdés and Hatcher (2010) expanded on this list and enumerated 99 specific benefits that may be expected of MPAs, including no-take zones (Table 4). The authors recognize, however, that only one third of these expected benefits have empirical support in the scientific literature, with the other two thirds' being based on weaker evidence, mathematical models, or logical conjecture based on what is known about MPAs.

Table 2. List of MPAs of Belize and Total Area and No-Take Area

Protected Area Name	Management/ Co-management Authority	IUCN Category	Marine area (Km^2)	No-take area (Km^2)
Bacalar Chico National Park and Marine Reserve	Fisheries Dept.	IV	52.8	9.2
Blue Hole Natural Monument	Forest Dept. / BAS	III	4.1	4.1
Caye Caulker Marine Reserve	Fisheries Dept. / FAMRACC	VI	38.9	14
Caye Glory Spawning Aggregation	Fisheries Dept.	IV	5.5	5.5
Corozal Bay	Forest Dept.	IV	703.7	0
Gladden Spit & Silk Cayes Marine Reserve	Fisheries Department/SEA	IV	110.4	1.5
Glovers Reef Marine Reserve	Fisheries Department	IV	350.7	73.4
Half Moon Caye Natural Monument	Forest Dept./BAS	II	39.2	39.2
Hol Chan Marine Reserve	Fisheries Dept.	II	54.4	4.2
Laughing Bird Caye National Park	Forest Department	II	41	41
Nicholas Caye Spawning Aggregation	Fisheries Dept.	IV	6.7	6.7
Northern Glover's Spawning Aggregation	Fisheries Dept.	IV	6.2	6.2
Port Honduras Marine Reserve	Fisheries Dept./TIDE	IV	395	13.2
Rise and Fall Bank Spawning Aggregation	Fisheries Dept.	IV	17.2	17.2
Rocky Point Spawning Aggregation	Fisheries Dept.	IV	5.7	5.7
Sandbore Spawning Aggregation	Fisheries Dept.	IV	4.5	4.5
Sapodilla Cayes Marine Reserve	Fisheries Dept./SEA	IV	156.2	4.9
Seal Caye Spawning Aggregation	Fisheries Dept.	IV	6.5	6.5
South Pt. Lighthouse Spawning Aggregation	Fisheries Dept.	IV	5.3	5.3
South Water Caye Marine Reserve	Fisheries Dept.	IV	476.7	89.9
Swallow Caye Wildlife Sanctuary	Forest Dept./FOSC	IV	33.5	36.3
Turneffe Atoll	Fisheries Dept.	IV	1176.2	152.15
Totals			**3690.4**	**540.7**

Table 3. Activities explicitly allowed (√) and prohibited (X) in various zones of Belize's MPAs. (Hol Chan excluded -See text for details.) Blank boxes indicate the activity is not addressed in relevant legislation. MR = Marine Reserve; CZ = Conservation Zone.

Conservation Zone Activities	General Fishing	Subsistence fishing by residents	Catch-and-release fishing
Glover's Reef MR CZ	X	√	√
South Water Caye MR CZ	X	X	X
Turneffe MR CZ I	X		
Turneffe MR CZ IIB	*		
Port Honduras MR CZ I	X	X	X
Port Honduras MR CZ II	X	X	√
Bacalar Chico MR CZ I	X	X	X
Bacalar Chico MR CZ II	X	**	√
Gladden Spit & Silk Cayes MR CZ I	X	X	X
Gladden Spit & Silk Cayes MR CZ II***	X		X
Caye Caulker MR CZ	X	X	X

*no conch fishing; **only for catch-and-release tours; ***special regulations for whale shark viewing

Activities in Wilderness/Preservation Zones	On/In Water activity (fishing, diving, sportfishing, etc.)	Motorized boats	Any Vessels
Glover's Reef MR	X	X	
South Water Caye MR	X	X	
Port Honduras MR	X		X
Bacalar Chico MR	X	X	
Caye Caulker MR	X	X	
Turneffe MR****	X	X	

**** New Turneffe MR includes spawning sites listed below

Spawning Aggregation Sites	Any Fishing	Some Traditional Fishing
Rocky Pt., Ambergis Caye	X	
Dog Flea Caye, Turneffe ****	X	
Caye Bokel, Turneffe****	X	
Sandbore, Lighthouse Reef	X	
South Pt., Lighthouse Reef	X	
Emily	X	
Northern, Glover's	X	
Gladden Spit		√
Rise and Fall Bank, Sapodilla Cayes		√
Nicholas Caye, Sapodilla Cayes		√
Seal Caye, Sapodilla Cayes		√

Not all no-take zones will provide the same benefits. Various factors influence the benefits that a no-take area provides, including: natural factors, such as the habitats within the no-take zone, the position of no-take zones within a seascape, and connectivity between no-take zones; the effectiveness of enforcement of the no-take zone; and the management context in which no-take zones exist. The management context includes how the fishery is managed around the no-take zone, the status of fisheries outside the no-take zones, and the type of fisheries that operate outside the no-take zones.

This report examines the expected benefits and identifies any potential costs of no-take zones. Based on the types of benefits expected and the amount of information that is available on various types of benefits, the discussion of benefits is broken down into sections, including benefits to:

- Conservation of target species
- Fisheries
- Ecosystems and their function
- Human populations, including direct economic and social benefits

While this classification of general benefits is somewhat different from those discussed earlier in this section, it reflects the type and amount of evidence for specific benefits. In addition to these benefits, considerations that influence the efficacy of no-take zones will be addressed, including natural factors, aspects of the design and implementation of no-take zones, and the surrounding management context.

In each case, examples from published literature (peer-reviewed and "gray literature") are examined to provide a better understanding of what expected benefits and potential costs no-take zones may produce. In particular, examples from Belize often rely on reports to government or other "gray literature" sources, but examples from elsewhere rely almost exclusively on peer-reviewed literature. While this review is comprehensive in examining the effects of no-take zones, it should be noted that the body of literature on no-take zones is vast, and a complete review of all literature related to no-take zones is outside the scope of this report. While efforts have been made to be inclusive of as much of the literature as possible, there is a focus on some of the seminal studies and some of the most advanced studies of no-take zones that build on previous work. Attempts were also made to include studies that are most relevant to no-take zones in Belize, including examples from other tropical marine systems, particularly those of the Wider Caribbean region, and examples for species of importance to Belize. The report also highlights examples of no-take zone effects from Belize from published studies and unpublished reports and datasets available from the Department of Fisheries, co-management organizations, and researchers who have worked in no-take zones and other MPAs in Belize.

Table 4. List of benefits of no-take zones from Angulo-Valdés and Hatcher (2010)

MPA benefits								
To humans					To nature			
Direct		Indirect/off site						
Fishery benefits	Non-fishery benefits	Management benefits	Education/Research benefits	Cultural benefits	Process benefits	Ecosystem benefits	Population benefits	Species benefits
Protect spawning stocks	Allow harvesting of renewable and non-renewable resources	Reduce use and user conflicts.	Improve understanding of natural systems	Improve peace-of-mind	Allow for suitable nutrient cycles	Eliminate second order impacts	Protect natural population structure and functioning.	Protect keystone and dominant species
Increase population fecundity	Expand non-consumptive recreation opportunities (SCUBA, ecotourism)	Reduce incidental and bycatch mortality.	Provide educational opportunities	Enhance aesthetic experiences and opportunities	Protect from coastal erosion	Maximize ecosystem resilience	Protect genetic resources and diversity	Prevent loss of vulnerable species
Foster reproductive capacity	Enhance and diversify economic activities	Reduce variance in yields.	Allow knowledge permanence of undisturbed sites	Foster constructive social activities	Provide physical refuge	Preserve natural communities composition and functioning	Restore population size and age structure	Sustain species presence and abundance
Provide undisturbed spawning sites	Increase wilderness opportunities	Maintain diversity of fishing opportunities.	Provide cumulative understanding from multiple studies at one site over time	Promote spiritual relations and development	Maintain global climate regulation	Ensure biodiversity protection	Protect spawning populations (commercial and non-commercial)	Prevent loss of rare species
Ensure viable spawning conditions	Promote alternative employment opportunities	Allow opportunities for mariculture.	Allow research, monitoring and data collection from untouched sites	Enhance conservation appreciation	Avoid physical damage to habitats	Prevent cascading ecosystem effects	Increase survival rate for juveniles and adults	Protect long-lived species (sea turtles)
Improve spawning habitats	Strengthen property and liability rights	Facilitate and simplify enforcement and compliance.	Provide control areas for assessing human-induced impacts	Promote international relations and cooperation	Sustain evolutionary processes	Maintain trophic structure and food web	Increase natural recruitment	Protect slow-growth species
Enhance eggs and larvae production	Broaden and strengthen economy	Improve management and efficiency.	Reduce risks to long-term experiments	Provide foundation to increase public awareness and compliance	Protect critical habitats	Maintain key areas (reproductive, nursery, feeding)	Allow recovery of depleted populations	Protect low-reproductive species
Provide export of egg and larvae	Enhance other forms of income generation	Insure against management failures.	Enhance synergy from cumulative studies	Promote concern for future generations.	Maintain biological diversity	Allow for ecosystem recovery	Increase reproductive outputs	Allow for complete species interaction
Build up fishery recruitment	Protect attractive habitats for tourism	Facilitate stakeholder involvement.	Provide long-term monitoring areas	Improve aesthetic values	Allow for the transformation, detoxification and sequestration of pollutants			Protect migratory species
Support sport trophy fisheries		Reduce possibility of irresponsible development	Maintain memory of natural ecosystems	Preserve and expand historical knowledge				Restore species abundance and biomass
Allow for spillover of adults and juveniles		Promote holistic approach to management	Provide sites for enhanced primary and adult education	Facilitate cultural resource management				Restore species diversity
Increase abundance of overfished stocks (inside and outside the reserve)		Promote bases for ecosystem management.	Provide sites for high-level graduate education					
Reduce overfishing			Provide undisturbed areas for particular experiments					
Increase spawning stock biomass			Preserve archeological sites					
Enhance spawning density			Provide biological information from unfished populations					
Diminish fishery-related genetic impacts								

2. Conservation Benefits of No-take Zones

Because no-take zones by definition prohibit extraction or consumption of marine resources, one of their greatest documented effects has been the increase in the abundance, size or biomass of targeted fisheries species. The conservation of target species is critical to providing other benefits, including benefits to fisheries and ecosystem protection. Thus, any discussion of the benefits of no-take zones must begin with the conservation of target species. Over the past 10-15 years, this effect has become well-established in the literature and the subject of several review, synthesis and meta-analysis studies.

2.1 Meta-analyses of the Conservation Benefits of No-take Zones

Empirical studies of no-take zones typically examine the density, individual size (or population size distribution), or biomass per unit area of target species and compare these values between no-take zones and similar nearby areas outside these zones, or they examine changes in these values over time within no-take zones and often in areas outside no-take zones. Both types of studies are useful in assessing the conservation value of no-take zones for target species. Hundreds of studies from no-take zones around the world have been conducted to date that examine the effect of no-take zones on density, biomass and size of target species. Meta-analyses of these studies have been useful in making generalizations about the conservation benefits of no-take zones.

For example, a review of 89 published studies comparing the density, biomass per unit area, and mean size of fish and invertebrates found that within no-take zones, density was doubled, biomass was nearly tripled, and organism size increased by 20-30% within no-take zones relative to unprotected areas (Halpern 2003).

In a more recent review of 221 peer-reviewed studies of 108 different fully protected areas, Lester et al. (2009) found that protection within no-take zones led to an increase in biomass of 446%, density (166%) and individual size (28%) over open-access areas for all species studied, including some non-fisheries taxa. Another meta-analysis found that fish were 66% more abundant inside than outside reserves, with the majority of this difference coming from large fished species (Molloy et al. 2009). Similarly Micheli et al. (2004) found that the vast majority of species showing a positive response to protection in no-take zones were ones that were targeted in fisheries or the aquarium trade. In a study of no-take zones from both temperate and tropical environments, Babcock et al. (2010b) found that populations of exploited species increased in 78% of reserves studied.

2.2 Conservation Examples from Species of Importance to Belize

While these syntheses and reviews highlight how prevalent it is for the density, biomass and individual size of fish and invertebrates to increase in a no-take zone, some species and systems may respond differently to this form of protection. It is important to understand how no-take zones might affect individual species of interest. Studies from around the Wider Caribbean that specifically examine the response of species that are important to Belize's fisheries can provide more insight into the expected fisheries benefits of no-take zones.

2.2.1 Queen conch

The queen conch, *Lobatus gigas* (formerly *Strombus gigas*), is one of the most important fishery species in Belize and elsewhere in the Wider Caribbean region but is threatened by overfishing throughout the region (Theile 2005). International trade in the species is regulated through its listing on Appendix II of the Convention on International Trade of Endangered Species (CITES). Studies of conch populations from Belize and elsewhere in the Caribbean provide examples of how conch populations respond to protection within no-take zones.

In the Turks and Caicos Islands, a no-take zone was found to have adult conch densities six times higher than those of a fished area (Béné and Tewfik 2003). Within The Bahamas, studies of conch within the Exuma Cays Land and Sea Park (ECLSP), a 456km² area in the central Bahamas that was designated in 1959 and in which all fishing and other resource extraction were prohibited in 1986, show a positive effect on conch populations. Comparisons of conch populations in the ECLSP to those in other areas in the central Bahamas show that adult conch densities were significantly greater within the ECLSP than in ll other sites, (except for one site near an extremely productive conch nursery area) within 5 years of the park's having been designated a no-take zone (Stoner and Ray 1996, Stoner et al. 1998). In 2011, approximately 20 years after initial surveys were conducted, a follow-up study of conch populations in the ECLSP and in one of the fished areas was conducted (Stoner et al. 2012a). This study found that conch populations in fished areas had decreased by 91% in deeper water to levels below the threshold required for reproduction. Within the ECLSP, conch populations remained at greater densities than in the fished area, but also saw a significant decrease at some depths (Stoner et al. 2012a).

In Belize, comparisons of conch populations within a no-take zone in Glover's Reef Marine Reserve (GRMR) and in areas open to fishing show several effects of the no-take zone (Fig. 2). The no-take zone experienced an increase in adult conch density from 1998 through 2004, but these were not observed in fished areas (Acosta 2006). Densities of conch in fished areas were below levels necessary for reproductive success, but densities in the no-take zone were typically above these threshold levels (Stoner and Ray-Culp 2000, Acosta 2006). While there were some decreases in adult density in 2003 and 2004, these periods appear to coincide with periods of no enforcement (Acosta 2006). The same study also found a greater density of large juvenile conch within the no-take zone than in fished areas, despite similar densities of recruiting juveniles (Acosta 2006). These findings indicate that:

- Fishing for conch on Glovers reef has had a negative impact on adult populations;
- Fishing can reduce populations below threshold levels needed for reproduction;
- Within the no-take zone, adult conch levels increased to levels above those necessary for reproductive success;
- Enforcement is necessary for the no-take zone to increase conch densities; and
- Taking juvenile conch in the fishery has reduced densities of larger juveniles.

In 2012, conch sizes and densities were somewhat greater in the no-take zones (e.g., Conservation Zone) at Glover's Reef than in general use areas, but results do not appear to be significant (Chicas and Williams 2012). Most of the conch appear to be juveniles in both areas based on measurements of lip thickness. It is difficult to determine changes in abundance over time within GRMR, however, because different sites were used for monitoring in 2011 and 2012 (Chicas and Williams 2012).

Elsewhere in Belize's MPA system, conch densities have been monitored as part of the Long-Term Atoll Monitoring Program (LAMP) program designed by Dr. Charles Acosta. The conch monitoring component of this program includes annual surveys to examine the frequency of encounters (an estimate of relative abundance) with conch in different MPAs and different zones within MPAs and measurements of shell length in these areas. There is also a national conch measuring program which is conducted in several marine reserves around the country.

Data from several no-take zones in Belize show that the relative abundance of conch in those areas is greater than in general use zones and areas open to all fishing. For example, relative abundance of conch was 2-4 times greater in no-take zones of the Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Laughing Bird Caye National Park (LCNP) than in unprotected areas or General Use zones (Hagan 2010). Data also show an increase in conch relative abundance in the GSSCMR, LCNP and Sapodilla Cayes Marine Reserve (SCMR, which had no no-take zone designation) of 400% to over 3,000% between the 2004-2006 time period and the 2008-2009 time period, but all sites saw declines in 2010 (with some starting to decline in 2009; Hagan 2010).

In the Bacalar Chico Marine Reserve, conch abundance in the Preservation Zone (a no-take zone) was greater than in all other areas from 2010-2012 at the start of the closed season and at the start of the open season in 2011 and 2012 (Brown 2012). Conch densities also more than tripled in the Preservation Zone from 2010 to 2012 (Brown 2012). Within the Caye Caulker Marine Reserve, 88% of conch observed during monitoring in 2012 were from within the no-take zones (Preservation Zone and Conservation Zone), and only 12% were from the General Use zone, despite this zone's representing 33% of the sampling effort (Cansino 2012). The majority of conch observed (66%) were juveniles (Cansino 2012). n the Hol Chan Marine Reserve, conch density increased from 1998 through 2010 but decreased subsequently (Forman 2012). While there is some evidence that no-take zones may be contributing to this increase, several factors, including a confounding effect of habitat quality and reserve zoning, make the data difficult to interpret.

Conch populations within the Port Honduras Marine Reserve varied over time and between zones within the marine reserve (Foley 2013). Conch densities increased from June 2009 to September 2010, particularly in the no-take zones that comprise 5% of the marine reserve area, but then decreased throughout the reserve, including in no-take zones, in 2011, followed by slight recovery in 2012. The reduction of conch inside the no-take zones is thought to be due to poaching (possibly from foreign fishers due to the proximity of East Snake Caye no-take zone to Guatemala), and general overfishing throughout the marine reserve in 2011 (Foley 2013). Based on the relatively small sizes of conch within no-take zones, these areas may be primarily nursery grounds for the species.
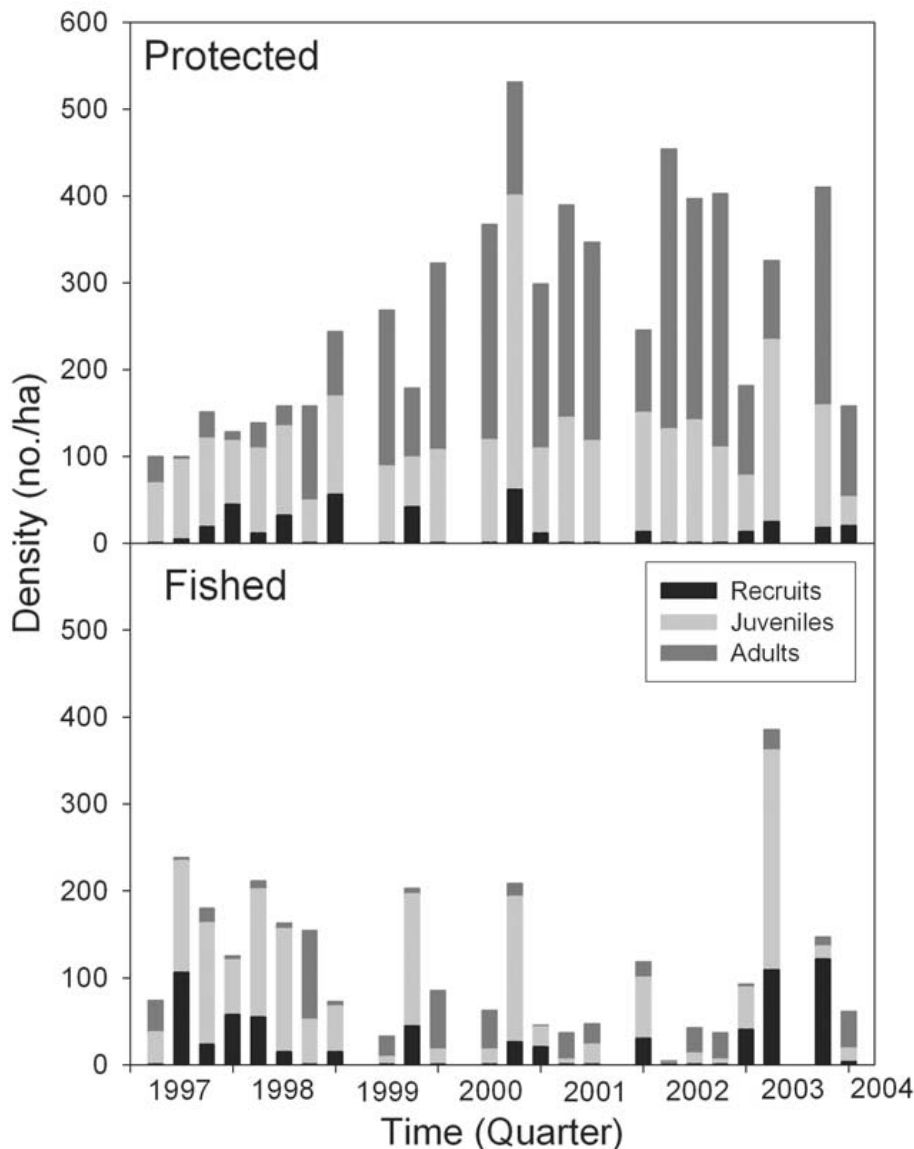

Figure 1. Conch population size and structure within a no-take zone and open fishing area in Glover's Reef Marine Reserve. Blank spaces represent missing surveys. (Reprinted from Acosta, (2006).

2.2.2 Caribbean Spiny Lobster

Studies of Caribbean spiny lobster in no-take zones within the Florida Keys (USA) show that within 4 years of establishment of the Western Sambo Ecological Reserve, a 3,000 hectare no-take zone, spiny lobster abundance was greater than in surrounding fished areas. In addition, the proportion of legal-sized lobster in the overall population was greater within the no-take zone than in fished areas, particularly during the open fishing season (Cox and Hunt 2005). The density of male lobsters within the Western Sambo Ecological Reserve doubled, and the density of females quadrupled over a similar time period (Bertelsen et al. 2004). In another part of the Florida Keys, the Dry Tortugas National Park serves as a large no-take zone (190 km^2); lobsters within the park have been found to be 20mm larger in carapace length than lobsters outside the park (Bertelsen and Cox 2001).

