TRINATIONAL GOVERNANCE TO PROTECT ECOLOGICAL CONNECTIVITY: SUPPORT FOR ESTABLISHING AN INTERNATIONAL GULF OF MEXICO MARINE PROTECTED AREA NETWORK

A Dissertation

by

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BS, Georgetown University, 1995
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Submitted in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in

COASTAL AND MARINE SYSTEM SCIENCE

Texas A&M University-Corpus Christi
Corpus Christi, Texas

August 2013

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This dissertation meets the standards for scope and quality of
Texas A&M University-Corpus Christi and is hereby approved.

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ABSTRACT

The Gulf of Mexico is a semi-enclosed, international sea that is bordered by the United States, Mexico, and Cuba. The three nations share transboundary living marine resources that move freely across political borders. Each nation has a vested interest in protecting the sustainability of living marine resources and the state of the large marine ecosystem. Uncommon, hard-bottom, high-biodiversity habitats occur on the continental shelf within United States, Mexican, and Cuban waters. An existing ecological network connects these hard-bottom habitats via migratory patterns and passive transportation of pelagic organisms through oceanic currents. Regional marine policy is needed to protect transboundary connectivity and ensure sustainability of shared living marine resources. An international network of marine protected areas throughout the Gulf of Mexico would conserve high-biodiversity habitats and ecological connectivity, which preserves the ecosystem's natural resiliency to natural and anthropogenic threats.

Legal systems, laws, and governance regimes of the United States, Mexico, Cuba, and the international arena vary. Although the regulatory frameworks differ among the nations, each has marine policy and governance objectives that support ecosystem-based management. Analysis of marine policy was conducted to propose a trinational policy approach to establish and administer the International Gulf of Mexico Marine Protected Area Network under existing law. Domestically, the three nations each have one or more agencies that regulate marine protected areas, and such agencies would likely administer a transboundary marine protected area network. Internationally, several treaties are in place to protect living marine resources in the Gulf of Mexico. The Cartagena Convention was identified as the treaty to best support creation of the

International Gulf of Mexico Marine Protected Area Network based on the treaty's scope and ratification by all three Gulf-facing nations. Collaboration and negotiation under the treaty could support an international memorandum of understanding and creation of a trinational commission to establish and oversee the network.

The marine protected area network would connect sites that share features or biota. Coral reef ecosystems are important sites in the Gulf of Mexico. Four well-studied coral reefs—Florida Keys, Flower Garden Banks, Veracruz Reef System, and Alacranes Reef—are cornerstones of connectivity. Selected coral and fish species that occur at the four cornerstone sites were explored as examples of stepping-stone connectivity among several sites on the continental shelf throughout the Gulf. The selected species exemplify biological connectivity and provide justification for regional connectivity in the human dimension also. Marine protected area practitioners from the United States, Mexico, and Cuba gathered at a workshop in July 2012 to create the International Gulf of Mexico Marine Protected Area Network. Trinational collaborators identified design parameters and candidate sites that demonstrate biophysical connectivity and can be linked through standardized governance methods for sustaining human and environmental health and well-being.

Of the candidate sites identified, several are collections of sites that are unprotected or not comprehensively protected. One example is the South Texas Banks; a case study for site selection was performed for the group of sites. Few biological data are available for the South Texas Banks. Multivariate statistical tests were performed on geomorphic variables that collectively acted as an abiotic surrogate for biodiversity patterns for 12 outer-shelf South Texas Banks. The analysis culminated with a ranking tool to guide prioritization of future biological explorations and site selection for designation of marine protected areas. A minimum of five outer-shelf South Texas Banks was proposed for place-based protection and inclusion in the International Gulf of Mexico Marine Protected Area Network. Similar methodology can be applied to other multi-site candidates to refine the spatial design of the network.

Analyses of marine policy, ecological connectivity, and biodiversity hotspots yielded results that serve as a foundation for the International Gulf of Mexico Marine Protected Area Network. The network's objectives are to preserve natural resiliency to adverse anthropogenic and natural disasters and phenomena, to protect ecological connectivity, and to conserve biodiversity through shared resources and management tools. Continued trinational communication and collaboration are critical for successful ecosystem-based management at the regional scale. Proper trilateral administration of the International Gulf of Mexico Marine Protected Area Network could mitigate adverse effects of chronic and episodic stressors and increase protection of the ecosystem's natural resiliency, connectivity, and biodiversity.

DEDICATION

This dissertation is dedicated to my parents for their unwavering support and encouragement. For my mother, Suzanne Nash, who has always taught me to persevere to achieve my goals, and for my father, Buddy Nash, who ignited my passion in marine biology at the age of 13 when we were certified to scuba dive together. I am very thankful for such positive role models. To my sisters Bonner and Elizabeth, my grandmother Josephine Nash, and many other family members and friends who have been enthusiastic cheerleaders throughout this academic process, I sincerely appreciate your support.

ACKNOWLEDGMENTS

With great pleasure I acknowledge my committee chair, Dr. Richard J. McLaughlin, who graciously took on the challenge of accepting a biologist as a student of marine policy and law. He has been an invaluable advisor and mentor, and I cherish his constant support and encouragement. Dr. John W. ("Wes") Tunnell, Jr. continually offered me extensive guidance and additional opportunities, which have greatly enhanced my knowledge and experience; I am very grateful. I thank Dr. Thomas S. Shirley who motivated me to constantly improve my writing with helpful suggestions and stimulating scientific discussions through which I learned more than I realized at the time. Dr. Billy D. Causey dedicated much time to help me when he had little time to spare; I thank him for the inspiring advice and encouragement. I greatly appreciate Dr. Jorge Brenner for providing me sound advice and helpful suggestions from a grounded, conservation-oriented perspective. I am indebted to Dr. Michael T. Masnik, my friend, mentor, and supervisor at the U.S. Nuclear Regulatory Commission, for his encouragement, support, flexibility, and advocacy without which I never would have pursued this degree. I thank Dr. Porfirio Álvarez and Orlando Iglesias who provided me with incredible international opportunities and gave me very helpful advice and information throughout my research. Frank Kelly has been an invaluable coauthor for statistical papers, and I appreciate the dedication and drive to continue collaboration. I thank Dr. Andre Droxler and Pankaj Khanna who generously hosted me at Rice University and worked tirelessly with me to process and analyze multibeam echosounder data from a geological perspective. I greatly appreciate Dr. John S. Wood who patiently helped me overcome technical GIS problems on several occasions. I am thankful for clarifying explanations regarding foreign policies and regulatory frameworks from Susana Perera of CNAP in Cuba and from Natalie Rodriguez Dowdell, Ana Luisa Figueroa

Carranza, and Dr. Jaime González Cano of CONANP in Mexico. Thank you to Dr. Larry McKinney, Gail Sutton, Roland Dominguez, Luke Eckert, Allison Knight, Kristen Dwyer, and Patrick Krepps for providing institutional, logistical, technical, and travel support. Finally, I am grateful for funding from the Harte Research Institute for Gulf of Mexico Studies primarily for a doctoral fellowship but also for travel and workshop activities. Additional support for my research was provided by NOAA's Environmental Cooperative Science Center, Schmidt Ocean Institute, Gulf of Mexico Large Marine Ecosystem Project, a Killebrew scholarship, and Texas A&M University – Corpus Christi College of Science and Engineering.

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CHAPTER 1

IMPORTANCE OF ECOLOGICALLY CONNECTED HABITAT SITES IN THE GULF OF MEXICO[*]

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Format: *Marine Policy* used as format.

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Abstract

Biological connections throughout the Gulf of Mexico region pervade waters of the United States, Mexico, and Cuba. Identification of important high-biodiversity habitats and the species that utilize such uncommon habitats in the Gulf of Mexico provides a scientific basis for cooperative international marine conservation and policy. Combined with a compatibility analysis of existing national marine policies, an ecosystem-based marine spatial planning tool would enhance the understanding of connectivity elements and processes, map distribution of habitats with high biodiversity, minimize discontinuity among national marine policies, and maximize coordinated international protection while managing transboundary living marine resources based on biophysical characteristics of the large marine ecosystem. Existing conditions in the Gulf of Mexico region support an enterprise to design several alternatives for an international network of marine protected areas in the Gulf of Mexico for joint consideration by policy decision-makers from the United States, Mexico, and Cuba.

1. Introduction

The Gulf of Mexico (GOM) is a semi-enclosed, international sea that comprises a large marine ecosystem bordered by three nations: the United States (U.S.), Mexico, and Cuba. As such, the GOM provides important habitat for many transboundary living marine resources, ranging from highly migratory species to sessile invertebrates. Most transboundary species represent connectivity of the existing ecological network within the GOM and into the Caribbean Sea. These species may rely on important habitat features, such as hard and soft banks, hard-substrate reefs, and even man-made structures such as petroleum platforms, distributed in a semicircular fashion around the GOM continental shelf. Known key habitat areas have varying vertical relief from the seabed, collectively constituting a complex seascape of submerged islands. Protection of these habitat features throughout the GOM is an integral component of international ecosystem conservation and management. Properly designed habitat protection is imperative for maintenance of ecological connectivity and biodiversity, which are the most commonly identified criteria necessary to sustain marine ecosystem health (Foley et al. 2010).

A healthy marine ecosystem is a prerequisite for the continued provision of ecosystem services to coastal communities in the U.S., Mexico, and Cuba. Fishing (commercial, recreational, and subsistence) is prominent in all three nations, and the stability of fisheries has rippling socioeconomic effects throughout coastal communities. Not only do fisheries provide food to communities, but they also provide economic security to related industries, such as seafood processors, marinas, and tourism. GOM coastal communities are inherently linked to the ability of the large marine ecosystem to provide other goods and services as well. The habitat complex in the GOM benefits humans by protecting the coast from routine and episodic disturbances (e.g., hurricanes), providing refugia for biota, and maintaining cultural and spiritual significance.

The U.S., Mexico, and Cuba already protect some important habitats as each nation has designated marine protected areas (MPAs) in the GOM. However, existing MPAs throughout the GOM are managed only in accordance with legislation of one nation, which may be inadequate considering the motility of many important living marine resources in the region. Continuation of existing MPAs is important as is collective consideration of their management goals and objectives to address the transboundary nature of many living marine resources in the GOM. Also, additional protection may be warranted at some sites that currently have little or no protection. Coordinated management and protection of transboundary living marine resources would ensure effectiveness through trinational collaboration with scientists and resource managers.

Scientists, resource managers, and policy analysts from the U.S., Mexico, and Cuba have been collaborating to address the joint concern regarding the future of shared living marine resources. In November 2007, a collaborative group called the Trinational Initiative for Marine Research and Conservation in the Gulf of Mexico and Western Caribbean developed, and the group met again in March 2009, October 2009, and September 2010 (Guggenheim and Fernández Chamero 2008; Trinational Initiative 2011). Participants from the U.S., Mexico, and Cuba agreed to encourage research and conservation of several taxa and strengthening and extending existing MPAs in the GOM and western Caribbean Sea. Although the Trinational Initiative does not yet have a fully developed implementation plan, the group does have participants from federal agencies of each of the three nations.

In 2008, the U.S. National Marine Sanctuary Program (NMSP) hosted a scientific forum to discuss the “Islands in the Stream” concept (Ritchie and Keller 2008). The concept is based on the distinct geological features in the GOM that represent habitat nodes with high biological connectivity, species abundance, and/or species richness. The NMSP’s existing statutory authority is limited to that provided by the National Marine Sanctuaries Act of 1972, as amended (16 U.S.C. § 1431 et seq.). However, the “Islands in the Stream” concept suggests additional authority provided by other statutes, such as the Magnuson-Stevens Fishery Conservation and Management Act of 1976, as amended (16 U.S.C. § 1801 et seq.), could expand the zone of marine conservation influence in the U.S. to protect more species and habitat sites. Several sites in the U.S. and Mexico were identified for inclusion in a network of MPAs at the forum. As a follow-up to the 2008 meeting, many of the same organizations and individuals and some additional supporters reconvened for a second scientific forum hosted by Mote Marine Laboratory in May 2011. The 2011 forum, entitled “Beyond the Horizon,” focused on “creating a network of special ocean places to strengthen the ecology, economy, and culture of the Gulf of Mexico” (Beyond the Horizon 2011). The group concluded that such a network requires development and agreement regarding international governance, selecting specific sites that warrant additional protection, centralizing economic data for cost/benefit analyses, and broad stakeholder support and involvement.

In 2009, the Global Environment Facility (GEF), partnered with the United Nations Industrial Development Organization, created the Gulf of Mexico Large Marine Ecosystem Project (GoM-LME 2011). The project’s goals were to identify hurdles, solutions, and strategies for transitioning the GOM to ecosystem-based management through collaborative efforts of the U.S., Mexico, and Cuba. Specific GEF study priorities for the GOM included hypoxia, fisheries, biodiversity, and coastal development. Originally supported by the federal governments of the three GOM-bordering nations, the project is currently supported by the U.S.’s National Oceanic and Atmospheric Administration (NOAA) and Mexico’s *Secretaría de Medio Ambiente y Recursos Naturales* (SEMARNAT). Perhaps in the future Cuba will rejoin the project to ensure a truly regional design for sustainable ecosystem-based management in the GOM.

In 2010, several organizations—Harte Research Institute for Gulf of Mexico Studies (HRI) at Texas A&M University-Corpus Christi, Gulf of Mexico Large Marine Ecosystem Project, and Universidad Veracruzana—collaborated to develop an annual series of trinational student workshops regarding governance in the GOM region. In June 2010, representatives from various universities and organizations from the U.S., Mexico, and Cuba participated in the first workshop, which HRI hosted. The focal point was sustainable governance of MPAs in the

GOM, and the participants identified important issues including biological, cultural, and socioeconomic connectivity; spatial planning; stakeholder pressures; and joint features of existing MPAs (Cruz and McLaughlin 2010). The Universidad Veracruzana hosted the second annual trinational governance workshop in Veracruz, Mexico in August 2011. The second workshop theme emphasized watershed and coastal issues throughout the GOM. Discussions focused on transition from sector-based governance to ecosystem-based management, integrated coastal zone management, spatial planning and geographic information systems, watershed planning approach, environmental risk assessment and prevention, freshwater inflow and river pollution, and protected areas. Influenced by the trinational scientific fora, ocean governance workshops, and the initiative group, this chapter presents the importance of unified, comprehensive protection of ecologically connected habitat sites throughout the GOM. With emphasis on habitats exhibiting biological connectivity and high biodiversity, the existing ecological network can be transformed into an international network of MPAs in the GOM. A protected network in the GOM would act as an ecological insurance policy in the face of natural and anthropogenic threats, both gradual and episodic. An international MPA network would facilitate the ecosystem's recovery and resiliency while strengthening international relations among the U.S., Mexico, and Cuba as they work together to protect shared, highly valued living marine resources. Chapter 1 presents the existing ecological nexus and the ripeness of desire among the three nations for integrated marine conservation and management policy in the GOM.

2. Biophysical setting

The region for the proposed international MPA network is the GOM, which encompasses waters of the U.S., Mexico, and Cuba. The GOM is a semi-enclosed oceanic basin that is connected to the Caribbean Sea via the Yucatán Channel and to the northwestern Atlantic Ocean by the Florida Straits. Terrestrial boundaries of the GOM include the U.S. to the north, Mexico to the south and west, and Cuba to the east. For the purposes of this analysis, the eastern marine boundaries of the GOM extend from Key Largo, Florida, U.S., to Punta Hicacos, Matanzas, Cuba, and from Cabo de San Antonio, Pinar del Río, Cuba, to Cabo Catoche, Quintana Roo, Mexico (Fig. 1.1; Felder et al. 2009).

As denoted by the contour lines in Fig. 1.1, the GOM is a large basin with a variable continental shelf, which is typically characterized by a broad, carbonate shelf in the eastern portions, a narrow shelf with terrigenous substrate in the western portion, and a terrigenous shelf of moderate width in the north (Tunnell 2009). The GOM has a surface area of about 1.5 million km^2, approximately a third of which covers the continental shelf (Tunnell 2009). The Sigsbee Abyssal Plain is the deepest region at over 3700 m and is located in the southwest quadrant of the basin. Other distinct, important physical features include the DeSoto Canyon in the northeast quadrant and the Florida and Campeche Escarpments off the Florida and Yucatán Peninsulas, respectively.

Regardless of shelf sediment type, the vast majority of the GOM continental shelf is composed of soft substrate. However, several hard-substrate habitats, including reefs, banks, diapirs, and rocky outcrops, exist in spots along the continental shelf and exhibit various levels of biodiversity. While hard-substrate habitats comprise only a small portion of the GOM continental shelf, they have concentrated, high biodiversity when compared to biodiversity of species that inhabit the surrounding soft-substrate habitats (Parker and Curray 1956; Rezak et al. 1985). Areas with true coral reefs include the Dry Tortugas and Florida Keys off southern Florida, the Flower Garden Banks on the outer continental shelf off Texas, the Tuxpan and

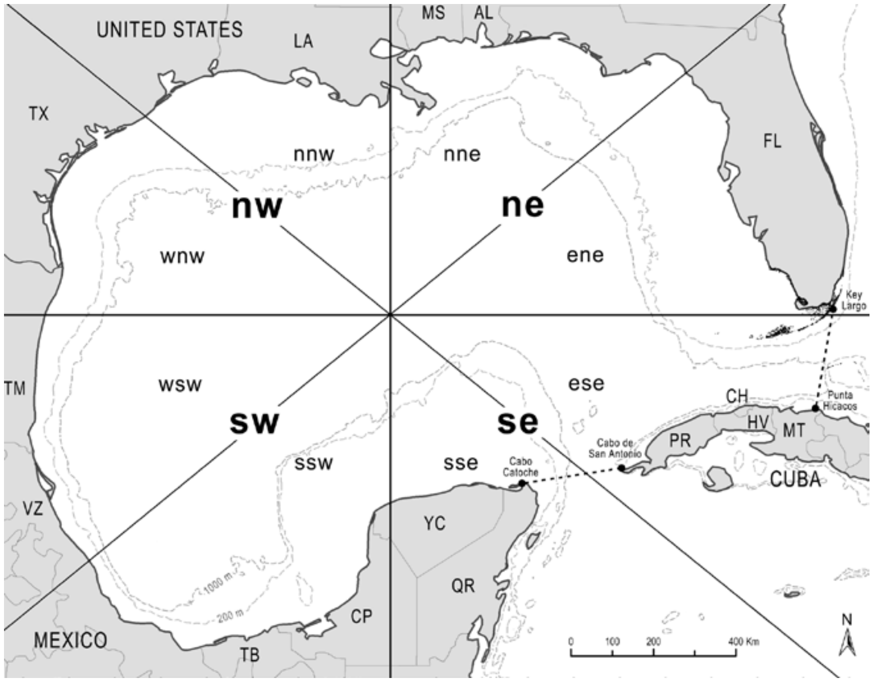

Fig. 1.1. Gulf of Mexico study area.
Adapted from: Felder et al. 2009.