In The Bahamas, effects of no-takes areas were found to be similar for lobster as they were for conch in the Exuma Cays Land and Sea Park. Within 8 years of having been designated a no-take marine reserve, spiny lobster densities in the park were greater than in fished areas outside the park, despite having lower post-larval recruitment and nursery habitat than other sites (Lipcius et al. 1997). Lobsters in the park also are larger, on average, than at other sites in The Bahamas (Dahlgren, unpublished data).

The LAMP surveys being implemented in MPAs in Belize also record data on spiny lobster encounter frequency and sizes. Similar to conch, lobster relative abundance in the Laughing Bird Caye National Park (LBCNP) increased over time, and in 2008 and 2009, there was a greater frequency of lobster encounters in the no-take zone than outside it (Hagan 2010). Lobster encounters in the Gladden Spit and Silk Cayes Marine Reserve (GSSCMR), however, did not vary based on the level of protection of different zones, but the likely cause of the failure of the no-take zones to increase the frequency of encounters (e.g., small size of no-take zones, poaching, small amounts of suitable habitats) was not identified.

Annual lobster surveys in the Bacalar Chico Marine Reserve showed there were 2-12 times as many lobsters in no-take zones (Preservation Zone and Conservation Zones, including Conservation Zone 2,where sport fishing is allowed with a license) than in General Use Zones at the close of the lobster season in 2012 (Brown 2012). In the Hol Chan Marine Reserve, lobster within no-take zones (Zone A and Zone D Exclusive Recreational Zone) in 2012 were 4-5 times more abundant than in the Zone D General Use Zone (Forman 2012). Monitoring over time has also shown a dramatic increase in lobster abundance in the Exclusive Recreational Zone since its creation in 2008 (Forman 2012).

Lobster data from the Port Honduras Marine Reserve from 2009 to 2012 show some mixed results, with little differences between no-take and General Use zones until 2012, when there was greater abundance in no-take zones, particularly before the closed season (Foley 2013). The effectiveness of no-take zones is also evident in the size distribution of lobster throughout the reserve, with no-take zones typically containing larger individuals, although sizes fluctuated from year to year (Foley 2013). In all years and in both General

Use and no-take zones, male lobsters dominated the population for which data are available (Foley 2013). At Glover's Reef Marine Reserve, where lobster fishing in General Use zones is limited to free diving (no shades or traps), the size of lobsters was nearly twice as large in the no-take zone than in the General Use Zone (Chicas and Williams 2012). Too few lobster were recorded in the 2012 annual surveys from Caye Caulker Marine Reserve for meaningful analysis (Cansino 2012).

2.2.3 Grouper and Snapper

Similarly to conch and lobster, no-take zones have been shown to have significant positive impacts on commercial finfish species of importance to Belize, including grouper and snapper. In the Exuma Cays Land and Sea Park in The Bahamas, for example, where increases in conch and lobster populations have already been discussed, Nassau grouper density and biomass are greater than in fished areas outside the park (Sluka et al. 1997, Dahlgren 1999, Mumby et al. 2006), in spite of the fact that Nassau grouper leave the park during spawning migrations (Bolden 2000, Dahlgren in prep.). Such benefits of no-take zone protection are particularly important for this species, which is of commercial importance but has been fished to the point where it has been classified as Endangered on the IUCN *Red List of Threatened Species*, the world's most authoritative threatened species list. In Belize, Nassau grouper spawning aggregations have nearly collapsed over a 25-35-year period as a result of fishing (Sala et al. 2001). Inclusion of these spawning sites within MPAs and designating them as seasonal fishing closures or full-time no-take zones are expected to improve the status of this species in Belize.

Other grouper and snapper species have also been shown to benefit from no-take zone protection. Within no-take zones of Brazil's Abrolhos Bank, for example, black grouper biomass increased 30-fold over five years while remaining low outside of no-take zones (Francini-Filho and de Moura 2008). In Belize, snapper were one of the fishery species groups seeing the greatest positive response to the creation of no-take zones in the Hol Chan Marine Reserve (Polunin and Roberts 1993).

2.3 No-take Zones vs. Other Forms of MPAs

While MPAs that allow some extractive uses may serve an important purpose for managing these uses or protecting resources against specific impacts, there is growing evidence that no-take zones have a greater impact on fished populations than other forms of MPA. For example, abalone abundances were found to be greater within no-take zones of the British Columbia (Canada) coastline (including areas around a prison where visitation is prohibited) than in areas where abalone fishing was prohibited but other fishing was allowed (Wallace 1999). In New Zealand, reef fish abundances were greater in no-take zones than in MPAs where some fishing was allowed (e.g., Denny and Babcock 2004). Shears et al. (2006) also found lobster densities to recover more within a New Zealand marine park where no fishing was allowed than in an MPA where recreational fishing was allowed. In the US Virgin Islands, Rogers and Beets (2001) found declines in habitats and species abundances to be similar within and outside MPAs that allowed multiple uses,

thereby highlighting the need for increased protection. Lester and Halpern (2008) conducted a meta-analysis of studies comparing fish and invertebrate density, biomass, species diversity, and individual size in no-take zones, partially protected areas, and open-access areas and found that no-take areas had higher biomass, density, species richness and individual organism size on average relative to partially protected areas; however, low statistical power resulted in this difference's being statistically significant only for density. The same study found partially protected areas were always similar to open-access areas. While the same study found some positive influence of partially protected areas over open-access areas for density, biomass and mean size of species, there was no statistically significant difference between partially protected areas and open-access areas (Lester and Halpern 2008).

2.4 How Long Does it Take for Conservation Benefits to Occur?

Key questions regarding the benefits of no-take zones include how long does it take to detect increases in abundance, size and biomass, and how quickly do populations within no-take zones recover to pristine conditions? The answer to these questions may depend on a variety of factors, including the status of populations before establishment of the no-take zone, the life history of the species of interest (e.g., growth rate, fecundity, planktonic larval duration, movement rates), and characteristics of the no-take zone (e.g., habitats, efficacy of enforcement) and the fishery operating around it (Côté et al. 2001, Molloy et al. 2009); these are addressed in later sections of this report. Meta-analyses of data in the published literature indicate that recovery of target species in no-take zones can be rapid. Halpern and Warner (2002), for example, examined changes in species abundance and biomass across a number of no-take zones and found a significant increase that persisted through time after one to three years. Another meta-analysis of data from published literature covering over 1000 species-specific comparisons of populations in no-take zones to fished areas indicated that fish density within no-take zones increased approximately 5% per year relative to unprotected areas, but only old reserves (>15 years) consistently harbored significantly more fish inside than outside their boundaries (Molloy et al. 2009). Similarly, older European marine reserves were more effective than newer reserves in increasing catchable sizes of commercial fishes and conserving species richness, with the density of commercial fishes increasing by 8.3% annually and number of species increasing by 0.20 species annually on average (Claudet et al. 2008).

Several empirical studies have addressed this question with mixed results. A study of 13 well-protected no-take zones in the Philippines found that within three to four years a significant increase in biomass of large fish predators could be detected, and, within 6 years, greater biomass could be detected within no-take zones than in fished areas (Russ et al. 2005). Along Australia's Great Barrier Reef, multiple no-take zones within the Great Barrier Reef Marine Park experienced increases in coral trout (*Plectropomus* spp.) densities by 50% or more after 1.5 to 2 years, but no increases were observed in fished areas (Russ et al. 2008). In other no-take zones within the Great Barrier Reef Marine Park, density and biomass of exploited predators increased by up to a factor of 6.3, over a 12-13-year period after the establishment of no-take zones, but there were no increases in fished areas

(Williamson et al. 2004). A study of exploited fish and invertebrates from a number of no-take zones in both temperate and tropical regions found that the direct effects of reserve protection on targeted populations occurred within 5 years on average when increases were detected (Babcock et al. 2010b). This study also found that the initial increases in populations stabilized for a period of about 6 years before increasing further or decreasing (Babcock et al. 2010b).

Some of the earliest examples of the conservation benefits of no-take zones of the Caribbean are from Belize and the Caribbean island of Saba. In a no-take zone in Saba, the overall biomass of commercially important fish families increased by 60% within two years, and the biomass of some families, including snappers, increased by up to 220% (Roberts 1995). In the latter study, however, increases in abundance were also observed in fished areas, suggesting that the increases may have been due to additional factors to protective management (Roberts 1995). In the no-take zone of Belize's Hol Chan Marine Reserve, after only four years of protection, nearly half of all targeted species observed in visual censuses had a greater abundance, size or biomass within the no-take zone than in ecologically similar fished areas, with snappers showing the greatest difference in biomass (Polunin and Roberts 1993). Within four years of protection, stocks of targeted species in the no-take zone during visual surveys were, overall, approximately double those of fished areas (Polunin and Roberts 1993). Other examples from the Caribbean are reported later in this chapter.

2.5 How Long Does It Take Populations to Fully Recover in No-take Zones?

The studies presented thus far in this report show populations of target species to increase or be greater in no-take zones than in fished areas after a period one to six years, but how long does it take for biomass to return to "pristine" conditions? Several studies have examined this question by looking at the shape of the curve describing the increase in biomass over time for a no-take zone, or the shape of the curve describing the relationship between biomass and no-take zone age for no-take zones of different ages, or a combination of these two approaches. Using these approaches involves examining the time it takes for these biological factors to stop increasing as evident in an asymptote in the curve describing the relationship between no-take zone age and the biological factor.

It should be noted that the leveling off of population growth over time in these studies is frequently interpreted as populations' reaching pristine conditions, as indicated in the studies cited in this section. Because actual pristine conditions are unknown, however, and can vary based on a wide range of environmental conditions, habitat quality, and other natural factors, it is not possible to determine if the population levels achieved over time reach these pristine conditions. The actual population levels that are achieved over time may fall short of actual pristine levels if target species move out of the no-take zone and are captured in the fishery, or if other conditions in the no-take zone (e.g., habitat quality) limit population growth. Instead of achieving pristine population levels, these studies should be viewed as demonstrating the time it takes for no-take zones to achieve achieving the natural carrying capacity for an area, which may vary among areas and species. Evidence

for achieving close to pristine population levels is strengthened, however, when similar "pristine" population levels are reported from multiple no-take zones, despite the fact that the size of the no-take zone or other aspects of no-take zone management may vary.

McClanahan and Graham (2005) examined biomass of fish assemblages in four Kenyan no-take zones of varying age that were monitored over different periods of time. They found that fish assemblages took just over 20 years to recover biomass to "pristine" levels. For some individual species in this system, recovery may take longer. The triggerfish, *Balistapus undulatus*, for example, is an important predator on Kenyan reefs. A study of populations of this species in five no-take zones and several unprotected sites showed that even after 30 years of protection, the density of this species was still increasing, indicating that it can take more than 30 years for this species to recover (McClanahan 2000). The length of time that it may take for populations to achieve "pristine" levels may depend on a variety of life-history characteristics, including growth rate, recruitment rates, home range size and movement patterns, age at sexual maturity, longevity, and other factors.

In the Philippines, biomass of large, exploited predatory fish species was greater in the no-take zones than in fished areas within five years of protection, and was still increasing exponentially in two no-take zones after 9 and 18 years of protection, with models predicting full recovery after 15 years of protection in one no-take zone and after 40 years in the other (Russ and Alcala 2004). Within the same MPA system, periodic opening of reserves to fishing resulted in decreases in fish density and biomass, while gains in density and biomass at one no-take zone, Sumilon Island, that accumulated over a 5-6 year period, were wiped out entirely after periods of fishing lasting 1.5 to 3 years (Russ and Alcala 2003). This example highlights the need for continued protection to sustain increases in density and biomass.

2.6 Other Direct Conservation Benefits for Target Species

Conservation benefits of no-take zones for target species may include other biological responses that have significant implications for the conservation of these species. There are numerous direct and indirect impacts on target species. Direct impacts are those that derive from no-take zones' preventing the capture of target species, while indirect benefits enhance populations of target species through reducing impacts to habitats or intra-specific interactions such as competition and predation. In this section, direct impacts are discussed. Because indirect impacts may affect both target and non-target species, these impacts are discussed later in this report with other "ecosystem benefits" of no-take zones.

The increase in adult density, size of individual fish, and overall biomass can result in increased reproductive output, making no-take zones important "banks" of spawning stock biomass for the recovery of the species on greater spatial scales than just within no-take zones, and surplus production from no-take zones may be available to support fisheries, as will be discussed in the next chapter. For most species of fish and invertebrates that are exploited, if populations are twice as large within a no-take zone, it will have twice the reproductive output of a similar-sized area that is fished. For some species, however, the

increase in density within a no-take zone has even greater effects. For example, species such as queen conch require minimum threshold densities before reproductive activity occurs (Stoner and Ray-Culp 2000), but these densities are rarely achieved outside of no-take zones (e.g., Stoner et al. 1998, Acosta 2006, Stoner et al. 2012a). Recent studies of queen conch have examined the number of conch required for reproduction. Within a large no-take area in The Bahamas, there was a 90% probability of successful mating at 100 adult conch per hectare, but outside the no-take zone, densities of 350-570 conch per hectare were needed for reproduction to occur (Stoner et al. 2012b). This difference is believed to be due to selective removal of larger individuals in fished areas. A related study found that current fisheries regulations for conch focusing on a minimum size (e.g., Belize) or the presence of a flared lip to the shell (e.g., Bahamas) are inadequate to ensure that individuals reach maturity, because size at maturity may vary, leading to the capture of many juveniles that mature at larger sizes, and development of a flared lip to the shell occurs prior to maturity, with 50% of the population reaching maturity only after the shell lip thickens to 24-26 mm (Stoner et al. 2012c). In these cases, nearly all of the reproduction that supports the population may be from no-take zones.

In addition to increases in abundance of fish or invertebrates causing an increase in reproductive output, increases in individual body size can have an even greater increase in reproductive output. For fish, increases in body size can have a greater influence on reproductive output than increases in abundance because the number of eggs that a female produces is usually correlated with her body size. Bohnsack (1990) uses red snapper (*Lutjanus campechanus*) as an example whereby a single, large (61 cm) female produces as many eggs as 212 smaller (42 cm) ones. Thus, a 69% increase in body size results in a more than 200-fold increase in reproduction for an individual fish. Similar results have been shown for other fish species.

Because increase in body size within a no-take zone is often the result of greater survivorship of fish or invertebrates that are free from fishing mortality, larger individuals in no-take zones are usually older ones as well. Recent studies of some fish species have shown that older females produce larvae that are hardier than those of smaller and younger females (Birkeland and Dayton 2005). These larvae can withstand starvation more than twice as long and grow up to three times faster than larvae from smaller and younger fish, such that they have greater fitness (Berkeley et al. 2004aa). Other fish show similar patterns in growth rate and survival (Birkeland and Dayton 2005). These results suggest that no-take zones may be the most effective way to preserve population structure and the fitness of individuals within a species (Berkeley et al. 2004bb).

Size may be important for males of some species as well. In Caribbean spiny lobster, for example, males are typically larger than females under natural conditions, but in fished populations, males and females tend to be similar in size (Bertelsen and Matthews 2001). Males and females mate by a male's depositing a spermatophore on the underside of the female (often referred to as a "tar spot"), which she then scratches to release sperm to fertilize her eggs deposited on the underside of her tail. When large males are not present, females may not mate and, therefore, may not bear fertilized eggs (MacDiarmid and Butler IV 1999); this phenomenon is also seen in other crustaceans (Jivoff 2003). Furthermore,

the size of the spermatophore and amount of sperm cells deposited on the female are correlated with the size of the male that deposits them, and spermatophore size accounts for nearly half of the variability in the clutch size (MacDiarmid and Butler IV 1999, Butler et al. 2011). In the Florida Keys, mated female lobsters within the Dry Tortugas Marine Reserve, a large no-take zone, had a sperm-to-egg ratio that was 40% higher than that found on average in a fished population (Butler et al. 2011).

There is also growing evidence that fishing can exert selective pressure on species that can lead to evolutionary shifts in the size at which they mature, which, based on size-dependent reproductive output, can have negative impacts on the sustainability of fisheries. A modeling study by Baskett et al. (2005) demonstrated this effect based on data from Atlantic cod (*Gadus morhua*) and predicted responses of other fish species under different fishery management scenarios. Results of this study indicated that the use of no-take zones produced the greatest equilibrium size at maturation when selection pressures were heavy. The study also indicated that MPAs, including no-take zones, were more robust to uncertainty than traditional fisheries management. Similarly, population modeling by Meithe et al. (2010) showed that no-take zones can prevent evolutionary pressures of selective fishing on reducing size at maturation if no-take zones are large enough to adequately contain adults. This model also indicated a trade-off between achieving spillover to support fisheries and reducing evolutionary pressures on size at maturation.

For fish that change sex, fishing may also have a significant impact on sex ratios and population structure. For example, in the Gulf of Mexico, fishing on grouper spawning aggregations over 20 years reduced the number of males in populations for two species (Coleman et al. 1996). The percentage of males in the gag grouper (*Mycteroperca microlepis*) population was reduced from 17% of the population to only 1%, and that of the scamp (*M. phenax*) dropped from 36% to 18%. The same study did not see a change in the percentage of males in the population for red grouper (*Epinephelus morio*), which do not aggregate to spawn. Models of a Pacific grouper species that switches from female to male indicates that such changes may affect the resilience and persistence of populations (Armsworth 2001).

In addition to groupers, fish that may switch from females to males as they grow include parrotfish (Scaridae) and wrasses (Labridae), including many target species in the Caribbean region. Hawkins (2004) examined the impact of fishing and no-take zones on parrotfish populations at several locations throughout the Caribbean. In addition to broad population impacts of fishing's reducing abundance of larger species, allowing for smaller species to comprise a greater percentage of the population, results of this study indicate that fishing reduced the size of fish and the proportion of terminal males in the population for four of five species. The implementation of reserves increased parrotfish densities and the size at which females switched to become terminal-phase males (Hawkins 2004).

A meta-analysis of studies of no-take zones on sex-changing fish found several noteworthy results (Molloy et al. 2008). While the general response of species that change sex was similar to that of non-sex-changing fish when all no-take zones were considered, when analyses were limited to older no-take zones, female-first (protogynous) sex-changing

species consistently benefited from protection in no-take zones, but male-first (protandrous) and non-sex-changing (gonochoristic) species had variable responses (Molloy et al. 2008). The fact that these results were only observed after ten years of protection suggests that some of the benefits of no-take zones to female-first sex-changing species may only be realized after several generations (Molloy et al. 2008).

2.7 Conclusions

No-take zones around the world, including in Belize, have been shown to have significant conservation benefits for target species, including increases in abundance or density, biomass, and individual sizes of target species. While other types of MPA have some benefits, conservation benefits have been shown to be greatest for no-take zones where extractive fishing is prohibited. For Belize and countries around the Caribbean, this finding applies for some of the region's most valuable fishery species, queen conch and Caribbean spiny lobster. In the Caribbean and other parts of the world, conservation benefits have been shown to occur within 1-6 years of protection; however, it may take decades for populations of some species to recover to near-pristine conditions. No-take zones may also provide conservation benefits related to the structure of populations, such as the ratio of males to females, and to other factors that contribute to conservation of target species. While not all no-take zones are guaranteed to produce conservation benefits, these benefits and others can be expected from no-take zones that are well-designed and enforced (as will be discussed in later chapters).

3. Fisheries Benefits of No-Take Zones

Numerous studies have demonstrated that spawning stock biomass within a no-take zone is higher than in fished areas for a number of fisheries species. Increased abundance and biomass within a no-take zone can enhance fisheries outside of it via two processes. The first is frequently referred to as larval replenishment or the "recruitment effect," and the second is the export of adults or the "spillover effect" (Fig. 2). Both of these are discussed in detail in the following sections.
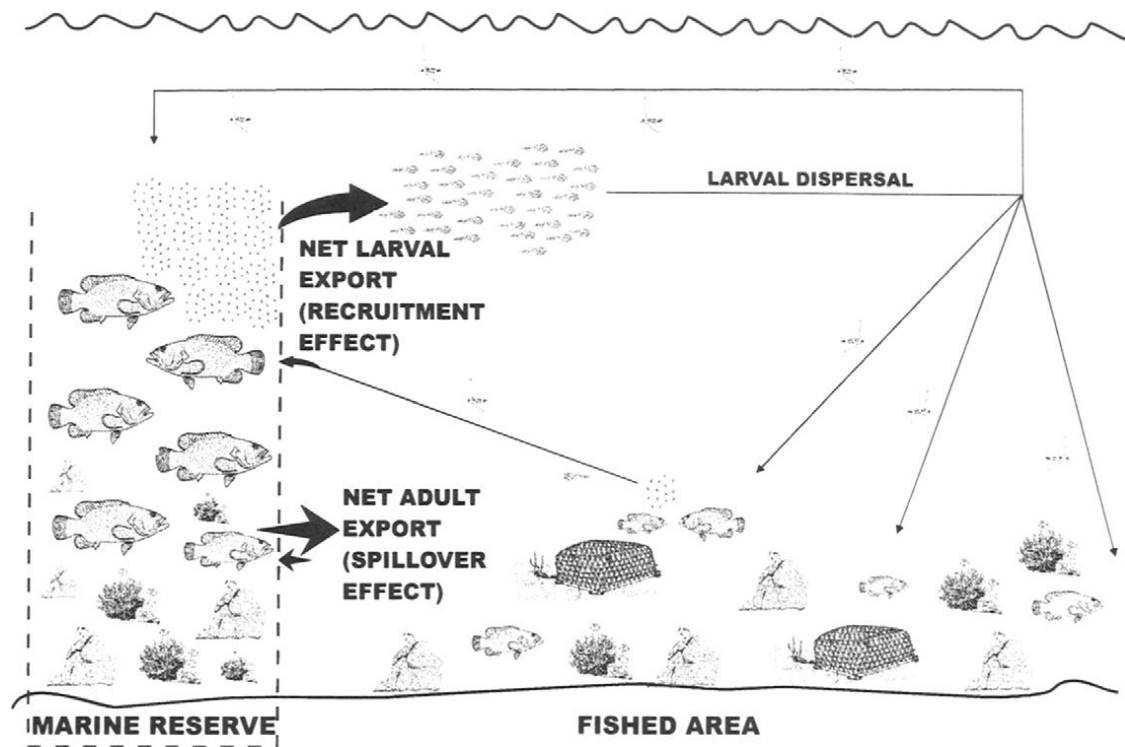
Figure 2 Diagram showing the means by which the build-up of abundance, individual size and biomass in a no-take zone (referred to as "marine reserve" in the figure) may support fisheries outside the no-take zone. (Reprinted from Russ (2002)

3.1 Recruitment Effect – Larval Replenishment

As discussed earlier, the increase in density and individual size of fish and invertebrates can lead to dramatic increases in reproductive output. For most marine species, reproduction results in the release of larvae that are carried by currents as plankton. While past studies often assumed that larvae were carried long distances as they drifted fairly passively in generalized currents (e.g., Roberts 1997), more recent studies have shown that dispersal "windows" may be much smaller, and self-recruitment may be more common

than once expected (Jones et al. 1999, Swearer et al. 1999, Almany et al. 2007). The planktonic larval duration for most species is typically on the order of days to weeks but varies from species to species. Queen conch, for example, have a planktonic larval duration of 3 weeks (Boettcher and Targett 1996); Nassau grouper have a planktonic larval duration of 42 days on average (Colin et al. 1997); and Caribbean spiny lobster have a planktonic duration of months to a year (Lewis 1951). Differences in local and regional currents, length of the planktonic larval stage, and swimming ability of planktonic larvae (or swimming post-larval/pelagic juvenile stage) can lead to variability in the dispersal of larvae from a spawning site to the location where the larvae settle out of the plankton and go through metamorphosis into juveniles. While many studies show relatively high rates of "local" larval retention, the window over which many larvae settle is often larger than the area of the no-take zone, with a large percentage of larvae spawned in the no-take zone recruiting to the juvenile population outside of the zone.

While theory predicts this benefit of no-take zones, it has been difficult to demonstrate empirically in the field due to the need to simultaneously sample larval supply to areas at distances away from the no-take zone, often over large distances, as well as natural variability in larval transport (Pelc et al. 2010). Several empirical field studies and modeling studies show some indication of larval recruitment from no-take zones for various species. For example, Pelc et al. (2009) estimated larval production by targeted intertidal mussel species to be greater within two of three South African no-take zones than in fished areas based on the increased size and abundance. While this is no different than other studies cited previously in this report, the study also found larval recruitment to be greatest within the no-take zones and decreasing exponentially with distance from the no-take zones, suggesting that larval export may enhance populations in fished areas within several kilometers (Pelc et al. 2009).

In the Gulf of California, the densities of two mollusk species, rock scallop (*Spondylus calcifer*) and black murex (*Hexaplex nigritus*), were examined within a newly established network of no-take zones and surrounding fished areas. After two years, density of juvenile rock scallops increased by over 40% in no-take zones and over 20% in fished areas (Cudney-Bueno et al. 2009), while black murex showed more than a three-fold increase in fished areas (Cudney-Bueno et al. 2009). These findings were consistent with predictions of a larval dispersal model and oceanographic studies of the area, suggesting that larval dispersal from the no-take zones was the cause of the increase in recruitment in the fished populations (Cudney-Bueno et al. 2009).

In The Bahamas, Stoner et al. (1998) examined the distribution of conch veliger larvae in Exuma Sound, near the Exuma Cays Land and Sea Park (ECLSP) and found that early-stage conch larvae occurred at densities of up to an order of magnitude greater around the park than in other areas, indicating greater larval production. Later-stage larvae, however, were more evenly distributed among sampling stations around Exuma Sound (Stoner et al. 1998), suggesting larval export to fished areas outside of the park. In the same Exuma Sound Bahamas system, Lipcius et al. (2001) examined larval dispersal using empirical data and hydrodynamic models. Based on ocean current models in Exuma Sound and empirical information on lobster population size and recruitment, these authors concluded

that lobster populations within the ECLSP support other populations throughout Exuma Sound. Using a metapopulation model, they examined how the park serves as a source population for other areas.

While these studies provide indirect evidence that larval export from no-take zones supports fisheries in surrounding areas, they do not provide direct evidence of this effect. The most compelling evidence of larval export from no-take zones comes from recent studies whereby researchers have been able to determine where larvae collected in an area were spawned, either through tagging them at the time of spawning or using genetic markers to determine parentage. For example, a recent study of fish recruitment along Australia's Great Barrier Reef uses genetic parentage analysis of two exploited species, stripey snapper (*Lutjanus carponotatus*) and coral trout (*Plectropomus maculatus*) (Harrison et al. 2012). This study found that stripey snapper exported 55% of their larvae to fished reefs, and coral trout exported 83% of larvae to fished reefs, with the remainder recruiting either to their natal no-take zone or other no-take zones. Based on this analysis, the study estimates that no-take zones that account for 28% of reef area in the study region produce about half of all recruits to reefs within 30km, including both no-take zones and fished reefs (Harrison et al. 2012).

Almany et al. (2007) examined tagged larvae of two species of fish with 11 and 38 day planktonic larval durations that were spawned within a small island no-take zone on the Great Barrier Reef. For both species, self-recruitment within the 0.3km² no-take zone was 60%, with the remaining 40% of recruits' having been spawned at other reefs that were a minimum of 10km away (Almany et al. 2007). This finding has significant implications for biomass within no-take zones, with a significant increase in density possibly occurring from recruitment within the reserve. It also suggests that a significant amount of larvae may be exported from the reserve to fished areas over 10km away.

So, assuming that the recruitment effect occurs for a no-take zone, will the export of larvae via the recruitment effect sustain or enhance fisheries? Several models indicate that this can be the case, depending on various assumptions, the size of the no-take zone, and the net export of larvae from the no-take zone. For example, Halpern et al. (2004) modeled the recruitment effect and the effect of displaced fishing effort from no-take zones to surrounding fished areas and found that the reported range of increase in fish biomass within no-take zones should be able to compensate for the increased fishing pressure from displaced effort. The fisheries benefits via larval export, however, can depend on the size and location of the no-take zone, as well as biophysical factors, such as characteristics of populations of interest and current patterns that influence larval dispersal (Gaines et al. 2003, Gerber et al. 2003, Gaines et al. 2010). For example, several authors suggest that no-take zones can be created to support high fishery yields outside their boundaries for sessile organisms via larval export (e.g., Hastings and Botsford 2003). In a spatially realistic system, Stockhausen and colleagues (Stockhausen et al. 2000, Stockhausen and Lipcius 2001) modeled various no-take zone configurations for Exuma Sound, Bahamas using hydrodynamic data and empirical data on lobster populations there to show how various no-take zone configurations can support lobster fisheries throughout Exuma Sound.

Further details of how various aspects of no-take zone design influence the benefits produced by no-take zones are discussed in Chapter 5 of this report.

3.2 Spillover Effect

The second manner in which no-take zones can enhance fisheries outside their boundaries is what is commonly referred to as the "spillover effect," whereby fish and mobile invertebrates leave the no-take zone and enter the fishery. As several authors point out, however, not all movement from a reserve benefit fisheries in the same way (Sobel and Dahlgren 2004). The spillover effect should result from movement that is caused by the effects of the no-take zone. For example, as the abundance of a species increases within a reserve, density-dependent movement should lead individuals to leave the reserve to avoid crowding for limited resources or other forms of competition, such as agonistic or aggressive behavior that leads to home range relocation (Kramer and Chapman 1999). Similarly, as fish or invertebrates live to older ages and get larger within a reserve, they may increase home range size and leave the reserve or undergo ontogenetic habitat shifts (e.g., cross-shelf migrations from nearshore nurseries to offshore habitats that may be outside of reserve boundaries).   In contrast, random movements that cause fish or invertebrates to leave the reserve may not have the same benefit of exporting biomass from the reserve to the fishery and may actually limit the increase in abundance, individual size or biomass within a reserve.

Theoretical models predict that: (1) spillover should be evident as a decline in species density or catches with distance away from a no-take zone, with greatest rates in the center of the no-take zone; (2) density-dependent emigration will only take effect after a build-up of abundance or biomass within a no-take zone; (3) the amount of spillover will depend on aspects of the no-take zone design, such as habitats, size, perimeter-to-area ratio, and natural barriers to movement; and (4) species with intermediate levels of mobility and density-dependence will provide the greatest spillover to surrounding fisheries (Kramer and Chapman 1999). In addition, aspects of the fishery outside the reserve that create the density gradient may also influence spillover (Kellner et al. 2007, Halpern et al. 2010). There are numerous examples of the spillover effect from around the world. In addition to models of population increases and movement, three types of empirical studies generally provide evidence for spillover: (1) studies of exploited species density, individual size, and biomass within a no-take zone and over a range of distances from a no-take zone; (2) studies of fisheries catches on a catch per unit effort (CPUE) or catch per unit area (CPUA) basis at different distances from a no-take zone; and (3) studies of fish movement through observation or tagging that directly measures movement across no-take zone boundaries.

3.2.1 Density Gradients

A small no-take zone in the Philippines, Apo Island (established in 1982), provides some of the best examples of spillover. As biomass of large, predatory, target species increased in this reserve, researchers also observed an increase in the biomass of these species outside the reserve, suggesting spillover from the reserve to fished areas (Russ and Alcala 2003). A

study of a wide range of targeted and non-targeted fish species examined the density and biomass of these species within and at different distances away from the Apo Island no-take zone and one at Balicasag Island in the Philippines (Abesamis et al. 2006). This study found greater density and biomass of targeted fish within the no-take zone for Apo Island, but not Balicasag Island. At Apo Island, a gradient in density was observed at the northern boundary of the no-take zone for targeted fish species, but not non-targeted species. This gradient extended out 350m when all targeted fish were examined, but the shape of the curve describing the decline in fish biomass and density varied based on the movement of fish, with sedentary species (e.g., groupers, grunts) showing a sharp decline in density and biomass within 50m of the no-take zone boundary, vagile species (i.e., species that are not site-attached but move within a fairly large home range, such as parrotfish, snappers, and goatfish) showing a more linear decline in biomass over the 350m distance from the no-take zone, and highly vagile species (i.e., species that move over large areas, such as jacks) showing the decline in density and biomass starting approximately 50m inside the reserve and extending out 150m from the reserve before density and biomass approached zero (Abesamis et al. 2006). These spatial distribution patterns indicate that the extent of the spillover effect is related to movement rates of target species.

Another study of spillover from the no-take reserve at Apo Island focused on a single targeted species, the surgeonfish *Naso vlamingii*. After 18 years of protection, the biomass of this surgeonfish increased by a factor of 40 within 200-250m of no-take zone boundaries, but not at distances greater than 250-500m (Russ et al. 2003). In addition, the modal size (i.e., most frequently occurring size in the population surveyed) of *N. vlamingii* individuals increased inside the reserve and 200-300m outside of the no-take reserve in a similar manner from 35cm total length (TL) to 45cm total length over 20 years, but a decrease in modal size was observed farther away from the no-take reserve over the same period (Abesamis and Russ 2005). Mean fish size outside the reserve was 35-36cm TL within 50-100m of the reserve and declined with increasing distance from the no-take reserve over 300m (Abesamis and Russ 2005).

There are other examples of density gradients as evidence of spillover in other parts of the world. For example, in a no-take zone in the Red Sea, the abundance of several fish families showed a decrease from the center of the no-take zone out to a distance of 1500m, but gradients varied among fish families and depth ranges surveyed (Ashworth and Ormond 2005). In Barbados, mean size of fish also decreased with increasing distance from the center of a no-take zone out to 750m (Chapman and Kramer 1999). In The Bahamas, grouper biomass showed a decrease with distance from the center of a large no-take zone, which was believed to correlate with fishing pressure, including illegal poaching along the edges of the no-take zone (Sluka et al. 1997).

In the Mediterranean Sea, an analysis of spillover around six MPAs (all of which included no-take zones ranging from 0.65 to 2.70 km^2) found that there was generally a gradient in biomass from no-take zones to fished areas and, to a lesser extent, a gradient in abundances (Harmelin-Vivien et al. 2008). There was an abrupt decline in biomass at the no-take zone boundary and again at the outer boundary of the MPA and open-access areas, with an estimated spillover distance ranging from 107m to 1959m and a mean estimated

spillover distance of 510m (Harmelin-Vivien et al. 2008). This system also showed gradients in catch per unit area (CPUA) as discussed in the following section.

3.2.2 Gradients in CPUE or CPUA

Spillover from the Apo Island no-take zone caused an increase in biomass of targeted species immediately outside the no-take zone and greater catch per unit effort (CPUE) in surgeonfish (Acanthuridae) and jack (Carangidae) fisheries within 200m of the no-take zone (Russ et al. 2004). Catch per unit effort in the fishery was 45 times higher within 200m of the no-take zone boundary than elsewhere. Over 62% of the hook-and-line catch records for this species were from within 200m of the no-take zone, an area that comprises only 11% of the total fishing area (Russ et al. 2003).

Around the same areas in the Mediterranean where gradients in biomass were detected (Harmelin-Vivien et al. 2008), fishing effort and fishery productivity (catch per unit area) were greatest near no-take zones, and the effects of spillover were consistent with fish movements and extended 700 to 250m from no-take zone boundaries (Goñi et al. 2008). Similar effects were observed for European lobster, *Palinurus elephas*. In a study of this species around a Spanish no-take zone, experimental and commercial netting found catch per unit effort to be greater within than outside the no-take zone, with a sharp decline at the boundary (Goñi et al. 2006). Outside of the no-take zone, commercial catch per unit effort and catch per unit area were greatest within 500m of the boundary and decreased over a distance of 4.5km away from the reserve (Goñi et al. 2006). This study of lobster spillover also had a tagging component that is discussed in the next section of this report.

In fished areas around a Kenyan no-take zone, spillover was evident in experimental trapping of fish as a function of distance away from the no-take zone, with total biomass captured per trap, size of fish captured, and number of species caught per trap decreasing with distance from the no-take zone, particularly one of the boundaries (McClanahan and Mangi 2000). Along this boundary, there was a sharp gradient over the first 300m outside of the no-take zone, but some of these gradients were observed along both northern and southern boundaries for up to several kilometers (McClanahan and Mangi 2000). Along the boundary where a gradient existed, there was an increase in catch per area and catch per fisher of more than 50% (McClanahan and Mangi 2000). Similarly, in Barbados, trap catches of fish decreased with increasing distance from a no-take zone (Chapman and Kramer 1999).

On a much bigger spatial scale, in an open ocean system including four large fishery closures off the New England (USA) coast, gradients in density across a range of distances from the no-take zones extending out 400km were evaluated for trawl catches (biomass per haul) of various species (Murawski et al. 2004). While most species did not show a significant gradient, haddock showed statistically significant declines in catch rates with distance from no-take zones, particularly within 20km of the no-take zone (Murawski et al. 2004).

The case of fishery closures within the Merritt Island National Wildlife Refuge on the east coast of Florida (USA) provides a noteworthy example of how no-take zones can enhance recreational fisheries in adjacent waters (Roberts et al. 2001). In this case, there were increases in world-record recreational catches for several species of fish 10 to 30 years following the implementation of no-take zones (Roberts et al. 2001). By 1999, the 200km stretch of shoreline surrounding the no-take zone had produced as many or more world-record-sized fish than all of the rest of the state of Florida. Furthermore, the cumulative number of world-records produced in the rest of the state showed little increase after 1985, but the majority of world-records for two of the three species around the no-take zone occurred after 1990 (Roberts et al. 2001).

3.2.3 Tagging

Tagging studies, including mark-recapture (or re-sighting) studies, as well as tracking using acoustic transmitters, can provide further evidence of spillover from no-take zones and the mechanisms underlying spillover. Results from tagging studies are mixed, however. In the same Spanish system where lobster CPUE effort increased, lobsters tagged within the no-take zone were recaptured there in 80% of net sets as opposed to in only 23% of net sets outside the reserve, out to a distance of up to 1500m from the no-take zone boundary (Goñi et al. 2006). A study of *Homarus gammarus* tagged within two Norwegian no-take zones found similar results, whereby only 4.7% of tagged lobsters moved outside of the small no-take zones (0.5-1km^2), with a median recapture distance outside the no-take zone of 164m (Huserbraten et al. 2013).

In contrast, several tagging studies in coral reef systems show that many fish species have small home range sizes (e.g., Chapman and Kramer 2000, Bolden 2001, Abesamis and Russ 2005) and may not move across no-take zone boundaries (Chapman and Kramer 2000, Abesamis and Russ 2005), or are rarely observed (Zeller and Russ 1998). For example, Zeller and Russ (1998) tagged grouper in an Australian no-take zone and found no movement across boundaries for fish tagged in the no-take zone. In the same study, grouper tagged with acoustic transmitters whose home ranges straddled no-take zone boundaries were only observed to cross reserve boundaries 15 times per month on average.

When movement is detected, however, tagging studies can provide valuable information on factors that affect movement of fish outside of no-take zones. For example, in The Bahamas, Nassau grouper tagged with acoustic transmitters in the Exuma Cays Land and Sea Park were observed to have small home ranges that did not cross no-take zone boundaries; however, larger fish (>58cm total length) were found to leave the park for long-distance spawning migrations (Bolden 2000, 2001, Dahlgren in prep.).

In Discovery Bay, Jamaica, fish tagged within a 27.5 hectare no-take zone were tagged and recaptured using traps within and outside of the no-take zone. While less than 5% of recaptures came from outside the no-take zone area, the size distribution of parrotfish captured within and outside the reserve showed that recaptures outside the reserve

tended to be in the larger size classes than those recaptured inside the reserve, supporting the prediction that the effect of reserve protection on individual size can lead to increased spillover (Munro 2000).

Understanding the mechanisms underlying spillover has been a greater challenge. In one of the few studies to explicitly address this topic, Abesamis and Russ (2005) observed movement of surgeonfish in the Apo Island, Philippines no-take zone and surrounding areas. In this study, movement across the reserve boundaries (9% of observations) and fish home range was small compared to the size of the reserve, with maximum observed movement only 40m from a starting point, suggesting that fish do not move across reserve boundaries in the course of their movement within their home range. However, the study also found aggressive interactions among *N. vlamingii* to be 3.7 times more common within the no-take zone than in fished areas. These interactions almost always resulted in larger individuals' chasing away smaller ones. Thus, the potential mechanism for spillover is the increased frequency and intensity of aggressive interactions due to increased density of fish within the reserve, which leads smaller individuals to relocate home ranges outside of the reserve (Abesamis and Russ 2005).

In a study of spillover from Australia's Great Barrier Reef, a combination of approaches was used (Zeller et al. 2003). Density gradients were observed across experimental boundaries of zones where fishing is prohibited and where fishing took place. In addition, a tag-recapture study of over 1,300 fish found that 60% of recaptures were from the initial capture locations and only 13% of all tagged fish were recaptured more than50m away from their initial tagging site. After experimentally removing fish from fished areas to increase the gradient in fish density across the no-take zone boundary, there was an increased propensity for fish to move 50m, but there was no statistically significant directional movement from high-density no-take zone to low-density fished area (Zeller et al. 2003).

The occurrence and extent of spillover may be affected by habitat and seascape characteristics (Forcada et al. 2008). For example, a study using telemetry to track Bermuda chub (*Kyphosus sectatrix*) within two no-take zones off Saint Lucia, found that fish spent 11% of their time moving out of one no-take zone and 63% of their time moving out of another (Eristhee and Oxenford 2001). In this case, habitat continuity could be attributed to differences in spillover, as fish spent less time outside of the boundaries of the no-take zone that encompassed the entire available reef than the fishes using a no-take zone that included only a small portion of a larger reef (Eristhee and Oxenford 2001).

3.2.4 How Long Does It Take for Spillover to Occur?

Studies of Apo Island's no-take zone also provide an indication of the time it takes for spillover to be observed. Russ et al. (2004) found greater biomass of surgeonfish and jacks right outside the no-take zone but not farther away from the no-take zone after approximately eight years. Monitoring populations of key fishery species around the Marine Extractive Reserve of Corumbau, a no-take zone on the Abrolhos Bank of Brazil,

before and after its designation, found populations to be low for several species, including black grouper (*Mycteroperca bonaci*), yellowtail snapper (*Ocyurus chrysurus*), and the parrotfish *Scarus tripinosus*, in all areas prior to no-take zone designation, but these species increased in biomass and showed a gradient with decreasing biomass at greater distance from the reserve boundary within 1-4 years of protection (Francini-Filho and Moura 2008).

3.2.5 Does Spillover Enhance Fisheries?

Whether the effects of spillover actually enhance fisheries depends upon whether the increase in density, biomass, or catches of target species around a no-take zone compensate for or exceed the loss of abundance, biomass or potential landings that would have been available to fishers if the no-take zone had not been in place, and whether they are sustainable. In an analysis of published empirical data, Halpern et al. (2010) used a spatially explicit population model to estimate spillover rates for each no-take zone for which data were available to determine whether the fishery catch would be sustainable if the no-take zone were not in place. Results of their analysis showed that in 12 of 14 (86%) of the no-take zones analyzed, fisheries were dependent upon spillover from the no-take zone to remain sustainable. In the two cases where fisheries would have been sustainable without the help of spillover from no-take zones, one showed fishery enhancement where spillover was fully able to compensate from the loss of the no-take zone to fishing, and the other showed partial compensation (Halpern et al. 2010). The results of Halpern et al. (2010) also show, however, that the spatial extent of spillover may be limited – to an average of only 800m from the no-take zone boundaries.

Few studies have compared the relative roles of the spillover effect versus the recruitment effect in supporting fisheries. A comparison of tag-recapture data and genetic analysis of Norwegian lobster populations around a no-take reserve found the extent of the spillover effect to be limited to less than 200m, but high level of gene flow over 400m of coastline indicates that larval connectivity is the primary mechanism by which these reserves may affect populations outside their boundaries (Huserbraten et al. 2013).