Veracruz Reef Systems off the Mexican state of Veracruz, the Campeche Bank Reefs on the shelf west of the Yucatán Peninsula, and reefs off northwestern Cuba (Fig. 1.2; Tunnell 2007a). Coral reefs in the northwestern GOM are submerged while coral reefs in the southern and eastern GOM are typically emergent. The hard-bottom banks, such as Stetson and Southern Banks, in the northwestern GOM exhibit a gradual transition from temperate communities nearshore to tropical communities offshore (Rezak et al. 1985). The transition for benthic communities on the GOM mid and outer shelf, as seen elsewhere as well, appears to be associated with substrate type (Rezak et al. 1985).

Many habitat areas with hard substrates were created by various geological processes, notably sedimentation and subsurface salt movement. The continental shelf in the areas of

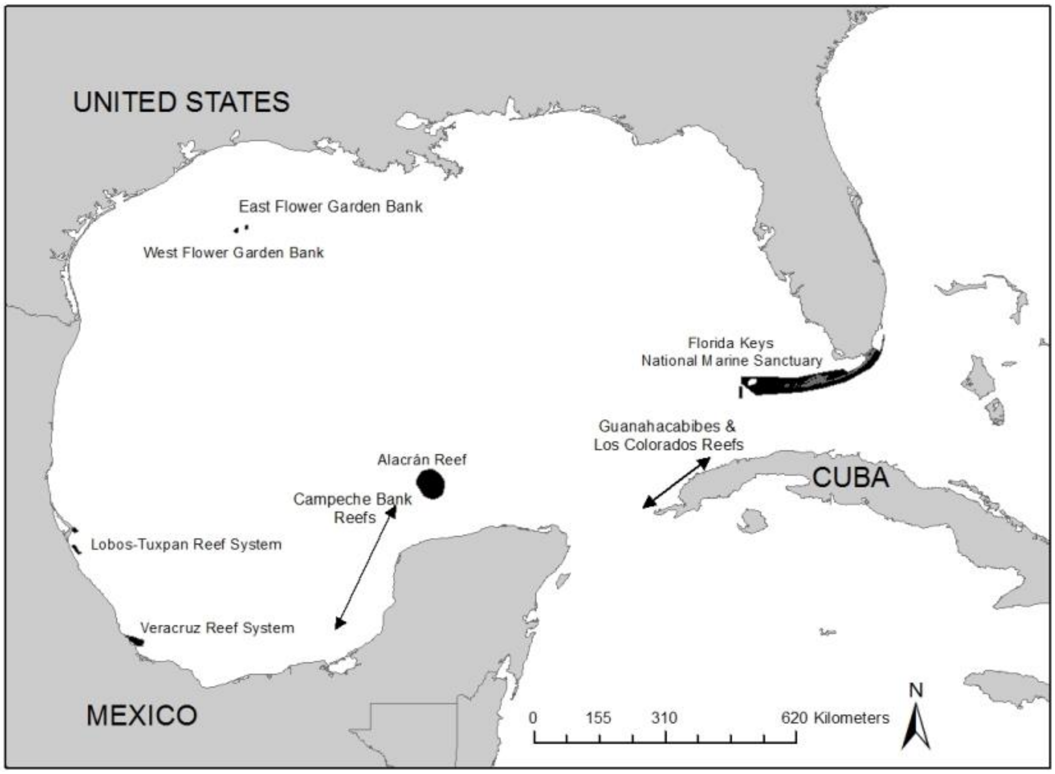

Fig. 1.2. Gulf of Mexico areas with true coral reefs. (Note that the Campeche Bank Reefs and the Guanahacabibes & Los Colorados Reefs are shown in more detail in Figs. 1.4 and 1.5, respectively.)

western Florida and the Yucatán Peninsula is composed of carbonate sediments while the continental shelf off eastern Mexico, Texas, and Louisiana consists of mostly terrigenous sediments (Rezak et al. 1985). The combination of sedimentation, subsurface salt movement, and rifting results in salt diapirism, which is common in some areas of the GOM. Salt diapirism is a process in which a subsurface base layer of allochthonous salt protrudes through dense, hard substrates, which, in the case of the GOM, results in a salt dome that can trap petroleum beneath the hard bottom while simultaneously creating shallower-water habitat for marine biota as the dome rises above the bottom (Liddell 2007). Salt domes or diapirs form in areas with substantial sediment loading, which explains why large salt formations on the outer continental slope are not as developed as salt structures closer to or on the continental shelf (Humphris 1979). As a result, the continental shelf has irregular bathymetric relief where there are salt diapirs, such as off the Texas and Louisiana coasts and in the Bay of Campeche, which is the southernmost portion of the GOM (Rezak et al. 1985).

In other areas, such as the continental slope off eastern Mexico, the bottom resembles a ridge system because the subsurface consists of denser shale instead of salt deposits (Rezak et al. 1985). Beyond the continental shelf in the GOM, salt movement in geopressured zones results in hydrocarbon seeps at the edge of the allochthonous salt layers where associated faults form in the overlying shale on the continental slope (Cordes et al. 2007; Roberts 2011). Expulsions on the continental slope can be classified into three types: mud-prone rapid delivery, mineral-prone slow delivery, and intermediate delivery (Roberts 2011). Intermediate-delivery cold seeps, including hydrocarbon expulsions and brine seeps, often have robust chemosynthetic communities. Most cold seeps, although fairly isolated, exhibit similar biodiversity usually predominated by tubeworms, clams, and mussels (Cordes et al. 2007). Therefore, salt diapirism produces densely populated habitats in areas with carbonate sediments (cold seeps on the continental slope) and areas characterized by terrigenous sediments (salt diapirs on the continental shelf).

Many rivers and estuaries deliver terrigenous sediments, nutrients, and freshwater as they flow into the GOM. Additionally, the Yucatán Current transports planktonic organisms from the Caribbean Sea through the Yucatán Strait. Upon entry into the GOM, surface water is entrained into the Loop Current, which intrudes to variable extents into the eastern GOM and then exits via the Florida Current, which becomes the Gulf Stream. When the Loop Current extends into the northwestern GOM, the flow destabilizes enough to shed, over the course of months, large anticyclonic eddies that gradually move to the west and southwest (Sturges and Leben 2000).

Neither the Loop Current's oscillation nor the eddy-shedding frequency presents a strong pattern, making surface circulation difficult to predict (DiMarco et al. 2005; Carrillo et al. 2007). Another major circulation phenomenon in the GOM is a large anticyclonic gyre off the coast of Texas. This gyre, the western portion of which is also called the western boundary current, is consistently present yet of variable velocity as it is driven by winds and Loop Current eddies (Sturges 1993). Finally, there is a cyclonic gyre in the Bay of Campeche, and numerous cyclonic eddies and other surface currents exist throughout the GOM (DiMarco et al. 2005; Carrillo et al. 2007).

3. Ecological framework

Although an MPA network would likely result in numerous ecological benefits, the goal to facilitate the ecosystem's resiliency and recovery after a disturbance is most strongly supported by two conservation targets: connectivity and biodiversity.

3.1. Biological connectivity

Biological connectivity can occur as genetic connectivity or demographic connectivity (Cowen 2002). The former is based on temporal "stepping stones" in the context of a large spatial scale, and the latter stems from the effects of geographic "stepping stones" over a long temporal scale. Accordingly, intact demographic connectivity generally maintains genetic connectivity (McCook et al. 2009). While studies of both types of connectivity are relevant to the task of designing a network of MPAs, a focus on maintaining demographic connectivity is better suited for a multi-species approach and spatial planning for a large marine ecosystem such as the GOM.

Demographic connectivity is a phenomenon of ecological linkage resulting from geographical movement of individuals of a population or metapopulation from one habitat site to another during any life stage. In the marine environment, particularly among coral reef communities, demographic connectivity likely occurs most widely through pelagic larval dispersal but is also evident in some species based on juvenile recruitment and post-settlement adult movement patterns. As a result, sustained demographic connectivity represents an ecological insurance policy providing populations with resilience to substantial disturbances, such as hurricanes or oil spills, which may affect one habitat site while another site in the protected network remains undisturbed and, thus, can contribute to recovery of some populations, subpopulations, or assemblages.

3.1.1. Passive ecological connectivity

Pelagic early life stages of some species undergo passive transport, either solely or in concert with active movements. Passive biological connectivity stems from oceanographic currents that act as vectors to transport nutrients and early life stages, such as planktonic eggs and larvae and juvenile sea turtles, from one habitat feature to another. Surface currents, deep currents, convergent currents, and episodic turbulence and their variable velocities and directions have substantial roles in dispersal or retention of eggs, larvae, and nutrients. However, currents alone do not determine connectivity paths (Roberts et al. 2006). Larval behavior, such as vertical migration and late-stage horizontal swimming, denotes active movement, which is an important species-specific factor that may help explain why some species have high larval retention while others have high larval dispersal from shared spawning grounds. Other factors, such as pelagic larval duration, distance to suitable recruitment habitat, life histories, adult spawning strategies, water temperatures, and extreme weather events, also affect connectivity at the larval stage.

Strong storms, such as hurricanes, likely increase larval dispersal for some species as long as turbulent conditions do not increase larval mortality. Therefore, population connectivity through larval transport varies greatly by species, location, and oceanographic conditions.