3.5 Conclusions

One of the most important benefits of conserving populations within no-take zones is the enhancement of populations outside of no-take zones that are available to fishers. While improved fishing by reducing the amount of area available to fishers may seem counterintuitive to some, this benefit has been demonstrated in several no-take zones around the world, and mathematical models have found that no-take zones can produce fisheries yields similar or greater than those produced through traditional fisheries management and are better for buffering against uncertainty. These effects occur through the "recruitment effect," whereby larvae spawned inside a no-take zone replenish populations outside the no-take zone and the "spillover effect," whereby juveniles or adults of target species move from inside no-take zones to areas outside due to increases in abundance or individual size within the no-take zone. When the export of target species from no-take zones exceeds the amount of target species that would have been available to

fishers inside the no-take zone area without protection, fisheries landings can be increased. The extent to which management outside the no-take zone and other factors affect these benefits is discussed later in this report.

While demonstrating the recruitment effect has proven difficult due to the nature of studies needed to examine this effect, there are several lines of evidence supporting the recruitment effect, including gradients in the density of larvae or recruits away from a no-take zone or genetic markers or tags that can show where larvae from a no-take zone recruit and the relative proportion of recruits from a no-take zone.

Evidence for the spillover effect has been demonstrated more frequently as decreasing gradients in abundance or catch per unit effort as distance from no-take zones increase. Tagging studies of fish and invertebrate movement from reserves also provide evidence for this effect.

While the recruitment effect may cover large areas open to fishing, depending on ocean currents, larval duration and other biophysical dynamics, the spillover effect may be more limited, with most studies showing spillover to be limited to an area within 1km of no-take zones. Specific distance of the spillover effect from a no-take zone may depend on movement rates of the species, continuity of habitat across reserve boundaries, and aspects of the fishery. While it was once assumed that the spillover effect was driven strictly by density differences across reserve boundaries, intra-specific (and possibly inter-specific) interactions, size differences, and other factors may contribute.

4. Ecosystem Benefits of No-take Zones

The conservation of target species in no-take zones contributes to fisheries benefits but can also provide what may broadly be called "ecosystem benefits." Such benefits include the conservation of biodiversity and support of ecosystem function. Ecosystem function includes indirect effects that the reserve may have on populations of non-target species to make the structure of these populations closer to pristine conditions. Preserving ecosystem function also includes enhancing or restoring ecosystem resistance or resiliency to various natural and anthropogenic threats and stressors, including climate change and invasive species. All of these potential ecosystem benefits will be discussed in this section.

4.1 Conserving Biodiversity – Direct Effects on Target Species, Non-target Species and Habitat

The conservation of biodiversity includes the conservation of various ecosystems and habitats within a region, species diversity and richness within ecosystems, as well as conservation of the diversity within a population of a species, including genetic diversity. As a form of ecosystem-based management, no-take zones are intended to provide more than just fisheries management benefits. They are also intended to preserve the ecological processes that influence ecosystem structure and function, restore populations of both target and non-target species to conditions that more closely resemble their "pristine" state with minimal human impacts, and allow interactions between these species to govern community and ecosystem structure, rather than human actions.

A review and meta-analysis by Halpern et al. (2003) found that the number of studies indicating an overall increase in species diversity (primarily fish diversity) within no-take zones was significantly greater than those finding no difference or a decrease in diversity within no-take zones (Jennings and Polunin 1997, Halpern 2003). No-take zones may affect species diversity in several ways. By eliminating extractive uses of living and/or non-living marine resources within their boundaries, no-take zones may allow exploited species to recover to levels that approach pristine conditions. In many cases, these exploited species (e.g., Nassau grouper, goliath grouper, hammerhead shark) may be at risk of extinction (as per the *IUCN Red List of Threatened Species*) and rare in exploited areas, such that no-take zones may significantly enhance biodiversity by simply protecting these species. For example, in no-take zones in New Caledonia, species diversity increased by 67%, primarily from increases in diversity of exploited fish families (Wantiez et al. 1997).

No-take zones may also affect species that are not targeted but directly affected by fisheries mortality. For example, non-target species taken as bycatch may be greatly reduced in abundance in fished areas but may remain abundant in no-take zones. While the theory that eliminating fishing in an area will benefit populations of species taken as bycatch may

seem like common sense and has been suggested by many authors (e.g., Sobel and Dahlgren 2004, Roberts et al. 2005) few empirical studies have quantified the impact of no-take zones on fish species taken as bycatch.

Various fishing gears can have considerable impact on marine ecosystems. While most of the literature has focused on impacts from "industrial" fishing fleets, even artisanal levels of fishing (Hawkins and Roberts 2004) and gears can have negative impacts. In artisanal fisheries of the Gulf of California, for example, comparisons of the ecosystem impacts of various traps and net fisheries found that set gill nets had the greatest impacts, with discard rates (over 34% by weight) higher than those of most industrial fisheries (Shester and Micheli 2011). Lobster traps and drift gill nets had lower discard rates (15.1% and 18.5% respectively), and fish traps had the lowest discard rates (0.1%). Nets also caused the greatest damage to benthic organisms (e.g., kelp and gorgonians).

Lobster traps attract not only lobsters but also fish and other invertebrate species. In a study of lobster traps in Florida (USA), nearly one-third of all traps contained species other than spiny lobster (Matthews et al. 2005). A total of 172 species of fish and invertebrates were observed, including key herbivores such as parrotfish and urchins. Occurrence of most species in traps was fairly low, with only 43 taxa present in at least 0.1% of traps (Matthews et al. 2005). Studies of bycatch included wooden slat traps, wire-reinforced traps, and plastic traps. Wire-reinforced traps caught significantly more fish than wooden traps, and wooden traps caught more of these species than plastic ones (Matthews and Donahue 1996, Matthews et al. 2005). Wooden traps also caught the most stone crabs (Matthews and Donahue 1996). Undersized snapper and grouper were captured in 0.5% of traps in Florida (Matthews et al. 2005), but they combined to comprise 5.5% of bycatch (Matthews and Donahue 1996). There was also spatial and seasonal variability in bycatch composition and bycatch rates for individual species (Matthews and Donahue 1996).

Determining mortality rate within traps is difficult since the decomposition rate of fish can be more rapid than the soak period of traps (Matthews and Donahue 1996). The fate of fish released from bycatch is unknown, but estimates of immediate mortality in Caribbean fish released from traps rage from as high as 48% to as low as 13% (Harper et al.). Longer-term survival for discarded bycatch is unknown for fish caught in lobster traps, but substantial mortality is likely to occur as a result of being captured and handled before being discarded. A study of temperate fish bycatch discards found that several environmental variables related to handling time, air exposure, and other factors can increase stress to discarded fish and lead to increased mortality (Davis 2002).

While discard rates from fish traps in the Gulf of California were low (Shester and Micheli 2011), in the Caribbean, fish traps have been shown to have greater bycatch rates and can remove key species important for supporting ecological function. Bycatch in fish traps in several parts of the Caribbean across a range of fishing pressure was examined to assess vulnerability to trapping (Hawkins et al. 2007). This study found several groups of fish to be particularly vulnerable to traps, particularly Tetraodontiformes (pufferfish, boxfish, trunkfish, triggerfish and filefish), as well as butterflyfish (Chaetodontidae) and angelfish (Pomacanthidae). In some locations, these fish were included in targeted catch, while in

others they were not targeted and taken only as bycatch. The abundance of these species on reefs was inversely related to fishing pressure across all sites. Parrotfish and other key ecological species on reefs were also common in traps in Jamaica and Saint Lucia where species composition on the reef and in traps was analyzed (Hawkins et al. 2007). Analysis of commercial species catch in Saint Lucia also found that for seven of the 23 commercial species sampled, over one-third of the catch consisted of immature fish (Hawkins et al. 2007). This included important grazers on reefs, such as ocean surgeonfish (*Acanthurus bahianus*, 30.2% juvenile), blue tang (*Acanthurus coeruleus*, 45.1%), and stoplight parrotfish (*Sparisoma viride*, 85.2%) (Hawkins et al. 2007). In Curaçao (Netherlands Antilles), similar results were found, with parrotfish being the most abundant species caught in traditional fish traps (Johnson 2010).

While parrotfish are part of the commercial catch in many parts of the Caribbean, it is illegal to fish them in Belize, although they figure as part of the bycatch from trap fisheries. An analysis of Healthy Reefs Initiative data from Atlantic and Gulf Rapid Reef Assessment (AGRRA) surveys in Belize that was conducted as part of the preparation of this report found that mean parrotfish biomass was significantly greater at sites within no-take zones than in unprotected sites or General Use zones of MPAs, which did not differ from each other in mean parrotfish biomass (Dahlgren, unpublished). In the Exuma Cays Land and Sea Park in The Bahamas, where these species are not targeted but captured in traps as bycatch, the biomass of large parrotfish species is significantly greater than in unprotected areas, but small parrotfish species had a lower biomass in the no-take area than in unprotected reefs (Mumby et al. 2006). This result is likely due to the exposure of smaller parrotfish to higher predation rates in the no-take area, where predator biomass was higher (Mumby et al. 2006; this example is discussed in further detail in section 4.4). Models of the impact of species taken as bycatch indicate that their response to protection in no-take zones may be dependent upon the interactions that those species have with target species (Reithe 2006, Kellner et al. 2010).

4.2 Indirect Effects of No-Take Zones: Habitat Impacts

Reviews of fishing methods indicate that some, such as trawling or use of chemicals or explosives, can result in habitat damage (e.g., Dayton et al. 1995, Thrush and Dayton 2002). In no-take zones, where fishing is excluded, these impacts will be prevented or allow benthic habitats to recover. Gell and Roberts (2003, and references therein) provide an example of how closing large areas off New England (USA) to trawling for groundfish not only improved stocks of target species (e.g., haddock, *Melanogrammus aeglefinus*) and species not targeted in the groundfish fishery (e.g., scallops, *Placopecten magellanicus*), but also benthic communities, including benthic species that create structure that other species use as habitat. Such changes in target species, non-target species and habitat can alter species interactions within a system to more closely resemble their "natural" condition.

In Belize, commonly used fishing gears that may damage habitats include fish and lobster traps, lobster "shades" (referred to as "condos" or "casitas" elsewhere), and gill nets. Fish traps are commonly wire mesh traps that may vary in design and may either by marked with a surface buoy or unmarked, with fishers relying on GPS to relocate traps and then use

a rope with a grapple or hook to recover individual traps or several traps strung together on a line. Lobster traps are wooden slat traps that are baited, while shades are unbaited, artificial shelters that are typically made of wooden poles stacked horizontally on with a corrugated metal roof. Gill nets vary in mesh size and catch fish passively (i.e., they are not dragged like trawls) by entanglement.

Recent studies of the use of fish and lobster traps in the Caribbean region have found that they can significantly impact coral reef and seagrass habitats. For example, lobster traps in seagrass meadows of the Florida Keys have been shown to reduce shoot densities of *Thalassia testudinum* and *Syringodium filiforme* when traps are deployed for 6 weeks or more (longer than the typical deployment period), and that shoot densities of *S. filiforme* did not recover after 24 weeks (Uhrin et al. 2005). On coral reefs in the Florida Keys (USA), live coral cover was lower under traps than control plots with trap damage evident as corals that were scraped or dislodged during deployment and retrieval, as well as due to movement during storm events (Sheridan et al. 2005). In the U.S. Virgin Islands, 50% of traps surveyed caused damage to benthic communities, including scrapes and breakage to gorgonians and sponges (nearly 50% of traps surveyed) and corals (13.7% of traps surveyed (Sheridan et al. 2005).

Habitat impacts may be greatest when traps are moved by winds and waves during hurricanes and even during winter cold front events. A study in the Florida Keys found lobster traps to be transported during winter cold fronts when winds exceeded 27.8 km/hr. (15 mph) and lasted for 2 days or more (Lewis et al. 2009). Under these conditions, movement of buoyed traps had a greater impact, affecting a mean area of up to 4.66 m^2, as opposed to 0.77m^2 to 0.9m^2 on average for unbuoyed traps (Lewis et al. 2009). Movement of traps resulted in scraped, fragmented or dislodged coral and other sessile fauna, reducing their coverage of the seafloor by 14% at 4 m depths, 10% at 8 m depths and 6% at 12 m depths (Lewis et al. 2009). In Belize, fishers have reported the use of unbuoyed traps that are strung together and retrieved with an anchor or hook that catches on the line connecting traps. Although unbuoyed, this form of trap fishing is likely to produce similar impacts to buoyed traps that move across the seafloor and damage corals and other organisms, and may even have greater impact, since the frequency of movement and possibly the distance moved across the seafloor is expected to be greater for this form of fishing.

As traps deteriorate and break apart, the debris left behind may also impact benthic communities. For example, in the Florida Keys, over one third of sites surveyed contained debris from lobster traps, including trap lines, wooden slats, and mesh from lobster traps, and debris from lobster traps accounted for over one third of all marine debris observed (Chiappone et al. 2002, Chiappone et al. 2005). Lobster trap debris was most common in patch reef and shallow fore reef habitats (Chiappone et al. 2002). This debris caused damage to a wide range of sessile benthic invertebrates, particularly gorgonians (sea fans and whips) and stony corals (Chiappone et al. 2005).

Shades used to catch lobster also have an impact, but because lobster shades are often deployed on a semi-permanent to permanent basis, are solid structures, occupy larger

areas, and function differently from traps, their impacts on marine habitats are different from those of traps. An ongoing study of the habitat impacts of shades in the Florida Keys found that shades altered benthic communities by changing the percent cover of benthic organisms out at least 7m from them (Hunt 2011). In this study, algae and sessile invertebrates such as gorgonians, corals and sponges were reduced in percent cover close to shades (although abundance of sessile invertebrates was increased on the shades themselves), and the amount of bare substrate was increased close to shades (Hunt 2011). Because shades often concentrate lobsters and attract other species, they may also affect the abundance of prey species (Eggleston et al. 1997, Nizinski 2007). While shades may provide shelter for lobster as well as non-target species, they alter habitat structure and benthic communities that may have impacts on both target and non-target species to alter ecosystem structure.

4.3 Indirect Effects of No-Take Zones: Predator-Prey Interactions

All of the benefits of no-take zones for biodiversity discussed thus far have been the direct result of prohibiting extraction within no-take zones. No-take zones may also have numerous indirect effects that benefit biodiversity. Indirect effects include changes in trophic and competitive interactions among species that can have a significant effect on populations of non-target species and overall assemblage and community structure. These effects may be positive (increasing biodiversity) or negative (decreasing biodiversity) within no-take zones. In a review and meta-analysis of 20 studies from 31 temperate and tropical locations, Micheli et al. (2004) found a mean of 35.8% of species to show an increase in abundance within no-take zones, but 19.2% showed a strong decrease in abundance. In this study, a greater proportion of species showing a negative response to protection in a no-take zone were not targeted by fisheries or aquarium trade, compared to species showing positive or intermediate responses, and had generally low mobility. Such species included those of the families Blennidae (blennies), Gobiidae (gobies), Anthiinae (small schooling basslets), Apogonidae (cardinalfish), and to a lesser extent Diodontidae (porcupinefish), Atherinidae (silversides), Pomacentridae (damselfish) and Labridae (wrasses) (Micheli et al. 2004). This study also found that overall community composition between no-take zones and fished areas in tropical habitats diverged over time and did not show signs of reaching a plateau, even with no-take zones that were 25 years old (Micheli et al. 2004).

The taxa showing decreases in abundance in the Micheli et al. (2004) study were generally those at lower trophic levels that may be prey species for target predators such as snappers and groupers. Such trophic interactions can be important in structuring fish communities in no-take zones. Similarly, a review of data from 12 European reserves indicated that while there was a positive effect on body size and density of some target species in no-take zones, non-target species rarely responded to protection, and when they did, densities were lower in no-take zones (Claudet et al. 2010).

On Australia's Great Barrier Reef, the biomass of a targeted grouper species, *Plectropomus leopardus*, was 3-4 times higher in no-take zones than fished areas after 14 years of protection in the Whitsunday and Palm Islands, but the density of all of their prey species

combined was twice as high in fished areas and the biomass of six of nine prey species was significantly lower in fished areas (Graham et al. 2003). The significant inverse relationship between predator biomass and prey biomass indicates that increased predation within no-take zones is a major factor in structuring prey fish populations. A recent modeling study suggests that in some cases, such predator-prey dynamics can lead to a considerable decline or even extinction of prey populations, particularly if the predator species is the main focus of protection for the no-take zone, is a generalist predator, and can migrate adaptively in association with a reduction in prey abundance (Takashina et al. 2012)

Target species are not free from these trophic interactions when they are prey for other species. An interesting example of this comes from a no-take zone in Barbados, where size and abundance of target piscivorous species, including large adult grunts (Haemulidae), were greater within the no-take zone than in surrounding reefs, but there was no difference in older juvenile grunts between the no-take zone and fished areas (Tupper and Juanes 1999). The inverse relationship between new recruits, which are not targeted in fisheries, and predator density suggests that high predation pressure within the no-take zone may impact population dynamics of grunts (Tupper and Juanes 1999). While recruitment levels may be depressed due to the increase in predators, the few individuals that survive to older juvenile sizes have an increased chance of reaching adult sizes in the no-take zone due to their escape from fishing in the no-take zone.

Biodiversity benefits may not only be experienced through effects on the abundance, size or biomass of target or non-target species but through behavioral interactions that may have an effect on population distribution or growth rates. For example, within a year of creating a small no-take zone in South Africa, endangered African penguins (*Spheniscus demersus*) showed a decrease in foraging effort by 25-30% and daily energy expenditures by 43%, whereas a control population of penguins in an unprotected area increased foraging effort and energy expenditures (Pichegru et al. 2010). Penguins near the no-take zone also shifted their core foraging area from outside the no-take zone to inside the zone (Pichegru et al. 2010). In this case, penguins were responding to increases in their prey species, which were targeted in fisheries and increased in abundance within the no-take zone. After more than a year of the fishery closure, however, intensified fishing immediately outside the no-take zone limited benefits of the no-take zone for penguins, suggesting that a larger no-take zone with reduced "edge effects" may be needed for continued benefits to this species (Pichegru et al. 2012). While conserving endangered penguins may not be immediately relevant to no-take zones in Belize, these findings may be applicable to other top predator species showing large-scale movement.

4.4 Indirect Effects of No-Take Zones Lead to Ecosystem Impacts

Indirect impacts of no-take zones can often have cascading effects that can alter the trophic structure of marine ecosystems and introduce top-down control of ecosystems. A review of cascading trophic interactions within no-take zones indicated that because target species are often predatory, their increase in abundance and biomass within no-take zones can often cause a decrease in primary consumers, which may lead to changes in primary

producers (Pinnegar et al. 2000). Such top-down control of food webs is well-documented in hard substrate systems such as rocky reefs and coral reefs (e.g., Pinnegar et al. 2000), but there are increasing examples throughout other marine food webs (Heck and Valentine 2007, Baum and Worm 2009).

In many rocky subtidal and coral reef systems, echinoderms play important functional roles within ecosystems as grazers and benthic predators. In New Zealand's rocky reef systems, numerous examples demonstrate how increases in predator populations can reduce urchin abundances, reducing grazing and leading to increased macroalgal abundance (e.g., Shears and Babcock 2002, 2004, Babcock et al. 2010a). Such indirect effects resulting in changes in urchin grazing can cause widespread habitat shifts from urchin barrens to areas dominated by kelp and other macroalgae (Parsons et al. 2004, Leleu et al. 2012).

Similar trophic interactions have been reported from no-take zones in Spain's Canary Islands, where increases in fish predators reduce the urchin *Diadema antillarum* abundance and grazing pressure, which then leads to changes in macroalgal coverage (Tuya et al. 2004a, Tuya et al. 2004b, Tuya et al. 2004c, Hernández et al. 2008a, b, Clemente et al. 2009), and in the Mediterranean, where increased predatory fish biomass reduces urchin grazing and leads to shifts in benthic communities from coralline algae-dominated urchin barrens to macroalgal communities (Guidetti 2006, Guidetti 2007b). These interactions may be influenced by environmental factors, such as wave exposure (Micheli et al. 2005). In other temperate systems, increases in fish or crustacean predators within no-take zones can have similar trophic effects where grazing is depressed and macroalgae increases (O'Sullivan and Emmerson 2011).

In tropical systems, trophic interactions may have similar impacts. Trophic cascades have been reported from no-take zones or locations where there are strong gradients in fishing pressure. For example, (McClanahan and Mangi 2000) found urchin grazing to increase with distance from a Kenyan no-take zone as fish grazing decreased. In Fiji, (Dulvy et al. 2004) found that predatory fish density decreased 61% along a gradient from low to high fishing intensity, and coral-eating crown-of-thorns starfish (*Acanthaster planci*) density increased by three orders of magnitude across the same gradient. Correlated with this was a decrease in reef-building corals and coralline algae, which declined by 35% and were replaced with filamentous algae and other non-reef building taxa (Dulvy et al. 2004). Because starfish undergo Allee effects, where density thresholds must be maintained for reproduction to occur, and areas of lower fishing pressure had densities below these thresholds, their population growth was negative (Dulvy et al. 2004).

The direct and indirect effects of no-take zones can combine to have significant impact on the processes that influence the structure and functions of ecosystems. These impacts may be complex and interact (Kellner et al. 2010). Studies by Mumby and colleagues in the Exuma Cays Land and Sea Park in The Bahamas illustrate this point. A direct effect of the Exuma Cays Land and Sea Park has been an increase in grouper biomass (Mumby et al. 2006) and that of other exploited predatory species (Harborne et al. 2009). Harborne et al. (2009) also found a significant inverse relationship between the elevated biomass of

benthic predators and the density of the important grazing urchin, *Diadema antillarum,* leading to a lower density of *Diadema* in the park than in other areas, although *Diadema* densities were relatively low for all areas surveyed. Elevated grouper biomass was correlated with lower biomass of small-bodied parrotfish grazers, potentially reducing grazing rates and allowing macroalgae to dominate reefs (Mumby et al. 2006). Nevertheless, coral cover was still higher in the park than at sites elsewhere in The Bahamas (Mumby et al. 2006). In this case, other trophic interactions proved to have stronger impacts on benthic communities than the reduction in *Diadema* and small-bodied parrotfish species. The biomass of large-bodied parrotfish species, which make the greatest contribution to grazing on reefs (in the absence or low densities of *Diadema* urchins), increased within the park, probably as a result of these species' being occasionally taken in subsistence fishing and/or as bait for fish traps. Correlated with the increased biomass of large parrotfish was a decrease in macroalgal coverage within the park, along with an increase in coral cover and recruitment (Mumby et al. 2006, Mumby et al. 2007).