Although scientific approaches for comprehensively describing larval dispersal, even for a single species, are not yet mature (Jones et al. 2009), many larval dispersal studies have yielded useful data. Larval retention and local self-recruitment drive population dynamics for some species (Cowen et al. 2002; Swearer et al. 2002). However, larval dispersal is also a means of ecological connectivity (Domeier 2004; Roberts et al. 2006; Christie et al. 2010). Ecological connectivity likely results from a combination of larval retention and larval dispersal at population and community levels (Swearer et al. 2002; Planes et al. 2009; Butler et al. 2011). For example, brooding corals at an individual reef may thrive from high levels of self-recruitment in addition to occasional long-distance supplements from other reefs up to tens of kilometers away; therefore, larval retention and larval dispersal are both important in sustaining the population (Jones et al. 2009). For example, various connectivity patterns existed within a single community in Hawaii, which is likely the case in most geographic locations (Toonen et al. 2011).

Much controversy exists, mostly as a result of few empirical data, regarding local retention versus larval dispersal for marine metapopulations with pelagic larval stages (Botsford et al. 2009). Many models and studies demonstrate that oceanic currents have a dominant role in larval dispersal with negligible or minor effects of late-stage larval swimming on distribution (Lugo-Fernandez et al. 2001; Yeung and Lee 2002; Siegel et al. 2008; Treml et al. 2008; Christie et al. 2010). However, geography and larval behavior, such as vertical migration and horizontal movement, can also minimize long-distance dispersal and contribute noticeably to local recruitment (Wolanski et al. 1997; Cowen 2002; Jones et al. 2009). Despite model predictions pointing toward greater larval retention, some regional, if not long-distance, dispersal also occurs for species whose larvae exhibit vertical migration or horizontal swimming. For example, most modeled recruitment for the Caribbean spiny lobster (*Panulirus argus*) was local, but about 20 percent of the simulated larvae settled more than 1000 km away from the spawning site (Butler et al. 2011). Also, orange clownfish (*Amphiprion percula*) larvae in Papua New Guinea have both retention and dispersal according to DNA parentage analysis (Planes et al. 2009). When taking into account larval behaviors such as diel and ontogenetic vertical migrations, even a small percentage of long-distance larval dispersal supports demographic connectivity.

3.1.2. Connectivity in the GOM

Specifically in the GOM, habitat "stepping stones" may appear topographically distinct and somewhat isolated, but they represent ecological nodes that are connected via passive and active movements throughout the GOM region. Several studies support connectivity in the GOM based on transport via ocean currents (Lugo-Fernandez et al. 2001; Phinney et al. 2001; Jordan-Dahlgren 2002; McBride and Horodosky 2004; Paris et al. 2008; Vásquez-Yeomans et al. 2009). Based on drifter routes, potential larval connectivity exists for broadcast-spawning coral species, and perhaps even some brooding species, between West and East Flower Garden Banks and to other banks and platforms to the east and southwest within the GOM (Lugo-Fernandez et al. 2001). Ocean currents may have had an important role in the die-off of *Diadema antillarum* most likely by dispersal of a waterborne pathogen from the western Caribbean Sea into the GOM in 1983-1984 (Phinney et al. 2001). A high degree of gorgonian species similarity occurs across large distances in the southern GOM, and gorgonian distribution appears to be linked by surface currents (Jordan-Dahlgren 2002). Ocean currents are also capable of dispersing long-lasting, planktonic ladyfish (morphs *Elops saurus* and *E.* sp.) larvae across long distances in the eastern GOM (McBride and Horodosky 2004). Currents are likely the driving mechanism for transporting bonefish larvae (*Albula* spp.) from offshore areas of the GOM and Mexican Caribbean to coastal nursery grounds (Vásquez-Yeomans et al. 2009). Some degree of connectivity is evident among populations of queen conch (*Strombus gigas*) that may support its existence as a metapopulation; although the population in Campeche Banks, Mexico, appears isolated, the Mexican Caribbean queen conch population is slightly related to the Cuban and Floridian populations as a result of some subregional larval exchange via the Loop Current (Paris et al. 2008). Therefore, the queen conch demonstrates weak demographic connectivity but steadily maintained genetic connectivity.

Beyond larval dispersal, other types of ecological connectivity also exist at higher trophic levels throughout the GOM. For example, post-settlement movements of large red snapper (*Lutjanus campechanus*) are evidence for connectivity on a regional scale, and red snapper have the demographic structure of a metapopulation in the GOM (Patterson 2007). Also, highly migratory species demonstrate ecological connectivity patterns on a wider scale. Some well-known migratory species, such as loggerhead turtle (*Caretta caretta*) and whale shark (*Rhincodon typus*), actively move throughout the GOM (Girard et al. 2009; Hueter et al. 2009).

Within the GOM region, ecological connectivity at various scales can be mapped according to specific life history strategies, suitable habitat sites, and geophysical conditions and patterns. As exemplified above, demographic connectivity of metapopulations, wide-ranging populations, and highly migratory species should be protected in the GOM to provide the ecosystem the best opportunity for recovery after a disturbance. The most reliable place-based method for protecting connectivity is to protect habitats that such species require to complete their life cycles.

3.2 Biodiversity

Biodiversity is the variety of species and the variability of their abundances throughout space and time of a defined study (Magurran 2004). Reduction of biodiversity can adversely affect ecological stability. Functional groups of species perform specific roles, many of which are linked to ecosystem services provided to society, and removal of a functional group can destabilize an ecosystem (Folke et al. 2004). Therefore, maintaining biodiversity, which includes isolated populations, is an important objective in ecosystem-based management and marine spatial planning initiatives.

Key biodiversity indicators include measures of species richness and species evenness and identification of occurrences of rare species, such as those listed according to federal statutes (i.e. Endangered Species Act of 1973, as amended [16 U.S.C. § 1531 et seq.]) and the IUCN (International Union for Conservation of Nature and Natural Resources) Red List of Threatened Species (IUCN 2010). The GOM hosts more than 15,000 species making it one of the most diverse marine ecosystems in the world (Tunnell 2009). The GOM is a faunal transition zone, or ecotone, with high biodiversity of mesopelagic fishes (Bangma and Haedrich 2008). GOM had the highest abundance, biomass, and species richness but intermediate species evenness and percent endemism when comparing mesopelagic fish fauna to those of the North and South Sargasso Seas and the Venezuelan and Columbian Basins of the Caribbean Sea. High but variable levels of biodiversity of benthic fauna exist throughout the GOM continental shelf (Rabalais et al. 1999). However, the northern GOM generally does not have high biodiversity of deep-benthic fauna, but the Mississippi Trough has the highest deep-benthic species richness in the northern GOM (Haedrich et al. 2008). Finally, seabird diversity varies seasonally, but the southern GOM hosts close to four times as many seabird species as the northern GOM (Peake 1999; Davis et al. 2000; Tunnell 2007c).

A comprehensive biological inventory of the GOM reported thousands of species in various habitats through 2007, which is the most recent biodiversity assessment published for the GOM region (Felder and Camp 2009). There are few site-specific biodiversity reports available, with the exception of many publications based on studies conducted at the Flower Garden Banks in the northwestern GOM. The northwestern GOM is the "center of distribution and evolution" for species and community diversity in the northern GOM (Fig. 1.3; Rezak et al. 1985). In the southern GOM, coral reef biodiversity gradients decrease from east to west and from south to north (Withers and Tunnell 2007). Beyond the available information for the Flower Garden Banks, biodiversity estimates can be calculated subregionally using query results from the online portal for the Biodiversity of the Gulf of Mexico Database, which is the most comprehensive, recent compilation of species accounts in the GOM (Moretzsohn et al. 2011). Biodiversity estimates and comparisons could be used to identify which of the many hard banks and reefs on the GOM continental shelf (Table 1.1) would be ideal sites for increased protection based on species richness and abundance.

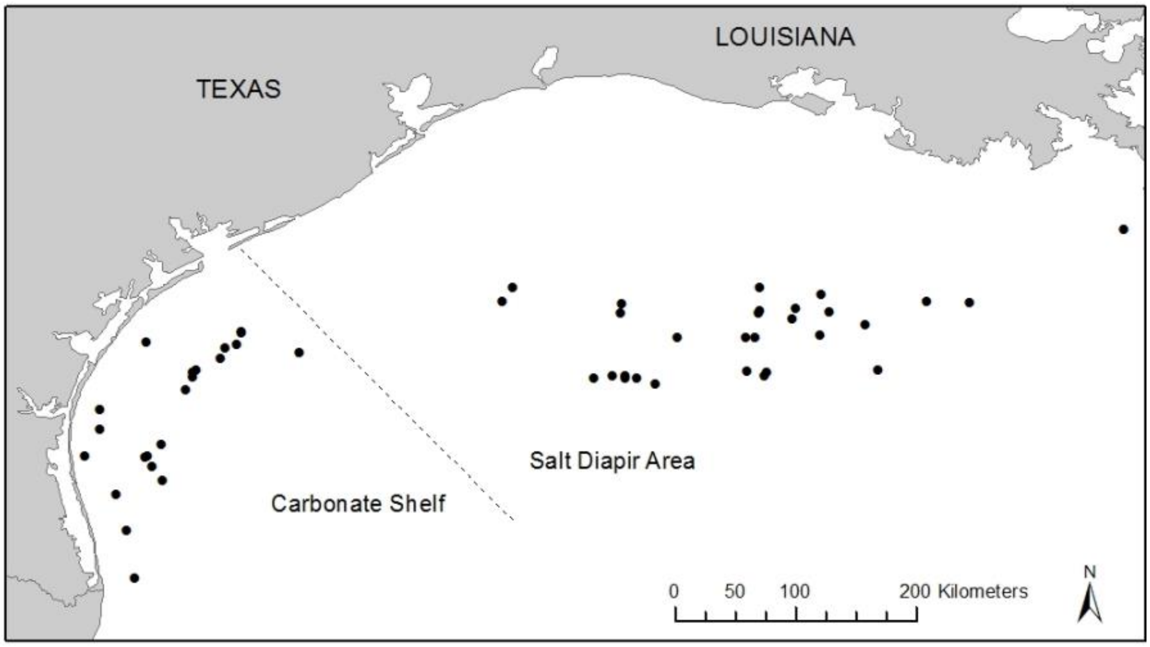

Fig. 1.3. Selected high-biodiversity sites in the northwestern GOM.
Adapted from: Rezak et al. 1985.