4.5 Indirect Effects on Invasive Species

The top-down control of key species and their impacts on ecosystem structure and function has led to suggestions that no-take zones may help control populations of invasive species, such as the Indo-Pacific lionfish (*Pterois* spp.) that has recently invaded the Caribbean and has the potential to cause dramatic changes in fish communities through predation (Green et al. 2012). The ability of no-take zones to prevent invasions or reduce populations or other impacts of invasive species without further intervention from managers is questionable (Simberloff 2000). At present, there is debate over whether no-take zones may suppress populations of lionfish in the Caribbean region. One study in the central Bahamas found an inverse relationship between the biomass of large grouper species (e.g., *Epinephelus* spp., *Mycteroperca* spp.) and lionfish populations, with high grouper biomass within no-take zones having the lowest frequency of occurrence of lionfish (Mumby et al. 2011). In a study of over 70 reefs from several parts of the Caribbean region, including Belize, however, there was no relationship between grouper biomass and lionfish populations (Hackerott et al. 2013). While the difference in results between these studies may be attributed in part to differences in habitats surveyed, fishing and dispersal (Mumby et al. 2013), it is clear that there is still much to learn about factors that influence lionfish populations and how these factors may be influenced by trophic interactions or competitive interactions within no-take zones.

4.6 Coral Reef Resilience

Another important function of no-take zones is maintaining resilience of ecosystems to natural and anthropogenic stressors and impacts unrelated to fishing. Ecosystem resilience is the ability to recover from impacts and return to a prior state. For coral reefs, resilience can be maintained by natural ecosystem processes that promote the recruitment of new corals following an impact that opens up living space on a reef. In particular, maintaining top-own control of algae by having healthy populations of grazing animals is critical for coral resilience. Various stresses, however, such as exploitation of grazing

species, disease, eutrophication and other impacts, can reduce the resilience of reefs. Events that open up space on a reef can be local impacts such as ship groundings, disease outbreaks, and storm events, or more widespread events like mass bleaching.

While coral reefs face a wide range of stresses and impacts that operate on various spatial scales, impacts and stresses associated with climate change (e.g., elevated sea temperatures, increased frequency of storm events, sea level rise, ocean acidification) are among those of greatest concern. Climate change is one of the most pervasive threats to marine ecosystems (e.g., Hoegh-Guldberg and Bruno 2010) and may combine with fishing impacts to produce ecosystem-level changes (Benoît and Swain 2008). Coral reefs and tropical mangrove systems are among the most vulnerable ecosystems to climate change impacts (Walther et al. 2002, Hughes et al. 2003, Guidetti , Hoegh-Guldberg et al. 2007). Sea level rise associated with climate change is expected to result in the loss of 15% of the world's mangroves, for example (Alongi 2008). One of the greatest impacts of climate change to coral reefs is an increasing frequency and intensity of bleaching events that can cause mass coral mortality. Most climate change models predict an increase in sea temperature in the tropics, with recent models suggesting an 80% probability of at least a 1°C increase in summer sea surface temperatures for much of the Wider Caribbean, and a 50% or greater probability of a 2°C increase (Meehl et al. 2007) associated with climate change. Elevated sea temperatures can cause corals to "bleach" or turn white in color. This is a stress response whereby corals expel or lose their associated zooxanthellae, endosymbiotic microalgae that provide corals with nutrients. If the thermal stress is severe or occurs over a prolonged period, corals can die from bleaching. Even if corals don't directly die from bleaching, sub-lethal impacts of bleaching, such as reduced coral growth rates, increased susceptibility to disease, and either reduced reproductive output or complete failure to reproduce following bleaching have the potential to be just as devastating (e.g., Szmant and Gassman 1990).

The loss of coral on reefs hinders reefs' growth and development and allows bioerosion and physical impacts to reduce the structure that the reefs provide. This reduces the functionality of reefs in several ways. For example, coral reefs and mangrove systems provide critical shoreline protection during storms by dissipating wave energy as waves break on reefs rather than directly on the shoreline, thus limiting beach erosion in storms (Moberg and Folke 1999). This is further compounded by other impacts, such as increased storm frequency, which may damage reef structure and/or kill coral, sea level rise, and ocean acidification. In Belize, for example, the economic value of the shoreline protection function of coral reefs is equal to or greater than that of tourism and far exceeds that of fisheries (Cooper et al. 2009). The ability of reefs to continue to provide these benefits in the face of climate change depends on the health of coral and other key organisms that are responsible for building reefs. As such, the importance and value of building resilience to climate change cannot be overstated.

Recent bleaching events over the past 25 years have resulted in dramatic reductions in coral cover and increases in algal coverage on reefs around the world, leading to phase shifts (Hughes et al. 2003, Bellwood et al. 2004, Hughes et al. 2007b, Dudgeon et al. 2010, Hughes et al. 2010). Caribbean reefs are believed to be particularly vulnerable due to

dramatic reductions in key functional groups that are necessary to maintain reef ecosystems (Bellwood et al. 2004). Several researchers have suggested that no-take zones have the greatest potential for conserving coral reefs and facilitating the resiliency of reefs to impacts of climate change (Hughes et al. 2003). While no-take zones will do little to prevent coral loss from global stressors like thermal stress associated with climate change (Selig and Bruno 2010, Selig et al. 2012), they may facilitate recovery by protecting ecosystem processes that support reef resiliency through reducing direct and indirect effects of fishing, such as maintaining high grazing rates by protecting key fish and invertebrate grazers, or maintaining cascading trophic interactions that reduce coral predators. An analysis of 8534 live coral cover surveys was used to assess annual change in coral cover inside 310 MPAs and unprotected areas and found that coral cover remained constant in MPAs but declined in unprotected areas (Selig and Bruno 2010), suggesting increased resiliency of reefs within MPAs.

In addition to building resiliency within no-take zones, healthier coral, fish and mobile invertebrate populations within no-take zones can help to replenish populations outside their boundaries. Examples of trophic cascades affecting coral reef benthic communities in a positive way (e.g., Mumby et al. 2006, Mumby et al. 2007), and examples of no-take zones affecting populations and communities outside their boundaries via spillover and larval replenishment support these assertions.

An example of how no-take zones increase ecosystem resiliency to an acute disturbance comes from Baja California, Mexico, where there was widespread loss of benthic invertebrates that may be attributable to hypoxia resulting from climate-change-driven impacts to nearshore upwelling (Micheli et al. 2012). While populations within and outside of no-take zones were affected, juvenile recruitment of pink abalone (*Haliotis corrugata*) remained stable in no-take zones due to larger sizes and higher egg production of adults in the no-take zones (Micheli et al. 2012), but were nearly four times lower in fished areas after the hypoxic event. Furthermore, the recruitment effect extended resilience into adjacent unprotected areas (Micheli et al. 2012).

Because even the biggest no-take zones are not entirely self-sustaining (i.e., their populations rely to an extent on recruitment from areas outside their boundaries), and the effects of no-take zones can only extend limited distances outside their boundaries, larger no-take zones that are not isolated from each other are necessary to support reef resiliency across large reef areas (Bellwood et al. 2004, Hughes et al. 2010). No-take zones also must be created within a greater management context that supports resiliency (Hughes et al. 2005). These and other aspects of the design of no-take zones are discussed in Chapter 5 of this report.

4.7 How Long Does It Take For Ecosystem Benefits To Occur?

Little information is available on the period of time required for various ecosystem benefits to occur, and different ecosystem benefits (e.g., increasing biodiversity vs. specific ecological processes that structure ecosystems) may take different amounts of time.

Trophic interactions that affect ecosystem structure and function may take a considerably longer time to develop than direct effects of no-take zones. In an analysis of multiple tropical and temperate datasets, the direct effects of increased density or biomass of target species occurred within a little over five years, but indirect effects through cascading trophic interactions occurred over a little more than 13 years (Babcock et al. 2010b). The stability of these indirect effects, once they were observed, exceeded nine years, whereas stability of the changes to target species was only 6.2 years (Babcock et al. 2010b). In Kenya, species richness in no-take zones recovered to maximum levels within ten years of protection, with some taxonomic groups recovering more rapidly than others and some rapidly increasing ones showing a decline after a period of time, as other competitive or predatory taxa increased (McClanahan et al. 2007).

Alteration of benthic habitats due to cascading trophic interactions within no-take zones in New Zealand was still present after two to three decades (Parsons et al. 2004, Leleu et al. 2012). Similarly, in the Philippines, there was a nine-fold increase in density and 15-fold increase in biomass for herbivorous fishes on average across 15 no-take zones, which resulted in a 13-fold decrease in macroalgal coverage after 11 years of protection (Stockwell et al. 2009). While these changes occurred rapidly over the first five years of protection, in older no-take zones, macroalgal coverage was 25 times lower on average than in fished sites (Stockwell et al. 2009). Similarly, coral reef resilience to coral cover declines takes time to become established in MPAs. In a global analysis of coral cover surveys in MPAs, Selig and Bruno (2010) found that coral cover continued to decrease in protected areas during the first four (Indo-Pacific) to 15 (Caribbean) years on average after MPA establishment, but after that time, coral cover increased.

4.8 Spatial Extent of Ecosystem Benefits

The area over which changes in coral cover and other ecosystem characteristics may occur can vary depending on characteristics of the system. For example, in a Kenyan reef system, urchin grazing was inversely related to the density gradient in fish and fish grazing gradient due to spillover across a no-take zone boundary (McClanahan and Mangi 2000). In the Mediterranean, however, a different spatial pattern exists in fish, urchin, and habitat interactions (Guidetti 2007a). In this case, the increased density of predatory fish within a no-take zone resulted in a spillover density gradient that extended less than 1km from the no-take zone. Similar to other examples discussed previously, urchins showed low density in the reserve due to trophic interactions, but their increasing density gradient outside the reserve extended more than 2m, as did the extent of urchin barrens (Guidetti 2007a). The difference in measured spillover of fish and the spillover of trophic effects on urchins and habitat was consistent with the foraging migrations of fish from the reserve to the surrounding areas.

4.9 Conclusions

No-take zones can affect non-target species in several ways. By reducing bycatch within their boundaries, no-take zones can provide direct protection for non-target species. This,

coupled with increases in target species that may be rare elsewhere, can lead to an increase in species diversity within no-take zones. The increase in populations of target and bycatch species within no-take zones can also have indirect effects that preserve the structure and function of marine ecosystems. Increases in target species abundance can often result in decreases in populations of non-target species that are prey for or compete with target species. These changes may ripple or cascade via trophic interactions throughout the ecosystem. In numerous examples, the increase in target predatory species results in decreases in grazing species, which are often their prey. The reduction in grazers, in turn, affects benthic community structure.

These cascading effects within no-take zones can produce ecosystem benefits by allowing natural processes (e.g., natural grazing or recruitment rates) responsible for maintaining resistance or resiliency to various natural and human threats and stresses to influence ecosystems. As such, no-take zones may be one of the only tools at our disposal to alleviate the effects of climate change on coral reefs and other marine ecosystems. It should be noted, however, that no-take zones alone may not be enough to protect ecosystems, and some threats may not be preventable with no-take zones. For example, there are mixed results with respect to the role that no-take zones may play in reducing the impacts of invasive species such as lionfish.

5. Social and Economic Benefits of No-take Zones

The benefits of no-take zones that have been reviewed thus far in this report have focused on biological or ecological benefits to fish and invertebrate populations, their ability to support fisheries, and their ability to affect ecosystem characteristics. But what about people? How can no-take zones benefit local communities? While the importance of the benefits that no-take zones provide to key species and ecosystems is widely recognized, people may be more concerned with how no-take zones provide direct benefits to them, their families and their community. This section examines the economic and societal aspects of benefits that no-take zones provide.

5.1 Economic Benefits to Fisheries

Perhaps the most obvious manner in which no-take zones may benefit local communities is through supporting stocks of target fishery species. The potential of the spillover effect or recruitment effect for enhancing fisheries was discussed earlier, and it has been demonstrated that there is ecological evidence for these effects of no-take zones. Here we will examine how no-take zones affect fisheries from an economic perspective.

As discussed in previous chapters, no-take zones can produce increased spawning stock biomass within their boundaries. At a most basic level of fishery management, this can help achieve some management targets. In Belize, this is particularly important for the conch fishery. According to the Department of Fisheries, abundance of conch in no-take zones has been high enough to meet the overall national target set for fulfilling CITES non-detriment finding requirements, and this has enabled Belize's conch exports to continue without CITES' proscription or other intervention. If Belize's conch management were deemed by CITES (through the CITES Animals and Standing Committees) not to meet the requirements of the treaty, exports could be suspended by CITES, and this would limit the fishery to the demands of the limited domestic market, with obvious economic consequences (Acosta 2006, Smith et al. 2008).

Hilborn et al. (2004) summarize how no-take zones may benefit fisheries. The authors argue that for no-take zones to benefit fisheries, they must result in increases in yields that are sustainable and outweigh the losses incurred by fishers from closing that area to fishing. For this to happen, no-take zones must increase yields in fished areas through spillover and recruitment effects. These conditions may depend on a number of characteristics of the life history of target species and of the surrounding fishery. For example, sedentary species that may need to achieve thresholds in abundance for reproductive success (e.g., queen conch) may be best protected in no-take zones where abundances exceed these thresholds. Similarly, changes in fishery yields due to no-take zones may differ between gonochoristic species and protogynous hermaphrodites (species

that change sex from female to male), with fisheries for sex-changing species receiving less benefit from no-take zones due to reduced fertilization success (Chan et al. 2012).

Smith et al. (2010) use economic modeling to show that there are always short-term costs to fishers from creating no-take zones due to a loss in the availability of fishery resources when a no-take zone is created. Over time, however, long-term benefits to fishers can be achieved, but these benefits may depend on the condition of the fishery and value of the no-take zone area to populations of target species (Smith et al. 2010). For example, when target populations exhibit spatial heterogeneity, whereby some locations serve as source populations that export individuals and others serve as sinks that rely on outside sources of individuals, long-run benefits will accrue from protecting source populations in no-take zones. In situations where target populations are independent, however, no-take zones in areas of high ecological value may result in losses of profitability since few benefits from larval replenishment or spillover will accrue to fishers (Smith et al. 2010).

Numerous models examine the change in fishery landings under different no-take zone scenarios. In a simulation model where different-sized no-take zones were examined and different assumptions made about fisher response (e.g., fishing effort after the creation of the no-take zone is uniformly distributed or distributed freely in response to resources), there was an immediate decline in landings following the creation of the no-take zone under all scenarios (Silvert and Moustakas 2011). Under each scenario, however, landings increased to pre-no-take zone levels and exceeded them over a period of 4.5-8.6 years (Silvert and Moustakas 2011). Another bio-economic model of a MPA that includes an open-access area, a limited access area, and a no-take zone examined fishery yields under various scenarios and found that if the fishery was at maximum sustainable yield, the no-take zone reduced yields, but when fishing levels were higher, the no-take zone increased yields in the fishery, with no-take zones sizes of 30-40% of the area being most appropriate to prevent stock collapse (Merino et al. 2009)

White et al. (2008) argue that, while examining how fishery yields may be increased with no-take zones is beneficial, the real test of the economic performance is how fisheries profits respond to no-take zones. Several studies have incorporated fishery profits in evaluations of no-take zones (Sanchirico et al. 2006, White et al. 2008). Modeling by Sanchirico et al. (2006) indicates that profitability of the fishery depends on where no-take zones are located relative to the spatial heterogeneity of target species' populations. These authors stress that no-take zones will improve profitability of the fishery when the value derived from the export of target species from the no-take zone exceeds the value of fishing in the area occupied by the no-take zone. This is more likely to occur when the closed area is a net exporter (source) of biomass and has higher costs of fishing than other areas, and for populations with dispersal that is density-independent (Sanchirico et al. 2006). This model also produced the counter-intuitive result of demonstrating how closing areas of low biological productivity can be more profitable than leaving them open to fishing. In this case, closing the area to fishing comes at little cost to the fishery, but the recovery of fished stocks in the area may export biomass to fished areas to increase profits there.

Bioeconomic models of profitability by White et al. (2008) indicated that even when no-take zones are not optimally designed, they can generate fishery profits that are approximately equal to or greater than those attainable under optimal conventional fisheries management. Other findings of these studies are discussed in the following chapter, in which various aspects of no-take zone design are considered in relation to the benefits that they produce.

5.2 Other Benefits to Fishery Management

In addition to the biological and economic benefits to fisheries management that no-take zones may generate, they may provide benefits to management. For example, many fisheries biologists and economists recognize that traditional fisheries management is vulnerable to uncertainty (e.g., Ludwig et al. 1993). This uncertainty arises from a variety of sources, including errors in stock estimates, an incomplete understanding of the factors that affect populations of target species, and the influence of various factors that are unpredictable in fisheries models. To address this uncertainty, managers are encouraged to address risks by taking a precautionary approach (Hilborn and Peterman 1995). Several authors recognize that no-take zones may also buffer against uncertainty arising in traditional fishery management from these and other factors, including changes in ecological conditions (e.g., Guénette et al. 1998, Lauck et al. 1998, Hilborn et al. 2004).

It has also been suggested that fisheries management may be simplified and enjoy higher levels of compliance with the establishment of no-take zones (e.g., Sobel and Dahlgren 2004). While it may make intuitive sense that the rules and regulations of no-take zones may be simplified and easier for managers to enforce, there is little evidence for this in published literature. Read et al. (2011) provide some evidence for high rates of compliance within no-take zones and other MPAs in Australia that meet several criteria. These criteria are discussed in greater detail in Chapter 6 of this report. Finally, it is important to note that even if no-take zones make enforcement and compliance easier for managers, it does not lessen the need for compliance with and enforcement of all fishery management measures outside of no-take zones.

5.3 Benefits to Tourism

In addition to enhancing fisheries, no-take zones may also provide local communities with non-extractive economic benefits through tourism and other activities. This is particularly important for a country like Belize, where nature-based tourism has been shown to benefit local economies and generate local support for conservation (e.g., Lindberg et al. 1996).

Tourism is an important component of Belize's marine reserves, providing economic opportunities for local communities, recreational and educational opportunities for local and foreign visitors, and revenues for protected area management (Table 5). The role of tourism has been found to vary considerably among the country's marine reserves in terms of the number of visitors and the activities that visitors conducted. In some marine reserves, visitation has remained constant over time with little annual variability (e.g.,

Bacalar Chico Marine Reserve), but at others, there have been dramatic increases in visitation. In Gladden Spit and Silk Cayes Marine Reserve, for example, visitation increased by over 50% from 2010 to 2012, while the breakdown of visitor activities remained constant (Cawich and Guerrero 2012). Within Hol Chan Marine Reserve, Belize's most visited MPA, visitation by tourists based in San Pedro increased by 21% and those based in Caye Caulker Marine Reserve increased by 11% from 2011 to 2012 (HCMR 2012). The origin of visitors also varied considerably between marine reserves. At Caye Caulker, for example, the majority (68%) of visitors were based locally in Caye Caulker, but an additional 14% came from Belize City, 8% from cruise ships, and 5% from San Pedro (Arnold 2012). At nearby Hol Chan Marine Reserve, over 75% were based in San Pedro, with most of the remainder coming from Caye Caulker (HCMR 2012). In contrast, at more remote Glover's Reef Marine Reserve, visitors came from a number of different areas in Belize, including Placencia (30%), Dangriga (28%) Hopkins Village (22%) and Sittee River (20%), thereby distributing the economic benefits of tourism to all of these areas (Chicas and Williams 2012).

The economic benefits of no-take zones in enhancing tourism can rival or exceed those of fisheries under some circumstances. When tourism is incorporated into bioeconomic models, tourism revenues may exceed fishing revenues when no-take zones are large or at very low and very high levels of fishing outside the no-take zone (Merino et al. 2009). When data from a Mediterranean MPA with a no-take zone were used in the model, revenues from tourism greatly exceeded those from fishing in surrounding areas (Merino et al. 2009).

The value to tourism of no-take zones and other MPAs derives from the improved quality and quantity of fish and benthic communities (Wielgus et al. 2003). In coral reef systems, the increase in abundance and size of fish and also trophic cascades that improve coral health often support high levels of dive tourism. Surveys of diving within tropical MPAs around the world show that there is a strong preference by divers for reefs with high coral cover and diversity, as well as high fish abundances and diversity (Wielgus et al. 2010). An economic valuation of the Bonaire Marine Park indicated that the park brought in USD4.8 million each year in scuba diving revenues (Dixon et al. 2000). Elsewhere in the Caribbean, Rudd and Tupper (2002) found diver preferences for sites with greater size and abundance of Nassau grouper. Similarly, Sala et al. (2001) found the long-term revenues generated from not fishing Nassau grouper spawning aggregations and developing dive-based tourism industry around them would be more than 20 times greater than the economic value of fishing the aggregations. Other species, such as sharks and manta rays, also support valuable dive tourism, with a value of USD140 million annually for manta rays in the 23 countries supporting manta ray watching operations (O'Malley et al. 2013). Shark ecotourism has been valued at more than USD314 million annually, which is approximately half the value of annual shark fishery landings; although this latter number has been declining, while shark-watching has been increasing (Cisneros-Montemayor et al. 2013). Much of this activity is in MPAs, including no-take zones.

A challenge to economists is assigning values to ecosystem goods and services that are not part of a market economy. For example, how can a no-take zone add value to a tourist's

experience? There are several methods that may be used to assess the value of goods and services that are not traded in a market, and there has been a burgeoning scientific and conservation literature discussing how to best operationalize the definition, measurement, policy, and economic uses of ecosystem services (Costanza and Farber 2002 and references therein). Details of these methods for valuing ecosystem goods and services are beyond the scope of this review, but the results of several of these studies are relevant to the discussion of the value of no-take zones to people.