Table 1.1
Hard banks and reefs on GOM continental shelf in federal waters.
Sources: Rezak et al. 1985; Tunnell 2007b.

Geographic group	Number of known sites	Location
Northwestern Reefs & Banks	34	Off Texas & Louisiana
Northeastern Reefs & Banks	9	Off Mississippi, Alabama, & northern and mid Florida
Southwestern Florida Shelf	3	Off southern Florida
Northwestern Cuban Reefs	4	Between Punta Hicacos & Cabo de San Antonio
Campeche Bank Reefs	15	Off western Yucatan
Veracruz Reef System	25	Off City of Veracruz
Tuxpan Reef System	6	Off City of Tuxpan and Cabo Rojo
South Texas Banks	22	Off Texas south of Matagorda Bay

4. Network design

From a spatial-planning perspective, the existing hard-substrate banks and reefs of the GOM large marine ecosystem would translate well into an international network of MPAs. Some of the many intermediate delivery cold seeps on the continental slope may have developed diverse communities that offer connectivity to some of the hard-bottom habitats as well. However, as a result of few studies on the relationship of chemosynthetic sites and their communities to other habitats and communities, currently no evidence exists to support or refute ecological connectivity with other habitats. While there is evidence of biological connectivity between hard banks and reefs and oil and gas platforms (Lugo-Fernandez et al. 2001), the relatively short lifespan of the platforms may not warrant their inclusion in an MPA network. Nevertheless, network management design should include features to incorporate flexibility to modify existing features and add future components and adaptability to accommodate temporal and spatial ecological shifts resulting from long-term dynamics, such as climate change, and episodic events, such as natural or anthropogenic disasters. An MPA network would facilitate ecological recovery following such destabilizing events. For example, if a hurricane destroys one habitat area and its subpopulation of a fish species, another habitat area might serve as a stepping stone in the restoration process as it supplies or receives larvae transported by currents.

Because larval dispersal is a fundamental, albeit poorly understood, concept on which connectivity is based, MPA network design benefits from the many studies of larval retention and dispersal. Successful larval dispersal and juvenile recruitment vary according to numerous factors, including species-specific behavior, pelagic larval duration, geographic location, food availability, predator presence, and oceanographic conditions. While protecting connectivity can inherently protect biodiversity concurrently to some extent, trade-offs between the two objectives likely persist. For example, to maximize connectivity through larval dispersal, optimal inter-MPA spacing would likely be much smaller than the optimal spacing for maintaining biodiversity or spreading risk (Almany et al. 2009). Hence, a group of MPAs designed to maintain passive connectivity would be relatively close together while a set of MPAs aimed at preserving many species would site the individual MPAs farther apart from each other.

In combination with information describing larval dispersal and biodiversity, key design factors to consider are span of the network, size and shape of the MPAs, number of MPAs, and placement of MPAs within the network (Lubchenco et al. 2003). Placement could be further divided into two criteria: geographic location of a single MPA and distance between MPAs within the network. Although demographic connectivity patterns are not yet reliably detectable, geographic location and availability of suitable habitat may influence connectivity more than larval duration, reef size, and distance (Jones et al. 2009; Toonen et al. 2011). Network design guidelines include ecological objectives of preserving connectivity and biodiversity (Sala et al. 2002; Lubchenco et al. 2003; Fernandes et al. 2005; Roberts et al. 2006; McCook et al. 2009). The Great Barrier Reef (GBR) Marine Park is the largest network of marine reserves (no-take MPAs) in the world and was rezoned in 2004 following many network design guidelines. The GBR Marine Park rezoning is an excellent example of successful, large-scale marine spatial planning with results that demonstrate substantial contributions to biodiversity protection and ecosystem resilience (McCook et al. 2010).

However, even the successful GBR rezoning marine spatial plan cannot be applied to the GOM region without considering major contextual differences. When compared to the GBR setting, the GOM region has very different biophysical features, ecology, socioeconomics, and policies. For example, the GOM has far fewer coral reefs but is more than four times larger than the GBR, and biodiversity is much higher in the GBR than in the larger GOM. Additionally, the Australian government strongly supported the GBR rezoning project while a network of MPAs in the GOM would require trinational support from countries with different histories, political structures, and cultures. Nonetheless, the GBR rezoning project is an excellent example of systematic marine spatial planning for conservation. Connectivity and biodiversity parameters in the GOM should be identified and prioritized to support several alternative designs for a trinational MPA network.

5. Marine policy and law in the GOM

Most waters in the GOM belong to one of the three bordering nations. However, there are two small areas, the Western Gap and the Eastern Gap, that are located beyond the Exclusive Economic Zone (EEZ) of the U.S., Mexico, or Cuba and, therefore, subject only to international law. For practical and geographical purposes, the scope of this analysis is limited to federal waters in the GOM, thus excluding the Western and Eastern Gaps and the state waters along the U.S. Gulf coast. Mexico and Cuba do not have designated state waters; thus, the analysis extends to the coast in Mexican and Cuban waters while the U.S. analysis is focused offshore beyond state waters. Coincidentally, geology and ecology in the GOM region favor such a demarcated analysis as well.

5.1. Existing marine protected areas in the GOM

The U.S., Mexico, and Cuba each have MPAs in their Gulf waters. However, the three nations do not use a consistent definition of MPA. Much confusion exists regarding the term "marine protected area." Some people confuse MPA with a no-take area or marine reserve. As a result, new terms, such as "marine managed area," are being used to avoid the misconception that an MPA is not a multi-use designation. The IUCN uses six categorical definitions, which helps alleviate the confusion to some extent by focusing on conservation criteria instead of nomenclature. In the U.S. and elsewhere, MPA examples include federal parks, sanctuaries, monuments, critical habitats, essential fish habitats, wildlife refuges, and National Estuarine Research Reserves (NERRs); tribal refuges; state and local NERRs (federal/state joint protection), parks, reserves, and conservation areas; non-governmental set-asides by organizations or other private property owners; and *de facto* MPAs designated for other purposes such as exclusion areas, oil and gas lease blocks, or shipping lanes.

For the sake of consistency in designing an international network of MPAs, this discussion uses the definition asserted in the U.S. President's Executive Order (13158) issued in 2000: "any area of the marine environment that has been preserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part of all of the natural and cultural resources therein." Therefore, non-governmental and *de facto* MPAs are excluded. Also, recall that the scope of this discussion is limited to federal waters in the GOM, which eliminates inclusion of state and local MPAs in the U.S. considering the jurisdictional boundaries within U.S. waters.

5.1.1. United States

Of all the GOM MPAs in the U.S., 95% by area are in federal waters (NOAA 2011); therefore, associating an MPA network with offshore waters of the U.S. Gulf is justified. MPAs cover about 40 percent of the U.S. GOM, and there are 295 MPAs in the U.S. waters of the GOM, which includes small state and local MPAs (NOAA 2011). Most areal coverage is protected to some extent by the National Marine Fisheries Service (mostly related to fisheries management). Only one percent of the U.S. MPAs in the GOM has a no-take restriction;

therefore, almost all GOM MPAs in U.S. waters are designated as multi-use (NOAA 2011). Domestically, the Rookery Bay National Estuarine Research Reserve is coordinating development of a communication framework for existing coastal MPAs (including state and local MPAs) to coordinate and cooperate as a network in the northern Gulf region (Young 2011). Although such a northern coastal network is beyond the scope of an international network, merging the coastal and offshore networks could be a future goal once they are both well established.

Legal authorities and managing agencies vary greatly for the U.S. MPAs. However, despite the legislative fragmentation, the National Marine Sanctuary Program (NMSP) is the federal agency that is most likely to coordinate an international network of MPAs from the U.S. perspective given that the NMSP's statutory authority stems from the National Marine Sanctuaries Act of 1972, as amended (16 U.S.C. § 1431 et seq), which is focused solely on MPAs. NMSP manages two GOM MPAs: Florida Keys National Marine Sanctuary located off southwestern Florida and Flower Garden Banks National Marine Sanctuary located about 100 mi off the Texas and Louisiana coasts. For the Flower Gardens site, NMSP issued a Draft Management Plan in October 2010 that includes a proposed expansion to modify existing boundaries and to add six banks with 500-m buffers in the northwestern GOM to the sanctuary (NOAA 2010). The site selections were based primarily on topography and presence of coral assemblages. If approved, the expanded sanctuary could provide a good starting point for developing a Gulfwide network of MPAs.