Analysis of non-market recreational value of a no-take zone in England indicated that designation of the no-take zone increased consumer surplus (Chae et al. 2012). In several coral reef systems with MPAs, this consumer surplus has been calculated to range from a little over USD2 per person for all tourists (Mathieu et al. 2003, Ransom and Mangi 2010) to as much as USD3,233 per person per dive trip for scuba divers (Barbier et al. 2011 and references therein). A contingent valuation method was used to assess the willingness to pay for marine parks in Jamaica and Curaçao and found that both tourists and local residents were willing to pay USD25 in support of coral reef diversity within the marine parks (Spash 2000).

It should be noted, however, that concentrating tourism within specific areas such as no-take zones may have negative ecological impacts. In protected areas within Australia's Great Barrier Reef Marine Park, for example, areas where tourism was concentrated had a greater prevalence of coral disease (Lamb and Willis 2011). Similarly, in a European no-take zone where divers were allowed, red coral growth rates were lower than those in a no-take zone where divers were not allowed (Linares et al. 2012). In this case, the difference was attributed to both increased poaching by divers and inadvertent contact between divers and corals, which resulted in damage or reduced growth rate. Similarly, increased boat traffic within a European MPA that surrounded a population of endangered seabirds reduced seabird foraging (Velando and Munilla 2011). These results suggest that a balance must be struck for no-take zones to achieve conservation goals as well as goals of providing non-extractive economic benefits for local communities.

5.4 Other Economic Benefits

In Belize, the ecosystem services provided by coral reefs and mangroves make large contributions to the economy. A recent report found coral reefs and mangroves to contribute USD14-16 million annually to fisheries and USD150-196 million to tourism; moreover, both these figures were far outweighed by the economic contribution that these habitats provide in terms of shoreline protection, with damage avoided due to these habitats valued at USD231-347 million annually (Cooper et al. 2009). Within Belize's MPA system, the economic value of ecosystem services is particularly high. For example, fisheries revenues from inside Glover's Reef Marine Reserve were estimated at USD0.7-1.1 million for 2007, as compared with USD3.8-5.6 million from reef-related tourism (Cooper et al. 2009). Both these economic benefits hinge on the health of the ecosystems and stocks within the reserve, which are largely dependent on the effectiveness of the reserve's no-take zones.

Table 5. Summary of recent visitation to selected Marine Reserves in Belize (based on data availability), including a breakdown of the number of visits by activity.

Marine Reserve	Year	Reference	Total visitors	Snorkel	Divers	Whale shark viewers	Sport-fishers	Guides	Comm. fishers	Belizeans	Kayak	Cata-marans	Other
Bacalar Chico Marine Reserve	2012	Novelo 2012	3024	671	82	0	904	838	170	199	0	0	160
Caye Caulker Marine Reserve	2012	Arnold et al. 2012	17563	12647	1633	0	0	3283	0	0	0	0	0
Gladden Spit and Silk Cayes Marine Reserve	2012	Cawich and Guerrero 2012	11384	8880	2391	0	0	0	0	0	0	0	0
Glover's Reef Marine Reserve	2012	Chicas and Williams 2012	3854	1245	1306	0	44	189	0	229	572	110	159
Hol Chan Marine Reserve	2012	HCMR 2012	63670	53799	5414	0	0	0	0	4457	0	0	0
Laughing Bird Caye National Park	2010	SEA 2010	7508	3153	1427	2478	75	0	0	0	0	0	0
Sapodilla Cayes Marine Reserve	2012	Chub 2012	4015	2438	164	0	198	867	221	26	0	0	101
Southwater Caye Marine Reserve	2012	Carballo 2012	7685	5894	1520	0	90	0	0	0	181	0	0

5.5 Reducing User Conflicts

Reducing conflicts among different user groups is frequently cited as an objective of MPAs, including no-take zones. In coral reef systems, there may be conflicts between overlapping but incompatible resource uses, such as those between dive operators whose business is influenced by reef condition and the abundance, size or diversity of fish (see examples in previous section), and fishers whose extractive activities may have a negative influence on these factors. In this case, setting up zones where certain uses are allowed or prohibited may be a way to reduce conflicts. Such user conflicts may be complex, however, and how zones are set up to effectively deal with these issues will depend on biological and socioeconomic factors.

There is a large body of literature on environmental dispute resolution that is beyond the scope of this review; however, several examples of MPAs' being deployed in conflict resolution are presented here. Before examining specific examples, Capitini et al. (2004) provide a useful framework for assessing the nature of user conflicts, whereby user conflicts may be grouped into three categories. The first is interest-based or resource-based conflicts, which are defined as those involving differences over the allotment, use or distribution of interests or resources. In this case, the interests or resources are usually tangible or observable things. The second classification is one where conflicts arise over identity-based or value-based differences. In this case, conflicts arise due to differences in personal values, long-standing concerns, beliefs or psychology. Finally, they outline a category of mixed-mode disputes, which include both interest-based and identity-based components in some form. Strategies for addressing these user conflicts will vary, with interest-based conflicts usually the easiest to address through open communication, and identity-based conflicts more difficult to bring to resolution.

Capitini et al. (2004) use a case study of user conflict in Hawaii as an example. On the island of Hawai'i, there has been a conflict between fish collectors who remove ornamental fish from the reef for sale in the aquarium trade and recreational dive tour operators. In response, Hawai'i's Division of Aquatic Resources established nine MPAs, encompassing over 35% of the West Hawai'i coastline, where fish collection was prohibited, in order to reduce impacts to the resource and resolve user conflicts (Capitini et al. 2004). While this measure is believed to have reduced conflicts and harassment among user groups, some community members feel that disputes were not fully resolved due to lack of participation by some users in the designation process. This was exacerbated by top-down influence by the state Attorney General's office, which removed some enforcement provisions, giving some stakeholders the impression that the no-take zones were "paper parks" and furthering conflicts. The Hawai'i case study also suggests that the role of science in the designation process was successful in helping to create the no-take zones but may have failed to resolve issues due to the view among some that it lacked legitimacy. This example shows the complexity in resolving user group conflicts, particularly when there is a mix of interest-based and identity-based disputes involved in the conflict (Capitini et al. 2004).

The Jervis Bay Marine Park in New South Wales, Australia provides another example of zoning to reduce user conflicts between fishers and divers (Lynch et al. 2004). In this case, many of the perceived conflicts were resolved by mapping use areas to address the interest-based issue of identifying where real (vs. perceived) conflicts resulted from the overlap in incompatible uses. Where actual conflicts in use were identified, zoning (sanctuary zone and no-anchoring zoning) was implemented to reduce conflicts, provide protection to the endangered gray nurse shark (*Carcharias taurus*), and reduce other environmental impacts (Lynch et al. 2004). In this case, data on use of the park was critical in guiding management decisions with regard to this "politically volatile" situation.

The importance of recognizing the complexity of human interactions and environmental protection that drive zoning cannot be overstated. In addition to the direct impacts of addressing user conflicts, caution must be also exercised when establishing no-take zones to reduce user conflicts, as indirect effects of no-take zones may favor one user group over another. Indirect effects may result through trophic cascades that change the distribution of resources that different user groups rely on in a way that may not be equitable. For example, Boncoeur et al. (2002) model a system in which a no-take zone is created where there are two user groups, fishers and marine mammal watching tour operators, and two main stocks that have a trophic interaction, seals (predator) that are not exploited and fish (prey), which are exploited. Results of bioeconomic modeling show that the dynamics between these two stocks limit the benefits of no-take zones for fishers but create ecotourism opportunities. These model results may be applicable to other systems where improvements to resources of value to tourists have a negative interaction with fishery resources.

5.6 Research and Education

Understanding how natural ecosystems function and how various human impacts affect this function is essential for the management of complex systems. Because few sites exist where marine habitats and resources remain in a pristine state, free from human impacts, our understanding of natural processes is limited. Some of the most significant advances in our understanding of ecosystem function over the past 25 years, however, have been from protected areas, particularly no-take zones. Declines in marine fisheries, habitats and ecosystems, particularly coral reef systems over the past several decades, have led to what scientists refer to as a "shifting baseline syndrome" (Pauly 1995), whereby the baseline or point of reference for assessing populations, ecological communities, or ecosystem properties for each generation of scientist is set early in their career, so declines leading up to that point are often overlooked, and the baseline for assessing change gets adjusted downward over time. Given this tendency, having areas where populations, habitats, ecological communities, and ecosystem characteristics are subject to minimal human impact, such as no-take zones, are invaluable tools for calibrating baselines. While these areas are by no means free of human impacts, since most of them still allow non-extractive human uses and all are subject to human influences from outside their boundaries, they are often the only areas where populations, habitats, communities and ecosystem structure come closest to what may be considered pristine. While few studies explicitly address this

benefit of no-take zones, the vast body of literature on the effect of no-take zones on species, habitats, communities and ecosystems, provides evidence for this important benefit.

5.7 Conclusions

No-take zones have been shown to produce numerous social and economic benefits for local communities. No-take zones may not only support sustainable fish yields similar to or better than those resulting from other forms of management, but they may increase local yields and profits to fishers. No-take zones can also generate or enhance alternative livelihoods by increasing tourism revenues. Increases in populations of target species and improvements to ecosystem health within no-take zones can increase their value to snorkelers and divers and increase the number of visitors and their willingness to pay to access these resources. This is particularly important to countries such as Belize where nature-based tourism plays an important role in the economy. There may be trade-offs, however, between increasing tourism revenues and effectively conserving resources within no-take zones, so managing tourism at sustainable levels may be necessary.

Other social benefits of no-take zones include potentially reducing conflicts between incompatible uses of resources, typically tourism interests and fishing interests. Managing these conflicts, however, must be done in a careful and transparent way to address interest-based issues and provide equitable compromise on access to resources. Other social benefits, including improved knowledge and understanding of marine ecosystems, are also generated by no-take zones.

6. Factors Affecting No-take Zone Benefits

All of the benefits derived from no-take zones that have been discussed in this report depend on various characteristics of no-take zones, the species, habitats and ecosystems that they are intended to conserve, uses of the no-take zone and surrounding areas, the overall management context in which they are created, as well as the designation process. No two no-take zones are alike with respect to these factors: each one brings its unique set of circumstances that managers need to understand in order to design and implement a no-take zone that achieves its intended goals and objectives.

In this section, some of the most important aspects of no-take zones that affect the benefits that they provide are discussed. This is by no means a complete discussion of all factors that influence no-take zone success but should provide important insights into factors that should be considered and examples that may be followed as Belize expands its network of no-take zones.

6.1 No-take Zone Design

Some of the richest literature on no-take zones focuses on how they should be designed. Where should they be located? How big should individual no-take zones be? How many should there be, and how far apart should they be spaced? While these may seem like simple questions, the answers are often complex and depend on the objectives of the no-take zones, and characteristics of uses of marine resources, habitats, and species being protected. The literature over the past decade includes many significant advances in identifying optimal no-take zone design characteristics to address specific management needs or specific suites of circumstances related to the habitats, species or uses of an area. Site selection algorithms, such as MARXAN, allow managers to optimize reserve design for a specific area, such as no-take zones that are expected to provide the greatest likelihood of achieving goals at the least size or cost. While these advances in our ability to design no-take zones are significant, many of them (e.g., Gaines et al. 2010) relate back to a set of scientific design principles put forth by Dr. Bill Ballantine in the 1990's (e.g., Ballantine 1997). These design principles include:

- **Representation** – Areas should be selected to include representative ecosystems, habitats and other factors that are present in the overall area where no-take zones are being created.
- **Replication** – More than one example of each type of area should be protected as insurance against potential negative impacts to a specific location (e.g., storm damage), and to spread benefits or protection to a wider population.
- **Network Design** – Because no no-take zone is isolated from surrounding areas that may have depleted resources, no-take zones that replenish each other may have more rapid rates of recovery and are more likely to be self-sustaining.

- **Network must be large enough to be self-sustaining** – Enough area must be protected within the no-take zone network to ensure that the network is self-sustaining in event of collapses outside of no-take zones.
- **System efficiency depends on supportive interactions** – No-take zone networks should not be designed to maximize any specific benefits but to optimize overall benefits.

Since these principles were put forward, a large body of literature has been produced that addresses aspects of no-take zone design and its influence on the benefits that no-take zones provide. The literature includes theoretical and analytical models, as well as empirical studies and metadata analyses from a large number of no-take zones. Factors considered include the size, number and spacing of no-take zones, and placement of no-take zones within a seascape. While much of the discussion that follows makes generalizations about these factors, it is important to keep in mind that all of these factors are likely to interact with the intended goals and objectives of the no-take zone or zones, as well as characteristics of the species that they protect and uses inside and outside of the zones.

6.1.1 No-take Zone Size

One of the most basic but most important questions that is asked when planning no-take zones is how big should they be. There is conflicting information in the literature on the size necessary to provide benefits. For example, one meta-analysis from many no-take zones around the world found that proportional differences in the increase in density or biomass within no-take zones were independent of the size of the no-take zone (Halpern 2003); in other words, a small reserve was equally likely to double density or biomass as a large reserve. Having said that, however, the author then points out that doubling of biomass in a small reserve may not have the same impact as doubling biomass over a larger area, and that larger areas may contain a greater diversity of habitats important to species throughout different life stages or for protecting different species (Halpern 2003).

Similarly, Micheli et al. (2004) found that the duration of protection, species trophic level and exploitation level explained only 3% of the variability in the magnitude of individual species' responses to protection, but no-take zone size, body size of species (maximum length) and adult mobility exhibited no significant no-take zone performance. In contrast to this, an empirical study evaluated diversity of fishes, invertebrate and algal species, and the density of commercially exploited species in four Tasmanian (Australia) no-take zones over a six-year period and found increases in diversity and densities for the largest no-take zone but not the three smaller ones, with the exception of an increase in density of large fish in the largest of the smaller no-take zones (Edgar and Barrett 1999).

Most other papers that model reserve benefits as a function of no-take zone size find that if a reserve is too small, migration of individuals outside the no-take zone will prevent them from achieving larger sizes, greater abundance, and/or increasing reproductive output. On the other hand, if a no-take zone is very large, it may conserve biomass within its

boundaries and may enhance larval output, but few individuals may leave the reserve to be captured in fisheries as spillover. Furthermore, if the no-take zone is very large and larval dispersal is low, it may not replenish surrounding areas. For this reason, optimal reserve size is likely to depend on the goals of the reserve (Halpern and Warner 2003).

The relationship between reserve size and benefits to conservation and fisheries is presented in Figure 4. These factors suggest that the relationship between reserve size and benefits of reserves for fisheries is non-linear, with intermediate-sized no-take zones providing the greatest increase in fishery yields. On the other hand, when conservation is the primary goal, larger no-take zones may be better suited to meet the goal. These trade-offs may be resolved, however, within a network of no-take zones (Gaines et al. 2010), which is discussed in the following section.
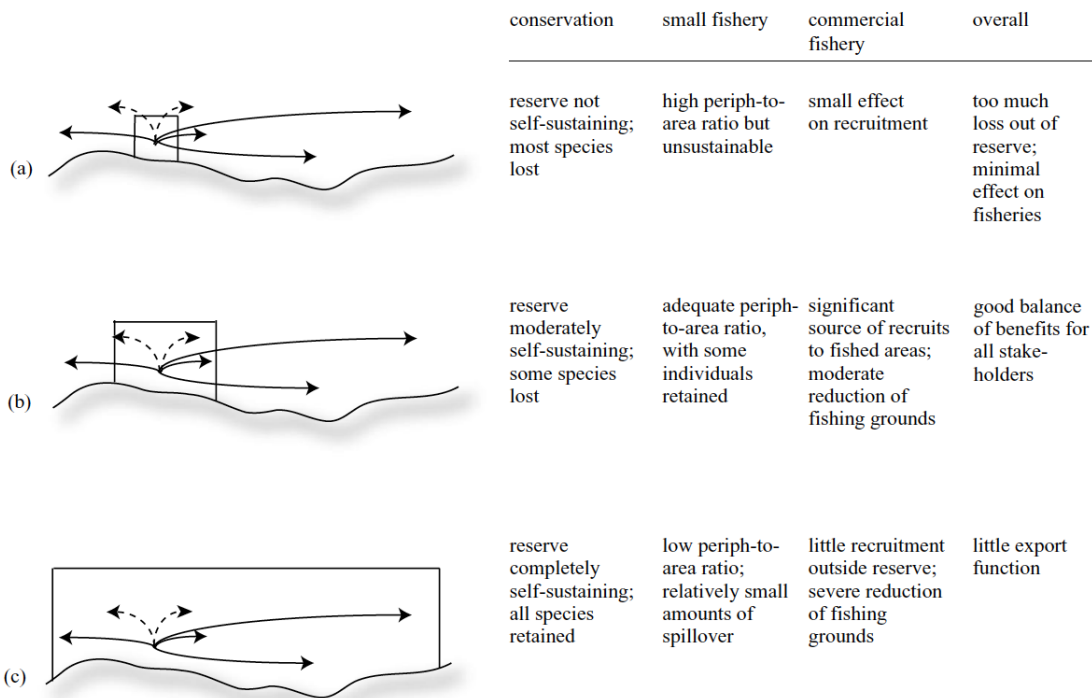
	conservation	small fishery	commercial fishery	overall
(a)	reserve not self-sustaining; most species lost	high periph-to-area ratio but unsustainable	small effect on recruitment	too much loss out of reserve; minimal effect on fisheries
(b)	reserve moderately self-sustaining; some species lost	adequate periph-to-area ratio, with some individuals retained	significant source of recruits to fished areas; moderate reduction of fishing grounds	good balance of benefits for all stake-holders
(c)	reserve completely self-sustaining; all species retained	low periph-to-area ratio; relatively small amounts of spillover	little recruitment outside reserve; severe reduction of fishing grounds	little export function

Figure 3. Diagram outline basic relationship between reserve size benefits that it may produce (From Halpern and Warner 2003).

6.1.2 No-take Zone Network Spacing

As suggested by the conceptual model shown in Fig. 3, the role of larval dispersal plays a major role in determining the size and spacing of no-take zones. Gaines et al. (2003) use dispersal models to show that multiple small no-take zones of the same total size as a single large no-take zone can be more effective if larval dispersal is high. Similarly, Shanks et al. (2003) examined larval dispersal for 32 taxa and found a correlation between larval dispersal rates (meters to thousands of kilometers) and time spent in the plankton (minutes to months), and concluded that no-take zones should be designed to be large

enough to contain short-distance-dispersing larvae and spaced far apart enough for long-distance-dispersing larvae released in one no-take zone to be able to settle in another.

A model developed for Caribbean spiny lobster (*Panulirus argus*) populations in the central Bahamas provides an example of a situation where multiple small no-take zones may not be the best option. The model incorporates real site characteristics, a model of ocean circulation, and characteristics of lobster populations in the area, including a long planktonic larval duration, to examine how yield, population growth rate, and larval production for the region respond with one large reserve as opposed to several smaller ones (Stockhausen and Lipcius 2001). While in this model a single large reserve was shown to perform better, it should be noted that both the single large reserve model and the several small reserve model performed better than models of a 20% reduction in fishing throughout the region (Stockhausen and Lipcius 2001). The performance of individual reserves in this model was likely to have been dependent on their location relative to hydrodynamic factors and metapopulation dynamics of lobsters in this system (Stockhausen et al. 2000).

Gaines et al. (2010) suggest that within a network of no-take zones, both conservation and fisheries enhancement benefits may be achieved through the implementation of moderately sized no-take zones, several to tens of kilometers along a shelf edge and out to suitable depths for the species being protected. These authors also indicate that if these no-take zones are spaced tens to about 100 kilometers apart in a network, they can also provide fisheries benefits for most coastal marine species.

6.1.3 No-take Zone Location

A number of studies have proposed various ecological and socioeconomic criteria for no-take zone site selection (e.g., Botsford et al. 2003, Roberts et al. 2003). The appropriate set of criteria may depend on the benefits that the no-take zone is intended to provide. Various models highlight the fact that not all areas are equally suited to achieve specific objectives (e.g., Stockhausen et al. 2000, Sanchirico et al. 2006). These researchers argue that because no-take zones created in poor locations may do little to achieve specific goals, they may actually do more harm than good since they provide a "false sense of protection". To avoid this potential pitfall, understanding habitat requirements of species of interest, ocean currents, and metapopulation dynamics of key species is necessary (Lipcius et al. 1997). In the latter case, populations of a species are connected by larval transport, with some "source" areas having a net export of larvae responsible for supporting populations elsewhere, and some "sink" areas relying on the influx of larvae for persistence of the population there. Under this scenario, protecting sink populations may do little to achieve goals, but protecting source populations may have widespread benefits outside their boundaries. Because information on metapopulation dynamics may not be known for key species in many areas, and incorporating details of population dynamics of multiple species into no-take zone location may not be feasible, Gaines et al. (2010) provide some guidelines for site selection to achieve specific objectives (Table 6).

Patch attribute	Place in reserve, given objective?	
	Conservation	Fishery
Persistent	Y	Y
High population growth rate	Y	N
High carrying capacity	Y	Y
Larval source	Y	Y
Already heavily/overexploited	Y	Y
Costly to harvest	N	
—Fishery goal: minimize costs		Y
—Fishery goal: maximize profits		N
Has distinct habitat edge	Y	N

Table 6. Attributes of sites or local populations and decision to protect them within a no-take zone given a conservation or fishery objective (Gaines et al. 2010).