5.1.2. Mexico

Unlike the U.S., Mexico has a national system of protected areas, which encompasses both terrestrial and aquatic environments. Such a consolidated system minimizes regulatory confusion and redundancy because one federal agency, *Comisión Nacional de Áreas Naturales Protegidas* (CONANP), manages and regulates the protected areas for the entire nation. The Mexican Gulf hosts several MPAs—two national parks, two protected areas of flora and fauna, and one sanctuary (CONANP 2011). In the western portion of the southern GOM, CONANP protects the Tuxpan and Veracruz reef systems, and in the eastern portion of the southern GOM, the agency protects the Alacrán reef and a couple of lagoon and beach areas. Mexico protects additional coastal areas, such as sea turtle beaches, that afford protection to the marine environment, but the protected area borders do not extend into the GOM. Coral reefs in the southern GOM (Fig. 1.4), whether existing or prospective Mexican MPAs, are likely candidates for inclusion in an international network.

5.1.3. Cuba

Like Mexico, Cuba has a national system of protected areas. The *Centro Nacional de Áreas Protegidas* (CNAP) is the centralized agency that manages and regulates Cuba's *Sistema Nacional de Áreas Protegidas* (SNAP), which is a national system for all protected areas and includes an MPA subsystem, *Subsistema de Áreas Marinas Protegidas* (SAMP). SNAP designates eight categories, each of which is aligned with one of the six IUCN categories describing protected areas.

Although Cuba has a much higher percentage of federal waters designated as MPAs than either the U.S. or Mexico, there are very few resources available for management, monitoring, and enforcement of the existing Cuban MPAs. Also, little protection exists off the northwestern coast that would be within the scope of an international MPA network in the GOM. In addition to the fore reefs that fringe the entire northwestern coast of Cuba, the Los Colorados Archipelago

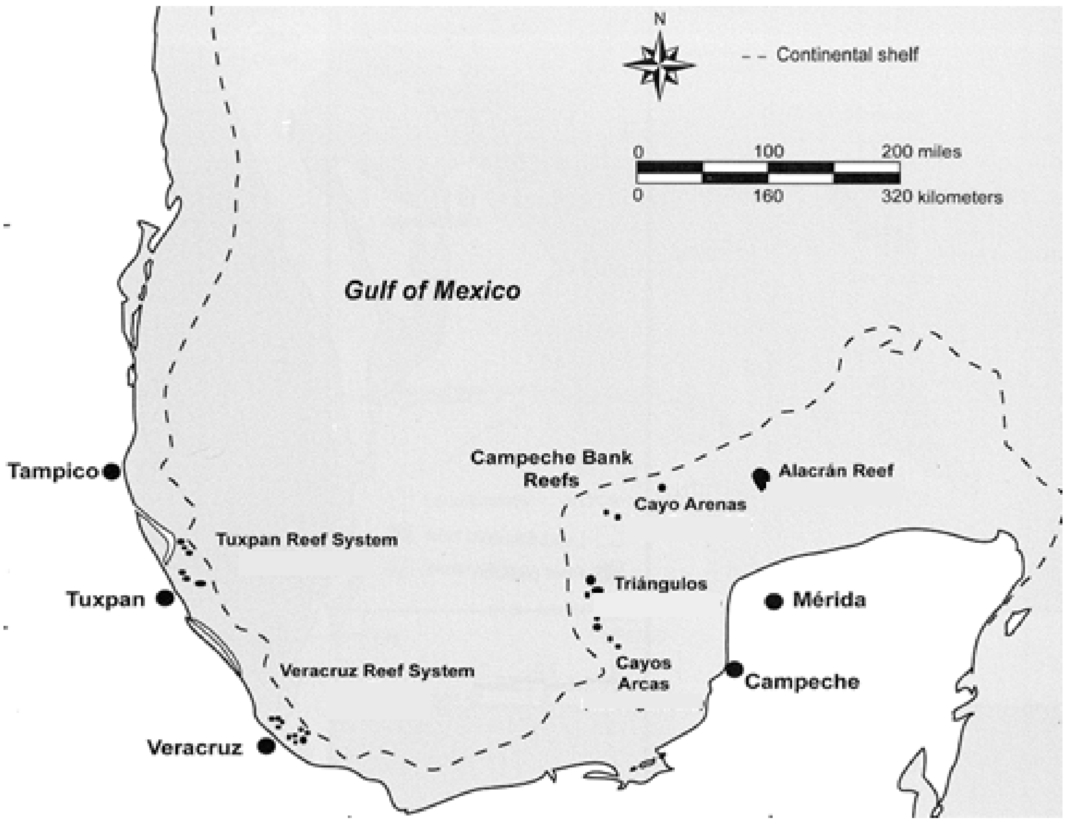

Fig. 1.4. Coral reefs in the southern GOM.
Adapted from: Tunnell 2007b.

contains many shallow reefs within and to the north of the Guanahacabibes Gulf, which extends west to northern tip of Cabo de San Antonio (Fig. 1.5; Alcolado et al. 2003). The only MPAs near the Los Colorados Archipelago, however, are the Guanahacabibes National Park and the Guanahacabibes Peninsula Protected Area of Managed Resources; these MPAs overlap to some extent and are located on the peninsula south of Guanahacabibes Gulf (SNAP 2010). Also, the Guanahacabibes Peninsula is recognized as a Biosphere Reserve by UNESCO (United Nations Educational, Scientific and Cultural Organization) (IUCN and UNEP-WCMC 2010). The northern coast within the study area has five smaller MPAs: Cinco Leguas Wildlife Refuge, Bacunayagua Ecological Reserve, Laguna de Maya Wildlife Refuge, Laguna del Cobre-Itabo

Wildlife Refuge, and Rincón de Guanabo Protected Natural Landscape (Estrada Estrada et al. 2004; IUCN and UNEP-WCMC 2010; SNAP 2010). Several other MPAs within the study area are recommended or proposed, but they have not yet been designated (Estrada Estrada et al. 2004; IUCN and UNEP-WCMC 2010; SNAP 2010).

5.2. Toward an integrated international governance in the GOM region

Transboundary species utilize habitats with disregard to political boundaries. Therefore, disconnected national marine policies and various anthropogenic pressures throughout the GOM region affect these species directly. Adverse and beneficial effects on transboundary resources caused by one nation's policies are felt by other nations that value the same resource. Therefore, objectives of effective trinational governance of living marine resources in the GOM are: (1) to understand the key elements that maintain biological connectivity and biodiversity; and, (2) to agree on international

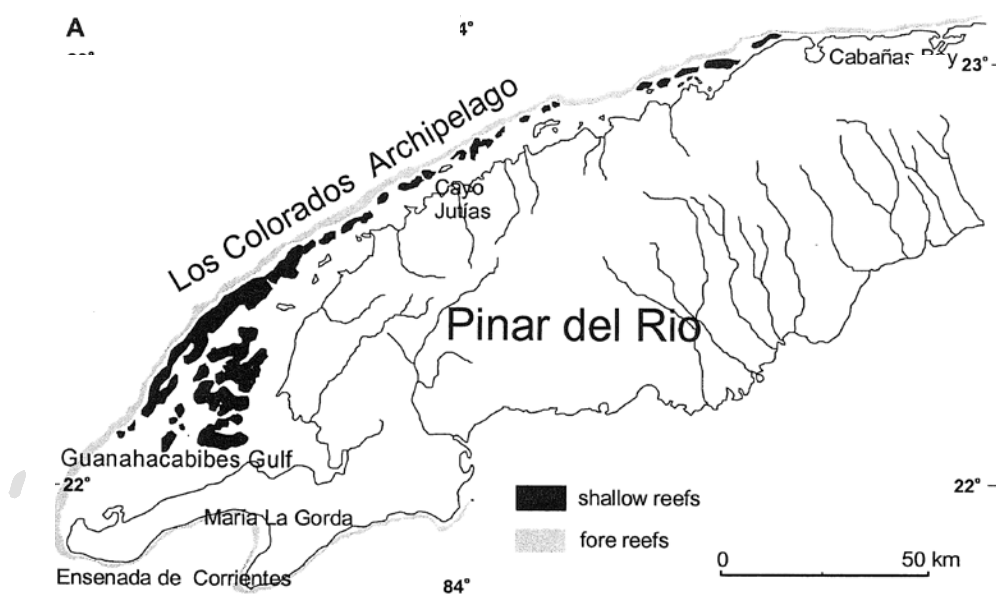

Fig. 1.5. Cuban reefs in the GOM.
Adapted from: Alcolado et al. 2003.

policies and governance mechanisms to seamlessly protect and conserve the large marine ecosystem and to sustainably manage its transboundary living marine resources.

International policy agreement must be flexible enough to apply within the various legal systems that govern management and use of marine resources in the GOM. The U.S., Mexico, and Cuba governments each have different legal systems. The U.S. government operates under the common law system, Mexico is governed by the civil law system, and Cuba has a legal system that is an evolving hybrid of common and civil laws that is based on communism. Despite the lack of similar legislative frameworks in the GOM region, the three nations each have governance mechanisms in place that could support an MPA network as discussed in section 5.1.

Additionally, the GOM is subject to international law, most notably the 1982 United Nations Convention on the Law of the Sea (UNCLOS 1982). One of the most important designations created by UNCLOS is the EEZ. The EEZ grants exclusive authority to the coastal nation over all marine resources out to 200 nmi. Per Article 56(1), such authority gives coastal nations "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources" (UNCLOS 1982). Authority within the EEZ even extends to marine scientific research; Article 24 states that foreign researchers must obtain the coastal nation's consent, which is typically granted when the coastal state is allowed access to data and participation in the research. Beyond the EEZ provisions, UNCLOS has language that mandates collaborative international marine policy. For example, Article 123 requires international coordination regarding living marine resources of semi-enclosed seas, such as the GOM (Alexander 1999).