6.1.4 Seascape Features

As indicated in the last line of Fig. 4 and the preceding discussion on the spillover effect, habitat configurations or how no-take zones are situated within a seascape is also an important aspect of no-take zone design. The relationship of various habitats in a seascape within no-take zones and their surrounding area can affect the distribution and abundance of species (Grober-Dunsmore et al. 2007, Nagelkerken et al. 2012). The relationship of no-take zone boundaries to habitat features can influence the retention of individuals within the no-take zone or promote their movement out of the no-take zone. For example, no-take zone boundaries that encompass breaks in habitat are likely to have low emigration rates compared to no-take zone boundaries that are more "permeable," as they bisect continuous habitat features like reefs. For example, the study of Eristhee and Oxenford (2001) on the spillover of Bermuda chub from a Caribbean no-take zone indicates that when no-take zone boundaries crossed a reef, spillover was higher than when the entire reef area was within the no-take zone. Similarly, Tewfik and Béné (2003) found shallow sandy areas served as barriers to conch movement and limited spillover from a protected area in the Turks and Caicos Islands.

The permeability of reserve boundaries and the shape of the reserve with respect to its perimeter-to-area ratio can influence the amount of emigration from the no-take zone and recovery of species within the no-take zone. Bartholomew et al. (2007) found some support for this in no-take zones within the Florida Keys National Marine Sanctuary, where they monitored populations of various exploited species from 1994 (three years before protection in no-take zones) to 2001. Results of this study found a significant relationship between the recovery rates for all exploitable fishes combined and the ratio of the amount of reserve boundary that intersects reef area to the amount of reef habitat within the no-take zone. This indicates that no-take zones that have boundaries that correspond to habitat breaks may have a higher rate of recovery of exploited species than those with permeable boundaries; however, this correlation was relatively weak, explaining little of

the variability in recovery rates, so other factors are likely to be more important in influencing recovery rates (Bartholomew et al. 2007).

6.2 Compliance

It is clear from the discussion in the previous section that no-take zone design can affect some benefits, particularly when no-take zones are intended to meet specific goals and objectives or provide specific benefits. There is evidence, however, that marine no-take zones provide some benefits, and may provide a wide range of benefits, regardless of their size or shape (Halpern 2003). Furthermore, since most no-take zones provide some benefits even when created opportunistically rather than in an attempt to optimize specific benefits, some researchers argue that aspects of no-take zone design may be less important than ensuring that no-take zones effectively protect resources within their boundaries – that regulations of the zone prohibit extraction of resources and that there is compliance with these regulations (Roberts 2000).

In a meta-analysis of coral reef protected areas of the Caribbean, Philippines and Western Indian Ocean, Pollnac et al. (2010) examined the relative importance of no-take zone design and socioeconomic factors in no-take zone performance for target reef fish. Results of this analysis differed among the regions, with the Caribbean showing an inverse relationship between human population density and fish biomass within no-take zones (expressed as the ratio of biomass within the no-take zone to biomass outside the no-take zone) and a positive correlation between compliance and fish biomass. Compliance in this analysis included indicators such as no-take zone features (e.g., marker buoys, management plans, signage, ecological monitoring, training and a community consultation process). This study also found that in other regions the relationship between both human socioeconomic variables and fish biomass in no-take zones varied, but nowhere was there a significant relationship between no-take zone size and fish biomass across regions or sites within a region (although the effect of reserve size was complex, with some sites showing a strong effect and others showing no effect; Pollnac et al. 2010). Enforcement was not included in the analysis of Pollnac et al. (2010), indicating that compliance may be related to a range of contextual conditions and processes rather than strictly the level of enforcement. This analysis suggests that compliance with no-take zone regulations, rather than no-take zone design or level of enforcement, may be the most important factor in determining the benefits, particularly for the Caribbean.

Within Australia's Great Barrier Reef System, differences in fish populations between no-entry zones and no-take zones suggests that compliance in no-take zones is not complete and that poaching results in impacts to fish populations within these areas (McCook et al. 2010). In a no-take zone in the Philippines, lack of enforcement led to a lack of compliance and loss of benefits. The no-take zone at Sumilon Island in the Philippines was designated in 1974 and has a long history of being protected for 5-9 years at a time, interrupted by periods where the no-take zone was fished for up to 2.5 years (Russ and Alcala 1994, Alcala et al. 2005). Opening the no-take zone to fishing resulted in decreases in landings outside the no-take zone and decreases in predatory fish density within the no-take zone (Russ and Alcala 2004, Alcala et al. 2005). Similarly, an analysis of Italian MPAs, including those

incorporating no-take zones, showed that only three of 15 no-take zones had adequate enforcement, and the positive response of species in terms of the ratio of biomass between no-take zones and fished areas was related to enforcement, with 17 of 28 species having a significant positive response under high enforcement, 2 of 35 species showing a significant positive response under medium enforcement, and no species showing a positive response under low enforcement conditions (Guidetti et al. 2008). In this case, level of enforcement, rather than age or size, was the most important factor in determining no-take zone impacts on species.

Within Belize, available data suggest that MPAs are well-enforced and compliance is high, with a few exceptions. In 2012, for example, enforcement patrols were conducted in Bacalar Chico Marine Reserve on 96% of all days, with multiple patrols occurring on several days (Novelo 2012). Within South Water Caye Marine Reserve, the number of patrols increased 60% from 2010 (288 patrols) to 2012 (477 patrols), resulting in an increase in arrests and warnings from 3 and 12, respectively, in 2010 to 23 and 14 in 2012 (Carballo 2012). The increase in arrests and warnings from 2010 to 2011 was substantial but leveled off from 2011 to 2012. For Gladden Spit and Silk Cayes Marine Reserve, a total of 507 patrols were conducted in 2012, resulting in 18 warnings and 14 arrests and 20 charges (Cawich and Guerrero 2012). In Caye Caulker Marine Reserve, a total of 19 enforcement actions were taken in 2012, with most of them related to general fishing regulations (e.g., undersized lobster or conch, out-of-season lobster and conch, possession of parrotfish), rather than poaching within no-take zones (Arnold 2012). Similar violations unrelated to poaching in the no-take zones were reported for Sapodilla Cayes Marine Reserve (Chub 2012). These results all suggest good compliance with no-take zones.

In contrast, within Hol Chan Marine Reserve, there were two confirmed and one reported incident of poaching in 2012 (HCMR 2012). Decreases in conch abundance within no-take zones of Port Honduras Marine Reserve is believed to be due to poaching, particularly by foreign fishers encroaching from nearby Guatemala; the fact that these no-take zones are somewhat small and isolated makes possible quick incursions escaping detection by enforcement officers (Foley 2013).

Some of the best data on enforcement in Belize comes from Glover's Reef Marine Reserve, where records of the number of patrols and violations reported have been tracked annually for most years since 2004 (Eck 2012). In 2004 and 2005, 237 and 157 patrols were conducted, but this number increased to between 500 and 600 patrols per year from 2009-2012. Since 2009, the rate of violations per patrol has decreased from 0.12 to 0.05 (Eck 2012). This suggests that the increased number of patrols and other factors (e.g., increased outreach and engagement with the fishing community) have improved compliance with reserve management. Of the 22 reported offences in 2012, only four were related to poaching in no-take zones (Eck 2012). Implementation of the Managed Access program in the General Use zone of Glover's Reef Marine Reserve is also likely to have contributed to the success of enforcement, as penalties for fishers that fail to comply with management regulations within the reserve can result in suspension of fishing permits for the area.

Similar to empirical studies in the Philippines, modeling of the impacts of poaching show that poaching impacts the recruitment effect of no-take zones, resulting in negative impacts to yields in areas open to fishing, as well as the population structure and overall reproductive output of the system in general (Sethi and Hilborn 2008). The relative impact of poaching, however, depended upon specific policy decisions, and the recommendation was made to take a precautionary approach in managing for reproductive thresholds outside of the no-take zone to hedge against poaching impacts (Sethi and Hilborn 2008).

Other studies illustrate the complexity of factors influencing no-take zone benefits. In Brazil, for example, biomass of various target and non-target fish was examined over time for several MPAs of Abrolhos Bank, including both no-take zones with different levels of enforcement and multiple-use zones (Francini-Filho and Moura 2008). This study found that habitat variability within these MPAs (e.g., depth, latitude, distance offshore, coral and algae cover) accounted for a great amount in the variability in the structure of reef fish assemblages, but increased protection resulted in higher biomass of several target species in the older no-take zone and a thirty-fold increase in biomass of black grouper (*Mycteroperca bonaci*) inside both no-take zones over the course of the study. Other fish species, however, including dog snapper (*Lutjanus jocu*) and a parrotfish species had greater biomass in open-access areas. Social components also played a role, however, with decreases in fish biomass in 2003 after poaching within no-take zones increased, and a ban on parrotfish fishing was disregarded in multiple-use zones.

This last example illustrates that neither ecological criteria or socioeconomic factors alone determines the success or benefits of no-take zones, but both need to be taken into account when designating no-take zones. Roberts et al. (2003) provide a framework for evaluating suitability of sites for protection in no-take zones using 12 criteria that account for social and economic factors (Table 6). They stress the fact that few suitable sites for protection will be indispensable and many will be of similar value, so providing numerous potential sites for consideration in the socioeconomic evaluation process will help meet both ecological and socioeconomic needs.

In Kenya, compliance with management restrictions (not just no-take zones) was related to stakeholder perceptions about the benefits and costs of management actions (McClanahan et al. 2012). This study found that this was particularly the case where a disparity was perceived between the benefits of management to themselves and their communities and benefits to the government. Efforts to reduce these real or perceived disparities are likely to increase compliance rates (McClanahan et al. 2012).

Read et al. (2011) provide a comprehensive analysis of various factors that optimize voluntary compliance by examining the attitudes of recreational fishers and enforcement officers in an Australian MPA that included no-take zones. This study also examined how various aspects of no-take zones affected the number of "management actions" taken by enforcement officers. An evaluation of various manageability criteria (Table 7) indicated

Table 6. Social and economic criteria used to select the locations of Marine Protected Areas (Roberts et al. 2003).

Value	Criteria
Economic	Number of fishers dependent on the area
	Value for tourism
	Potential contribution of protection to enhancing or maintaining economic value
Social	Ease of access
	Maintenance of traditional fishing methods
	Presence of cultural artifacts/wrecks
	Heritage value
	Recreational value
	Educational value
	Aesthetic appeal
Scientific	Amount of previous scientific work undertaken
	Regularity of survey or monitoring work done
	Presence of current research projects
	Educational value
Feasibility/practicality	Social/political acceptability
	Accessibility for education/tourism
	Compatibility with existing uses
	Ease of management
	Enforceability

that zoning identification and other factors were viewed as being important for compliance by both resource users and enforcement officers (Read et al. 2011). Incorporating these criteria into the MPA planning process is expected to help to promote voluntary compliance with regulations.

6.3 Designation Process

During the zoning of the Florida Keys National Marine Sanctuary, several no-take zones were designated. Surveys of different stakeholders showed differences in attitudes about these zones and their participation in the designation process (Suman et al. 1999). Fishers felt alienated from the process, believed it was top-down with little regard to their interests, and were angry about what they perceived to be an effort to exclude them from these zones. Diver-operators were highly participatory in the process but still felt that some of their activities would be restricted in no-take zones. Environmental groups were the strongest supporters of the zones. As with the Hawai'i example, the veracity of science in this process was questioned by some stakeholders, and there was an acrimonious and polarizing debate about the benefits of no-take zones that led to changes in the planned zoning, including a change in name for no-take zones from "No-take Reserves" to "Ecological Reserves" due to concerns of some stakeholders about whether these zones would actually replenish stocks outside their boundaries. Suman et al. (1999) concluded that improvements could be made to the means by which stakeholders are informed about plans for zoning and the strategy for engaging them in the process. Had improvements been made in these processes, a greater area may have been protected in no-take zones to the benefit of the resources they were intended to protect and potentially to the benefit of all stakeholders.

6.4 Management Context

Few studies have considered the management context outside no-take zones and its effect on no-take zone benefits. The few examples of such analyses, however, provide some insights into how management outside of no-take zones effects their performance. For example, Yamazaki et al. (2012) used a bioeconomic model to evaluate how management goals outside the no-take zone influence the effectiveness of no-take zones. Their model indicated that for a wide range of scenarios, the fisheries would be better off in terms of both conservation and economic objectives if the no-take zone were established in conjunction with a target of maximizing the value of returns to fishing (i.e., profitability) rather than with a target of maximizing sustainable yields.

One form of management outside of no-take zones that is increasing in use are catch shares. Catch shares, or their spatial counterpart, territorial user rights fisheries (TURFs), are a system of fisheries management that allocates shares of the allowable catch to fishermen. These systems are designed to improve management and economic efficiency of fisheries by essentially giving fishers ownership of their share of the resource and eliminating the "race to fish" or incentives to over-exploit fishery resources. Recent studies have also shown that these programs also produce conservation benefits by (Costello et al. 2008). In Belize, such a system is being implemented as a Managed Access program that has been piloted in Port Honduras Marine Reserve and Glover's Reef Marine Reserve and is being expanded to the General Use zones of all of the MPAs in the country. Such rights-based approaches for managing fished areas can be complementary to no-take zones (Costello and Kaffine 2010). In the case where there is no coordination among TURF owners, each TURF owner (or in the case of Belize, participant in Managed Access) may experience increased profits from spillover from the no-take zone. Furthermore, fish abundances also increase when MPAs and TURFs are implemented together (Costello and Kaffine 2010).

In Belize, the Managed Access system being developed within the General Use zones of the country's marine reserves is similar to a TURF system in that it restricts access to these zones through a licensing system for "traditional fishermen" who meet criteria defined via community consultation (Foley 2012). Within General Use zones, licensed fishermen will follow guidelines of the Belize Fisheries Department for catch limits of various commercial species. Managed Access is likely to have significant impacts on landings, fisheries profits and ecological conditions within the country's MPAs, including on the benefits of no-take zones.

At Glover's Reef Marine Reserve, since the Managed Access program began issuing licenses in 2010, there has been a steady decline in the number of license renewals, from a starting number of 212 in 2010 and a total of 127 licenses for 2012 and 2013 (WCS 2013). Some of the benefits of Managed Access that have been experienced by fishers include increases in total landings of conch and finfish over the past two years, as well as an increase in catch per unit effort (WCS 2013). During the first year of the Managed Access program at Glover's Reef, there was a slight decrease in CPUE of lobster, from 1.4 lobster/ hour/fisher,

Table 7. Weighting of various "manageability criteria" by recreational fishers (RFWG) and compliance officers (COWG) (Read et al. (2011).

Weighted manageability criteria for optimizing compliance in MPAs identified by recreational fisher working group (RFWG).

First order criteria group	Weighting score		Second order criteria	Weighting score		Application
	RFWG	COWG		RFWG	COWG	
Zoning Identification	100	100	Align boundaries north and south/east west.	100	100	Zone
			Seaward boundaries to have straight lines.	100	100	Zone
			Provision of GPS plotter layer of zoning plan	100	N/A	Whole park
			Boundaries with a line of sight to terrestrial feature	100	85	Zone
			Provision of marker buoys, (where appropriate)	75	85	Zone
			Signage feasibility	50	75	Zone
			Provision of identification signage, where appropriate	50	50	Zone
			Align with contour lines	25	15	Zone
Education	100	80	Promotion and awareness of marine park	100	80	Whole park
			Provision of training of vessel plotting and GPS equipment	75	40	Whole park
Impact on Existing Use	80	20	Minimise impact on common fishing grounds	100	25	Zone/whole park
			Minimise proximity to fishing areas	100	25	Zone
			Alternative options for fishing	100	N/A	Whole park
			Minimise effort transfer to other places	80	N/A	Whole park
Legitimacy	40	30	Ensure justification of zone location and that boundaries are logical	100	80	Zone/whole park
Distance from high use areas	60	65	Maximise distance of zones away from highly populated areas	75	10	Zone
			Minimise distance from marine park office	25	80	Zone
Off park impacts	100	N/A	Minimise economic impact on towns	100	N/A	Zone/whole park
			Minimise disruption to local community	100	N/A	Zone/whole park
			Minimise impact on tourism	100	N/A	Whole park
Equity between users	60	0	Minimise conflict between com and rec. fishers, scuba and cultural use	75	15	Zone
Alternative fishing sites	70	N/A	Maximise fishing access for visitors	75	N/A	Whole park
			Provide for artificial reefs to compensate loss of fishing grounds	50	N/A	Whole park
Simple Rules	80	95	Apply simple rules and fewer number of zones adjacent to no-take zones	100	100	Zone
Buffer no-take zones	40	0	Provide for buffers around no-take zones	100	0	Zone

which had been the CPUE rate for the six previous lobster seasons, to 1.2 lobsters/hour/ fisher. In the second year, however, CPUE increased to 2.3 lobsters/hour/ fisher, the highest ever recorded in over eight seasons. The two highest CPUE rates for conch were also recorded during the first two years of Managed Access for Glover's Reef Marine Reserve (WCS 2013). It is also important to note that poaching violations within the Glover's Reef Marine Reserve decreased following implementation of Managed Access. At Port Honduras Marine Reserve, the other Managed Access pilot site, there is preliminary evidence for an increase in conch densities within the General Use zone following the implementation of Managed Access (Foley 2013).

While few studies have looked at the interaction between zones where access is restricted, as it will be throughout Belize's MPA system and no-take zones within the system, there are some examples from bioeconomic models (e.g., Merino et al. 2009) and empirical studies from the Mediterranean (Goñi et al. 2008, Harmelin-Vivien et al. 2008) where MPAs typically have no-take zones where fishing is restricted and areas where fishing is allowed but limited based on a license or permit system. While these studies show that spillover from no-take zones occurs and increases both yields and revenues outside of no-take zones to support fisheries, it is expected that the Managed Access Program in Belize will help to reduce exploitation levels within General use Zones and enhance benefits provided by no-take zones.

6.5 Balancing Costs

It is widely recognized that there will be short-term costs associated with the implementation of no-take zones, and any MPA. First, there is the cost of actually establishing the MPA, followed by costs of managing the area, as well as costs to fishers associated with the reduction in fishing area. McCrea-Strub et al. (2011) examined the cost of establishing 13 MPAs ranging in size from less than one km^2 to more than 360,000 km^2 and varying in distance from land, objectives, and degree of protection. This study found the cost of establishing an MPA to be most significantly related to MPA size and how long the planning and establishment phase took to complete.

Smith et al. (2010) evaluated the short-term and long-term costs and benefits of no-take zones to fishers using an economic model and assessed how these will affect political support for the no-take zone. Their results indicate that in the short term:

1. Fisher opposition to the no-take zone will be minimal when other economic opportunities are available.
2. Support for the no-take zone will be greater if stocks are still large in fished areas.
3. The more important available fished areas (vs. no-take zone areas) are to profitability of fishers, the less opposition will be encountered, and the more important the no-take zone area is to profitability, the greater the resistance to the no-take zone.

4. Fisher opposition or support for the no-take zone will vary with skill level when stocks inside the no-take zone are greater than in fished areas before protection; more skilled fishers will show greater opposition to the no-take zone.
5. There will be cost to fishers, and the certainty of short-term costs often outweigh the potential long-term benefits in fisher perceptions of no-take zones.

Richardson et al. (2006) incorporated high-resolution socioeconomic data in a reserve selection model that had been designed to allow simultaneous optimization for ecological objectives while minimizing costs and found that incorporating coarse resolution socioeconomic data from government statistics only marginally reduced costs to the fishery than models run without socioeconomic data, but data from an intensive survey of fishers substantially reduced fishery losses. They conclude that detailed socioeconomic data is an essential input to the design of cost-effective no-take zone networks. While short-term costs must be expected, long-term economic and social benefits are expected to outweigh these costs.

6.6 Sportfishing and Other Non-Extractive Uses

Within many no-take zones, non-extractive uses of marine resources are often allowed. In many cases, these uses are regulated, but some may not be. Such non-extractive activities are often recreational activities such as boating, scuba diving and snorkeling, wildlife viewing, scientific research, and in some cases, catch-and-release angling. Many of these activities also involve mooring or anchoring vessels within the no-take zone. While these activities can be an important source of revenue to the protected area and local communities, encourage enjoyment of the area by local residents and visitors, and provide critical scientific knowledge of marine species, habitats and ecosystems, they may not be without impact. This leads to the question of what activities should be permitted within no-take zones and how they should be regulated.

Thurstan et al. (2012) examined a variety of non-extractive and non-depositional uses of no-take areas to determine their impacts on marine resources and habitats. They evaluated 16 activities in 91 no-take areas around the world to determine the extent to which they were allowed or prohibited (Fig. 5) and evaluated their impacts according to six criteria, namely: potential to change animal behavior; potential to cause injury or stress to animals or habitats; likelihood of collision with wildlife; potential to create pollution; potential to cause scouring or erosion damage; and potential to result in trampling damage or sediment disturbance. Based on each criterion, the authors scored the risk that high impact and low impact forms of each activity had on a scale of 0-4 and calculated a range of risk scores for each activity. Highest risk values were for high impact levels of water skiing and jet skiing, closely followed by high impact levels of snorkeling, scuba diving, motor boating, scientific research, catch-and-release angling, and wildlife viewing (Fig. 6). Most of these high-risk activities fell within a large range of risk depending on whether high or low impact variants of each activity were assessed. This study highlights the fact that even non-extractive activities can have negative impacts on marine resources. Other studies have also demonstrated that no-take areas that also restrict these activities or even prevent

access can have greater conservation benefits than no-take zones that allow these activities (Robbins et al. 2006).

There is an ongoing debate as to whether catch-and-release angling is compatible with optimal no-take management. Within Belize, fishing that is done primarily for sport rather than sale or subsistence is considered to be "sportfishing" (often referred to as recreational fishing in the scientific literature but referred to as sportfishing throughout this report). This includes both capture and killing of fish and catch-and-release angling. While commercial fishing and sportfishing that extract resources are logically prohibited in no-take zones, whether catch-and-release sportfishing should be permitted merits examination. While catch-and-release fishing does not remove resources from the no-take zone, some argue that these activities are not compatible with no-take zone management because: (1) they potentially result in high levels of post-release mortality or reduction in fitness, which may decrease populations similarly to extractive fishing; (2) they may disturb fish and wildlife or impact habitats (e.g., propeller scars on seagrass beds, pollution from boats); or (3) the act of fishing of any kind of no-take zone makes enforcement more difficult since enforcement officials cannot simply survey an area to determine if fishing is taking place, but must investigate further to see what type of fishing is being conducted.