Important differences among the three GOM-bordering nations extend beyond legal systems as evidenced by the tenet that a nation's law is generally compatible with and reflective of the nation's social culture (Licht et al. 2005). Hence, the scope of international policy analysis includes cultural considerations of history, politics, religion, and socioeconomics as factors that influence legal systems. As an example of different historical biases, the American legal system looks toward the future while Mexican law reflects the past cultural and historical influences (Vargas 1998). Regardless of culture or legal system, however, undisputed scientific knowledge is widely accepted as factual. Therefore, internationally accepted science provides a strong basis for international policy, which often represents compromise or trade-offs among conflicting interests, such as those regarding social welfare or political agendas (Underdal 2000).

Historically, few, if any, efforts have been made in the GOM to manage transboundary living marine resources on an international scale through federal cooperation of the U.S., Mexico, and Cuba (Cruz and McLaughlin 2008). The design of an ecology-based decision support tool for international marine policy in the GOM region will be strengthened when coupled with a compatibility analysis of existing U.S., Mexican, and Cuban national marine policies and legislation applicable to the GOM. Such analysis would identify similarities and consistencies, resolvable differences, and impassable divergences among the three nations' legal frameworks and laws while recognizing each nation's cultural values. By focusing on similarities and resolvable differences and international law, the three nations may reach an agreement regarding resource management while protecting stakeholder interests, such as fishing practices, cultural resources, and offshore energy production.

Regarding a transboundary MPA network, several implementation mechanisms exist and fall within the scope of marine spatial planning efforts. Continuation of existing trinational collaborations, such as those mentioned in section 1, would certainly support long-term success of the network. Bottom-up coordination through data-sharing portals would connect MPA practitioners throughout the GOM region. In turn, top-down governance strategies would be more successful with strong local support for similar initiatives. International funding opportunities through environmental organizations could encourage investment of national resources into international marine conservation, policy, and governance. Moreover, the creation of a trinational commission or advisory body charged with implementation and management of the international MPA network would emphasize the importance of Gulf-wide, place-based management of shared living marine resources.

6. Next steps

Based on identifiable physical and biological features and phenomena, the GOM would be an ideal location for a large-scale network of MPAs. As a result of past and ongoing trinational efforts, scientists and policy makers from the U.S., Mexico, and Cuba have identified strategies and continue to work together to ensure success of international management of shared living marine resources. An ecology-based spatial planning tool would enhance the understanding of connectivity elements and processes, identify specific sites with high biodiversity, minimize political discontinuity, and maximize coordinated protection while managing transboundary living marine resources based on biological requirements. A geographic information system (GIS) would be an optimal platform for conducting a gap analysis stemming from the composite of several layers of physical and biological data describing the GOM's ecological network. Optimization analyses could produce alternative designs for consideration of a network of MPAs linking existing and potential new sites based on the connectivity strength of biological parameters, including species diversity. Connectivity strengths, biodiversity conservation needs, and national policies and priorities would drive the design of several scenarios for international management of an MPA network in the GOM. Also, a network design would include features to incorporate flexibility to add future components and adaptability to accommodate temporal and spatial ecological shifts resulting from episodic events, such as natural or anthropogenic disasters, and long-term dynamics, such as climate change. An MPA network would facilitate ecological recovery following such destabilizing events. Proposed and alternative network designs, along with metrics for measuring success, would be presented to the trinational group as the first step in the international policy decision-making process to protect and conserve transboundary living marine resources in the GOM. Successive steps should include socioeconomic analyses and stakeholder participation opportunities.

Although the GBR rezoning success is a superb example, many regions in the world, including the GOM region, may not fit the GBR model scenario closely enough to duplicate the process for reasons stated in section 4. Much planning and international collaboration in the GOM could provide a second global example for creation of a large-scale MPA network, which, in this case, would also have a prominent international marine policy component. Simplification of such a decision support tool could be considered to apply the modeling concept to other international water bodies with similar characteristics.

Given the focusing event of the Deepwater Horizon oil spill in April 2010, implementation of an international MPA network in the GOM is timely. In 2010, the U.S. President issued an Executive Order (13547), which focused on issues including, but not limited to, marine biodiversity protection, improving resilience of marine ecosystems, development of coastal and marine spatial plans, and international cooperation. In response to the disaster and to the Executive Order, the U.S. federal government created task forces, planning bodies, funding vehicles, and goals to enable clean-up and recovery efforts to succeed in the GOM. With the heightened incentive for collaboration among the three GOM-bordering nations, effective and efficient conservation and management of transboundary living marine resources could become a reality. The existing ecologically connected habitat sites throughout the continental shelf and slope of U.S., Mexican, and Cuban waters provide an opportunity for innovative international marine policy at a regional scale. Although a toolbox full of sectoral management options exists, an international MPA network would unify regional management strategies for sustainable transboundary living marine resources in the GOM large marine ecosystem.

The ecological principles presented in this chapter provide a solid foundation for designing an international network of MPAs in the GOM. Next steps in this research include policy analyses and spatial designs for creation of an MPA network. Successful implementation, however, would require socioeconomic research to address the GOM's human ecology, including valuation of ecosystem services and strong stakeholder support. The trifecta of ecology-based spatial design, trinational governance, and socioeconomic incentives would present the U.S., Mexico, and Cuba with the opportunity to form an international MPA network that facilitates sustainable, ecosystem-based management of transboundary living marine resources in the GOM while creating a cooperative environment among nations with historically disparate political and policy objectives.

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CHAPTER 2

A POLICY APPROACH TO ESTABLISH AN INTERNATIONAL NETWORK OF MARINE PROTECTED AREAS IN THE GULF OF MEXICO REGION

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Format: *Marine Policy* used as format.

Abstract

Existing conditions in the Gulf of Mexico region support an enterprise to establish an international network of marine protected areas for joint consideration by policy decision-makers from the United States, Mexico, and Cuba. The analysis presented in this chapter explores governance of living marine resources in the Gulf of Mexico and discusses legal frameworks and authorizing laws specific to marine protected areas in the United States, Mexico, Cuba, and the international arena. Although the three nations have different legal systems and regulatory frameworks, the United States, Mexico, and Cuba each have governance objectives to move toward ecosystem-based management, which inherently includes protection of transboundary living marine resources. Federal and international legal mechanisms, including creation of a trinational memorandum of understanding and implementation of the Cartagena Convention, are identified as the most logical and efficient next steps toward creating the International Gulf of Mexico Marine Protected Area Network to protect transboundary living marine resources.

1. Introduction

The Gulf of Mexico (GOM) is a semi-enclosed, international sea that comprises a large marine ecosystem bordered by three nations: the United States (U.S.), Mexico, and Cuba. Each of the three very different countries has similar and dissimilar uses for GOM resources, both living and non-living. Research presented here focuses on governance and policies related to transboundary living marine resources, which is a phrase intended to include not only highly migratory species but also species with movement patterns on smaller spatial scales and species that are not motile in all life stages, such as sessile adult mollusks that have pelagic larvae. While transboundary living marine resources ignore GOM political boundaries, national governance regimes and policies concerning living marine resources do not extend beyond borders. Therefore, discontinuity among national marine policies inevitably ensues. However, even disparate national marine policies have similar goals from an ecological perspective, and international collaborations are underway in the GOM region to align conservation and policy initiatives to protect shared living marine resources, maintain connectivity, exchange best management practices, and respond to threats.

One policy tool proposed by scientists and managers is an international network of marine protected areas (MPAs) to protect important habitat features. Such a network in the GOM could ensure habitat protection for transboundary species and, therefore, contribute to sustainability of living marine resources shared by the U.S., Mexico, and Cuba. Currently no international policy scheme exists for creation and maintenance of an international MPA network in the GOM. However, other international MPA networks exist and may provide helpful lessons learned. For example, the Commission for Environmental Cooperation (CEC) manages the North American Marine Protected Areas Network, which includes the U.S., Canada, and Mexico. The compatibility analysis of existing marine policies and laws in the GOM region presented herein provides a governance-based platform for development of cooperative international marine conservation and policy, specifically addressing place-based management options. The proposed solution targets trilateral place-based management through identification of legislative mechanisms for consideration by policy decision-makers from the U.S., Mexico, and Cuba who strive to establish the International Gulf of Mexico Marine Protected Area Network (IGOMMPAN).

2. Research objectives and methods

The research objectives are 1) to determine whether existing legal frameworks of the GOM-bordering nations would allow for IGOMMPAN, and 2) to identify compatible aspects of policy and law related to place-based management among the three nations. The premise is that existing statutes, regulations, and/or policies of the U.S., Mexico, and Cuba and the international community have language describing vehicles or mechanisms to support design, creation, and management of IGOMMPAN. The ultimate goal of the research is to combine the policy results with science-based network designs to maximize coordinated international protection while managing transboundary living marine resources based on biophysical characteristics of the GOM region.

The first step in the research was to describe legal systems and government structures and legislation applying to living marine resources. Next, place-based management types and existing MPAs in the GOM region were identified. Domestic and international laws and policy tools from the three countries were compared to identify compatible language and vehicles that would support IGOMMPAN. Potential non-legislative challenges were also identified based on cultural differences among the U.S., Mexico, and Cuba. Finally, results from the legislative and policy compatibility analysis and from the study of cross-cultural challenges were combined to propose a policy solution for creation and sustainable management of IGOMMPAN. Results of each research phase are discussed in the following sections.