Most no-take zones around the world prohibit all forms of fishing, but in some places, catch-and-release fishing is allowed. This is typically in areas where such activities are important to the economies of local communities. In The Bahamas, for example, most marine parks and marine fishery reserves prohibit all fishing and removal of marine resources, including shells, but in a few recently created parks and marine reserves where flats fishing for bonefish, permit and tarpon is an important source of income for local residents who serve as fishing guides, allowances have been made for catch-and-release fishing for these species (e.g., South Berry Islands Marine Reserve, Westside Andros National Park). In Belize, several Conservation Zones that are considered no-take zones within the country's marine reserves also allow some form of catch-and-release sportfishing, particularly for flats fish.

From a scientific perspective, there has been much research recently on the effects of catch-and-release sportfishing. In a review comparing the impacts of sportfishing to commercial fishing (Cooke and Cowx 2006) found that both types of fishing can have similar impacts. The question is how does catch-and-release fishing contribute to these impacts. A review and meta-analysis by Bartholomew and Bohnsack (2005) examined 53 studies of mortality resulting from catch-and-release fishing and found a wide range of release mortalities (0%-95%) with much intra- and inter-specific variability. Factors found to contribute to post-release mortality included anatomical hooking location, use of natural bait, removal of hooks in deeply hooked fish, use of J-hooks vs. circle hooks, deeper depth of capture, warm water temperatures, extended playing and handling times and, to a lesser extent, barbed vs. barbless hooks. The authors recommend that the precautionary principle dictates that catch-and-release fishing should not be allowed in no-take zones until more information is obtained (Bartholomew and Bohnsack 2005), and that protected areas where catch-and-release fishing is the only form of fishing allowed be used in

addition to, but not instead of, no-take zones for reducing user conflicts and providing some benefits to target species.

Another review paper evaluating the compatibility of catch-and-release angling and no-take zones agreed that it is not possible, based on available data, to definitively answer the question of whether catch-and-release angling should be allowed in no-take zones (Cooke et al. 2006). These authors argue that current research on factors that can reduce post-release mortality suggests that with appropriate regulation and angler education, reductions in post-release mortality may be minimized to an acceptable level within no-take zones. They further suggest that allowing catch-and-release angling under these conditions may enhance conservation and management goals of the no-take zones while maintaining public support and providing tourism-based revenues to local communities (Cooke et al. 2006).
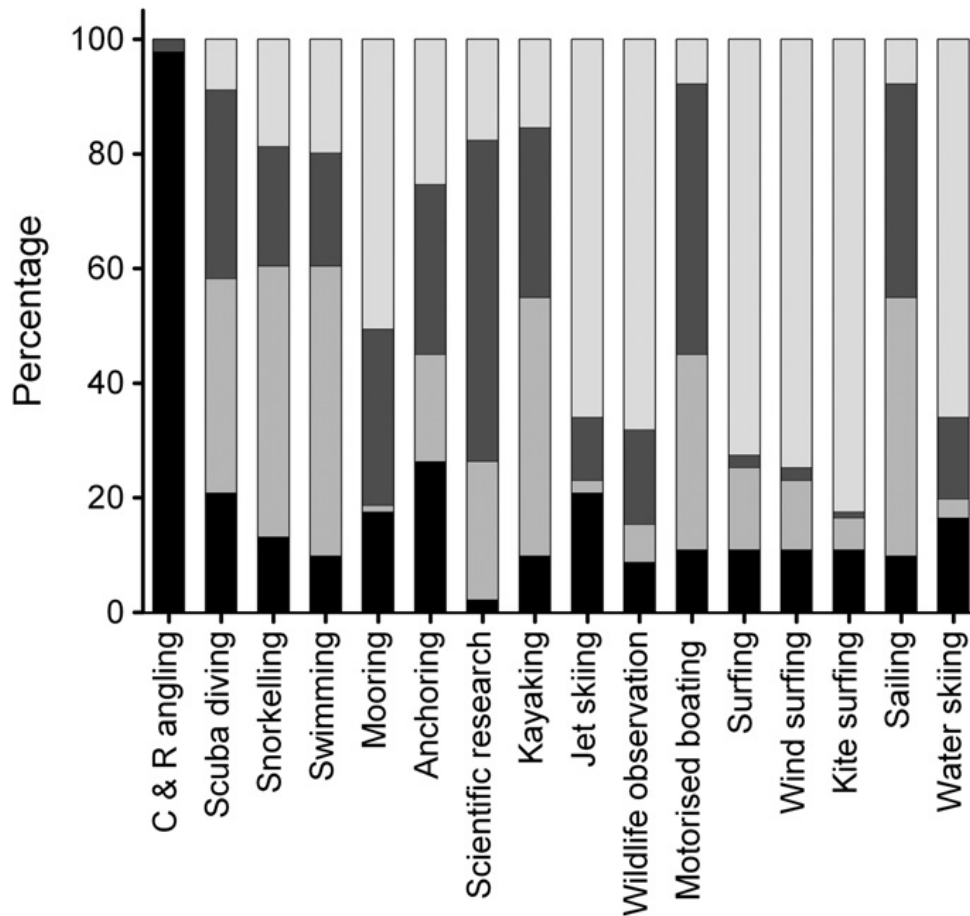
Figure 4. Evaluation of the extent to which various activities are managed in 91 no-take areas around the world, with black bars representing the percentage of no-take areas that prohibit an activity; medium gray bars representing the percentage or no take areas that allow the activity; dark gray bars represent the percentage that allow activities with some form of regulation; and light gray bars representing the percentage of no-take areas that did not mention the activity. C&R angling = Catch-and-release angling. Figure from Thurstan et al. (2012).
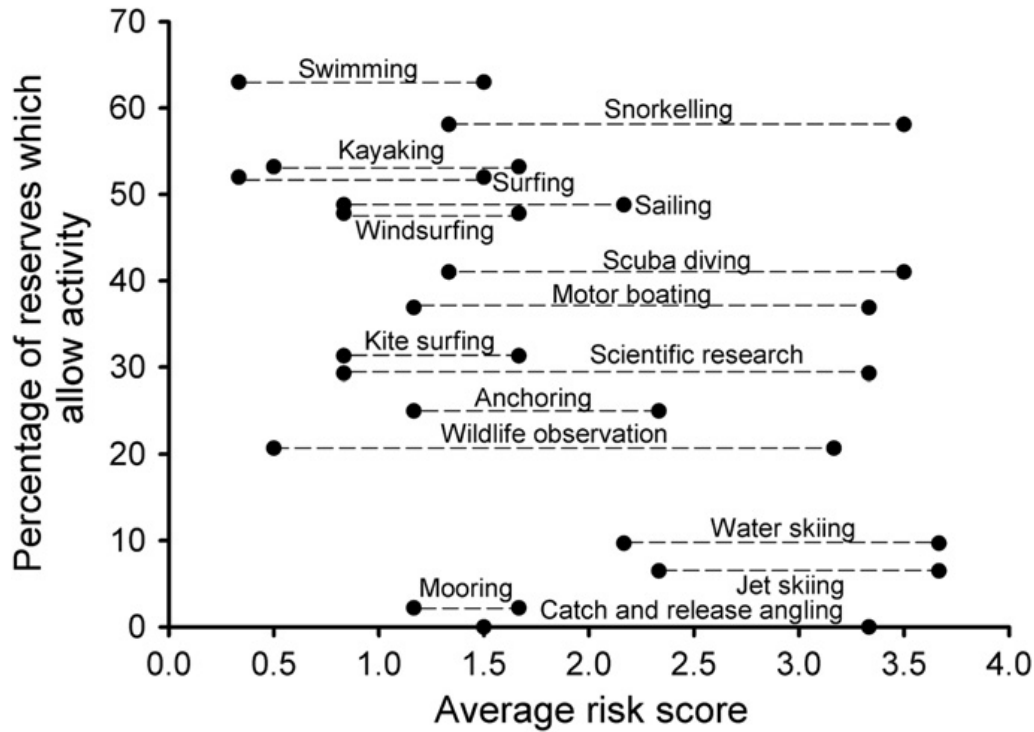
Figure 5. Average risk scores for each activity in relation to the percentage of no-take areas studied that allowed the activity. Percentages were calculated to include no-take areas that allowed the activity and excluded sites where activities were regulated or did not mention the activity. Dashed lines indicate the range between risk scores for high and low impact versions of the activity (Thurston et al. 2012).

It is interesting to note that while both reviews found similar results, their conclusions differed somewhat, with one suggesting to hold off on allowing catch-and-release angling until more data were available (Bartholomew and Bohnsack 2005) and the other recognizing limitations in available data, but suggesting catch-and-release angling may be regulated and anglers educated to the point where it may be compatible with no-take zones (Cooke et al. 2006). These differences may be due to some slight differences in the data analyzed but may also be influenced by the perspective of the authors. Whether one approach or the other is better for no-take zones in Belize should focus on data available for catch-and-release species found in Belize.

The best-studied catch-and-release fishery of relevance for Belize is that of bonefish (*Albula* spp.). In the bonefish fishery, where release is nearly 100% (Policansky 2002), catch-and-release mortality can exceed 40% when sharks are present (Cooke and Philipp 2004). When bonefish were released with a negative orientation (unable to hold themselves upright in the water column), they were more likely to be eaten by lemon sharks (*Negaprion brevirostris*) or barracuda (*Sphryaena barracuda*) within minutes of release than fish that were allowed to return to equilibrium (Danylchuk et al. 2007b). Fish that survived through the first hour after release were tracked for at least 13 days and up

to 24 days (Danylchuk et al. 2007a). This latter study also found that handling had little impact on long-term survival (Danylchuk et al. 2007a); however, other studies have shown that handling can induce behavioral changes that may be alleviated by release practices such as the use of a recovery bag for 15 minutes prior to release (Brownscombe et al. 2013). The site where fish were hooked had an impact on the rate of hook expulsion (when not removed by an angler), but the presence of a hook did not affect feeding rates or short-term survival (Stein et al. 2012). While the behavior and feeding ability of fish may not be impacted after release, other sub-lethal impacts may have consequences on populations.

In the absence of data on sub-lethal impacts of catch-and-release fishing for key species in Belize, reviews of the literature can provide useful insights. Cooke et al. (2013) review sub-lethal impacts of catch-and-release angling and show that that stresses associated with catch-and-release angling include physiological changes associated with energy expenditures while fish are being captured or injuries associated with hooking fish and hook removal. The latter injuries include hooking wounds, loss of protective mucous, loss of scales, and damage to skin and appendages (fins and opercula), all of which may lead to infections. A recent review by Arlinghaus et al. (2007) also highlights behavioral changes in released fish and the effect that barotrauma (caused by changes in pressure as fish are brought from depth to the surface) can have by injuring internal organs, causing hemorrhaging, and causing other tissue damage. Sub-lethal impacts may cause an increase in mortality well after the release event (Raby et al. 2013) or have other impacts on populations. Cooke et al. (2013) point out that such sub-lethal impacts may have population consequences due to depressed individual growth rates, but these population-level impacts are under-studied. In an example of sub-lethal impacts to Caribbean spiny lobster in a recreational fishery, the research of Parsons and Eggleston (2005, 2006, 2007) shows that lobsters wounded in the recreational fishery have altered behavior and an increased risk of being consumed by predators, resulting in significant losses to the population and to the commercial fishery.

While there is evidence that post-release mortality can be minimized by using appropriate release practices, it is important to recognize that cumulative effects of catch-and-release may have impacts on individuals (Bartholomew and Bohnsack 2005). Furthermore, a study of California rockfish found that even low levels of catch-and-release mortality (5% or less) can have a strong negative impact on long-lived species with low reproductive rates (Schroeder and Love 2002). Sportfishing has also been shown to selectively target some of the fittest individuals in populations (e.g., largest sizes, aggression levels, intensity of parental care and reproductive fitness), potentially causing negative consequences for populations over time (Sutter et al. 2012).

6.7 Conclusions

The benefits that individual, or networks of, no-take zones may provide can be influenced by a wide range of factors. While most no-take zones are likely to produce some benefits and achieve some management goals and objectives, the extent to which they provide specific benefits can be influenced by their design, the rules and regulations applying

within the no-take zones, level of compliance with those rules and regulations, and characteristics of fisheries management outside their boundaries. Design factors that can influence no-take zone benefits include the location, size, position of boundaries within a seascape, and spacing between no-take zones. In general, smaller no-take zones spaced close together may provide more benefits to fisheries, and larger no-take zones may be better for conserving target species and producing ecosystem benefits. There are exceptions to these generalizations, however, and evidence suggests that moderate-sized no-take zones spaced at intermediate distances apart may be most effective for achieving a combination of fisheries and non-fisheries benefits. To design no-take zones, as much data as possible should be included on species and habitats of interest, current patterns, and other biophysical characteristics of the system.

The other half of the equation for creating effective no-take zones is the human dimension. Because no-take zones actually manage humans and not the resources that they use, there must be adequate compliance with no-take zone regulations. During the designation process and implementation of no-take, voluntary compliance may be increased through consultations with resource users, strong science justifying no-take zones that are effectively communicated to the public, clear communication of no-take zone boundaries and regulations, and, ideally, ongoing participation of fishers and others in the management process. Effective enforcement may also be necessary to ensure compliance.

There is a lack of consensus as to what non-extractive uses are compatible with no-take zone management. As regards catch-and-release fishing, a review of the information on its impacts suggests that it may be acceptable in some, but not all, no-take zones and should be limited only to species for which data indicate there are low post-release mortality and sub-lethal impacts. Furthermore, such fishing activities should be regulated to ensure that best practices are being used for release of fish, including monitoring the effects of catch-and-release on fish populations.

Finally, while there are likely to be costs associated with creating no-take zones for some user groups more than others, collecting and using site-specific socioeconomic information in the designation process and review of other management actions may alleviate costs and build support. It is also important to communicate to stakeholders that the long-term benefits are expected to outweigh any short-term costs associated with implementing no-take zones.

7. Recommendations for Belize

Belize is in the process of expanding its national network of no-take zones that prohibit all fishing. With the recent addition of Turneffe Atoll into Belize's MPA system, no-take zones comprise 15% of the country's marine reserves and 3% of its territorial seas. The current goal for expanding no-take zones is to 10% of the territorial sea by 2015. In Belize, areas considered fully protected or no-take zones include Conservation Zones as well as Preservation Zones or Wilderness Zones. As indicated in Table 3, some of these MPAs allow local subsistence fishing (which is being phased out at Glover's Reef) or catch-and-release angling. In this section, recommendations are made with respect to the no-take zone expansion.

First and foremost, experience from around the world shows that what a protected area is called matters. Fishers and other resource users associate different terms used for describing MPAs with positive or negative connotations. Based on this experience, it is recommended that Belize not use the terms "no-take" or "fully protected," since they emphasize the fact that areas are being taken away from fishers. Instead, these areas should be named according to what benefits they may provide fishers and other stakeholders. The term "replenishment zone" has been proposed to replace the term "no-take zone" in referring to what are legally designated as Conservation Zones and Preservation/ Wilderness Zones within Belize's marine reserves and to new sites outside these reserves that may be designated as part of Belize's national expansion process. This change in nomenclature shifts the focus from the exclusion of various activities to the benefits that these zones will provide. Since the expected benefits of these areas will be to replenish fish and invertebrate stocks impacted by fishing, fished areas through recruitment and spillover effects, and biodiversity and improve coral reef resilience by serving as areas that will replenish corals throughout much of Belize, this term is an appropriate one to use to describe these zones. It is proposed that the term ***Replenishment Zone* be defined as: an area of the sea where the extraction of living marine resources is prohibited and other uses may be regulated, for the purposes of replenishing ecosystems and the functions and services they provide, replenishing and rebuilding of target fish and invertebrate stocks for the benefit of fisheries, promoting the recovery of key species, and enhancing economic opportunities for the people of Belize.**

Another issue that must be addressed is to determine what uses should be allowed or prohibited in Replenishment Zones. As indicated earlier, several of Belize's Conservation Zones allow some small level of fishing or catch-and-release angling, and all allow in-water activities such as boating, diving and snorkeling. Studies from the peer-reviewed literature suggest that some of these uses can have negative impacts on marine species, habitats and ecosystems. As such, it is recommended that the highest-risk activities, such as water skiing and jet skiing, be severely restricted if not completely prohibited in these areas.

Other activities that have the potential for high levels of impact, such as snorkeling, diving, and wildlife viewing, should also be regulated in these areas to ensure that these activities are being conducted following best practices. Monitoring the impacts of these activities is also essential to determine their impact on species and ecosystems and allow for adaptive management if their impacts become incompatible with Replenishment Zone management objectives.

Catch-and-release angling can also have negative impacts on marine resources and habitats. In addition, because other forms of angling are – by definition – prohibited in no-take zones, allowing catch-and-release angling can complicate the job of enforcement personnel. In Belize, sportfishing is an important activity for visitors to several marine protected areas, including Gladden Spit and Silk Cayes Marine Reserve (SEA 2010). Recreational angling for flats species such as bonefish, tarpon and permit accounted for direct expenditures of USD25 million in Belize in 2007, which represented 6.3% of tourist expenditures and accounted for 6.3% of tourism-related jobs (Fedler and Hayes 2008). The decision as to whether to allow catch-and-release fishing in no-take zones has important socioeconomic, as well as ecological, implications. Based on available information, several recommendations can be made for catch-and-release fishing in Belize's marine reserves.

As is the case now, some no-take zones should prohibit all fishing and other extractive uses, including catch-and-release fishing, while other no-take zones could allow catch-and-release fishing provided certain criteria are met, namely:

- Catch-and-release fishing should only be allowed in areas where it is not known to disturb other species that require protection within the protected area or affect essential habitats (e.g. birds, manatees, nursery or spawning areas for key species).
- Catch-and-release angling should only be allowed for species for which the lethal and sub-lethal impacts are known and within acceptable levels. At present, this criterion may limit catch-and-release fishing in no-take zones to bonefish and flats species with similar biological and ecological traits.
- Use of best practices for minimizing post-release mortality should be required in no-take zones where catch-and-release fishing is allowed. To facilitate this, a guide and/or angler education program should be implemented.
- The amount of catch-and-release angling should be regulated using a permitting system or other instrument for regulating sportfisher access to areas where catch-and-release fishing is allowed. Sportfishing permits for specific areas may be obtained by individual anglers or to guides that have been certified through the education program. Requiring anglers to use a certified and licensed guide may also facilitate the use of best practices.
- A monitoring program should be developed to assess the impacts of catch-and-release fishing on recreational species and other key resources in each no-take zone where it is allowed.

Also warranting consideration in the expansion of Belize's network of replenishment zones are criteria for selecting sites for expansion. Based on the current governance framework and the costs and logistics of designating new replenishment zones, it is recommended that efforts be made to locate new or expanded replenishment zones within the existing network of MPAs when possible, unless there is strong grass-roots support for designating new areas. This is the policy of the technical mapping and analysis under this project that is presently underway and being led by the Nature Conservancy. Specific areas for protection are being identified following criteria outlined in this report (e.g., habitat representation and replication) and elsewhere. Because data on species distributions, bathymetry, habitat distribution and socioeconomic factors are available at a relatively high resolution for most of Belize, these data layers are included in the analysis using a site selection tool known as MARXAN. Use of this special software is helping to select areas that address critical gaps in the current replenishment zone network and select replenishment zone configurations that meet multiple criteria and minimize cost of implementation as well as cost to resource users.

Engaging stakeholders in the process of expanding the replenishment zone network is also critical to ensure they understand the need, goals and expected benefits of the expansion, as well as provide a means to get their input to help guide the expansion. This process, which is also being led by the Nature Conservancy, is underway in an effort to address and resolve issues effectively. It should also help to minimize implementation costs and reduce short-term costs to fishers or other stakeholder groups by avoiding areas that will cause excessive costs to a specific group or community. The preliminary results of the MARXAN analysis have been discussed with the project Steering Committee and the marine reserve managers. Consultations with fishers to obtain their feedback and input will be held over the next few months. Implementation should also include clear marking of marine reserves and easily understood rules and regulations. In cases where fishers may be displaced or have to bear increased costs, providing training or incentives for alterative livelihoods may help marine resources outside replenishment zones by reducing any concentration in fishing effort resulting from the replenishment zone expansion and reducing competition among fishers.

Finally, it is important to realize that, while the expansion of the replenishment zone network is a major step forward in protecting marine resources in Belize and promoting sustainable fisheries, additional management measures outside of these areas must continue. Such measures should embrace ecosystem-based management that recognizes the connectivity of various marine ecosystems as well as the relationship between marine systems and terrestrial watershed management (i.e., a ridge to reef approach), to ensure water quality and habitat protection for marine life within and outside of replenishment zones. The new Fisheries Act being developed for Belize will help to promote sustainable fisheries and incorporate ecosystem-based management concepts into management planning. The new Act provides for the development and adoption of management plans for marine reserves, which must include physical, biological, and socioeconomic aspects of the reserve, its conservation and management objectives, and its management programs. The new Act also provides for the development and adoption of fishery management plans. Furthermore, the expansion of the Managed Access program to all of Belize's Marine

Reserves where fishing is allowed should greatly enhance marine reserve and replenishment zone management, as well as promote sustainable catches and use of non-destructive fishing methods. The concurrent and coordinated expansion of Replenishment Zones and Managed Access – and eventual development of fishery management plans – will provide fishery managers with the tools needed to maintain sustainable use of fishery resources, limit habitat damage from fishing, reduce poaching in Replenishment Zones, and promote high yields for fishers without increasing fishing effort.

The vast number of examples from around the world, including Belize and its Caribbean neighbors, show that no-take zones can produce a wide range of benefits for multiple stakeholders, including residents of coastal communities who do not rely on the sea for their livelihood, but rely on marine resources for food and coral reefs for shoreline protection against storms. Replenishment zones will also provide critical conservation benefits for marine species, habitats and ecosystems of Belize that face various anthropogenic threats and stressors. As part of a larger ecosystem-based management approach, the expansion of Belize's replenishment zones will play a critical role in supporting the bounty of Belize's marine resources for current and future generations.

8. Acknowledgments

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