3. Management and protection of living marine resources in the GOM region

Although the GOM is a large international sea, the majority of the living marine resources fall within a national jurisdiction. A coastal state’s exclusive economic zone (EEZ) extends to 200 nmi beyond the shoreline, and the coastal state has complete authority within its EEZ to explore, exploit, conserve, and manage resources (UNCLOS 1982). The U.S. EEZ covers most of the northern Gulf, the Mexican EEZ includes most of the southern and southwestern Gulf, and the Cuban EEZ includes much of the southeastern Gulf (Fig. 2.1). Two small triangular areas, the Western and Eastern Gaps, are beyond all three EEZs and are categorized as the high seas, which are considered *res nullius*, meaning that they are owned by nobody. The two gap areas are isolated pockets of international waters with no known special or rare habitat features for living marine resources. Although no international treaties currently exist to protect habitat for living marine resources in the GOM high seas, which includes only the water column, one regional fishery management organization, the International Commission for the Conservation of Atlantic Tunas (ICCAT), has responsibilities within the Western and Eastern Gaps. The U.S. and Mexico are members of ICCAT, which conducts research and collects information on the populations and fisheries of tunas and tuna-like species. ICCAT members must follow ICCAT recommendations, unless member-specific objections are filed, and must collect statistical, biological, and economic data describing the fisheries (ICCAT 2007).

The U.S. and Mexico signed a treaty delimiting the continental shelf in the Western Gap; as a result, the two countries have authority to manage the non-motile living marine resources in or on the seabed within the Western Gap (Treaty on the Delimitation of the Continental Shelf 2000). If a delimitation treaty for the Eastern Gap is signed among the U.S., Mexico, and Cuba, the three countries will have authority to manage such living marine resources in or on the seabed of the Eastern Gap as well.

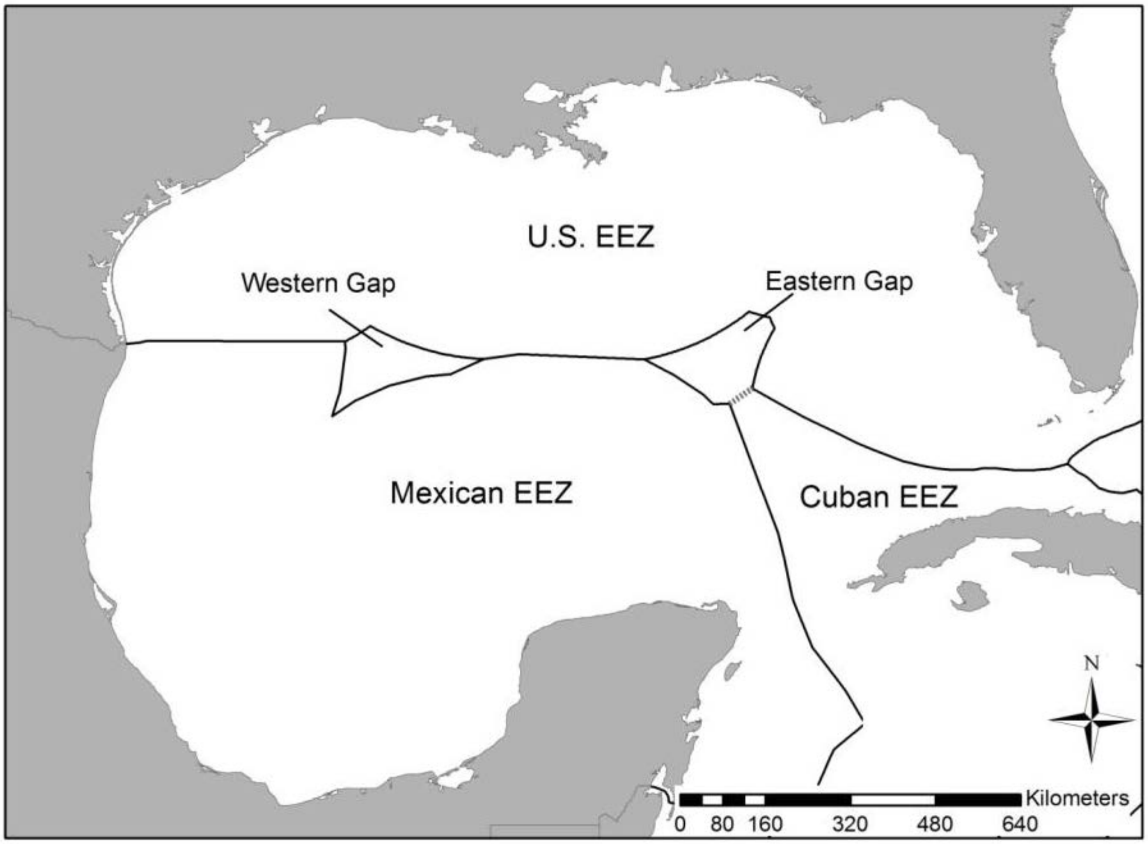


Fig. 2.1. Exclusive economic zones in the Gulf of Mexico. Dotted line indicates that the formal boundary has not yet been agreed upon for the Eastern Gap.

Each of the three Gulf-bordering nations has its own set of laws, regulations, and policies that apply to living marine resources. In general, the U.S., Mexico, and Cuba and the international community exhibit a bifurcated approach toward management and protection of living marine resources and their habitats—typically, regulatory measures are focused on 1) sustainable management of species and/or populations targeted by a fishery, or 2) species and/or populations in need of conservation protection based on their rarity or rapidly declining abundance. These management approaches often include habitat protection features based on the species-specific requirements. Although the trend toward ecosystem-based management is strengthening, ecological complexities present hurdles to resource managers, particularly while management authority remains sectoral.

While management provisions specific to some highly migratory species exist, no legal protections apply to highly migratory species that are not fishery targets, transboundary species that are not migratory on large spatial scales, or pelagic early life stages for species with sessile adults. However, a properly designed IGOMMPAN could provide ecosystem-scale protection for such species that are not covered by species-specific legislation, sector-based management, or international treaties. To set the stage for a legislative approach toward creating IGOMMPAN, a synthesis of federal and international governance regimes regarding living marine resources follows.

3.1. United States legal and governance regime

The U.S. federal government operates under the common law system, and therefore, power lies with the judicial branch. Statutory language is intentionally vague, which leads to much case law to determine a statute's specific implementation. As a result, common law is heavily based on interpretations of statutes, which is often strongly influenced by the legislative intent (through readings of Congressional debates, deliberations, and statements of consideration). Variable statutory interpretations allow for legal adaptation without amending a statute or enacting a new one, but the concept of following precedent maintains legal consistency and order in a legal system with specialized, yet vague, statutes. Precedence is based on *stare decisis*, which is the practice of letting the decision stand, meaning that a judge would not likely overturn a previous judicial decision within the same jurisdiction. Hence, case law is very important in the common law system.

3.1.1. Fragmented federal authority

The structure of federal agencies with environmental authority in the U.S. has remained largely unchanged since their inceptions in the 1960s and 1970s. A recent notable exception, which occurred in the wake of the BP Deepwater Horizon oil spill disaster, is the renaming of Minerals Management Service to Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) and the successive split of BOEMRE into the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). U.S. federal agencies typically operate within the limitations of an agency-specific statute and its implementing regulations, which often have very specific language to ensure robust regulatory oversight. For example, most of the National Park Service's (NPS) activities fall within the scope of the National Park Service Organic Act (16 U.S.C. § 1 et seq.). The National Oceanic and Atmospheric Administration (NOAA), however, is an exception. No organic act grants statutory authority to various agencies within NOAA. Instead, a collection of statutes, including, but not limited to, the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (16 U.S.C. § 1801 et seq.), the Marine Mammal Protection Act of 1972 (16 U.S.C. § 1362 et seq.), and the National Marine Sanctuaries Act of 1972 (NMSA; 16 U.S.C. § 1431 et seq.), specify requirements of regulatory agencies within NOAA. Additionally, the U.S. Coast Guard (USCG) enforces many of NOAA's regulations concerning living marine resources (Showalter and Schiavinato 2003). Several overarching environmental statutes, such as the National Environmental Policy Act of 1969 (NEPA; 42 U.S.C. § 4321 et seq.) and the Endangered Species Act of 1973 (16 U.S.C. § 1531 et seq.), have language that applies to all federal agencies.

Because the U.S. federal government exhibits stovepipe organization that is often reinforced by agency-specific organic statutes, federal authority is fragmented despite overlapping geographical delineations and strong ecological connectivity of natural resources subject to regulatory control. A prime example of fragmented authority in the U.S. GOM occurs off the southern coast of Florida. Within a relatively small region, three federal agencies exert separate control over living marine resources, many of which move regularly among the different jurisdictional areas, instead of having a single, multiagency management plan. The National Marine Fisheries Service (NMFS) imposes fishing restrictions within the Pulley Ridge and East Hump MPA Habitat Areas of Particular Concern (HAPCs); the NPS regulates activities within the Dry Tortugas National Park (DTNP); and the Office of National Marine Sanctuaries (ONMS) manages resources within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and the Tortugas Ecological Reserves (Fig. 2.2). Various statutory authorities for MPAs are discussed in detail in section 4.

Furthermore, the U.S. has a component of jurisdictional complexity that Mexico and Cuba do not face. Within the U.S. EEZ, jurisdiction is divided between federal and state government authorities. Most states control waters from the shoreline out to 3 nmi. Two exceptions are Texas and the Gulf coast of Florida, both of which control waters out to 9 nmi. Federal waters exist beyond the state waters to the outer boundary of the EEZ. For the purposes of this dissertation, only federal waters will be considered within the scope of analysis.

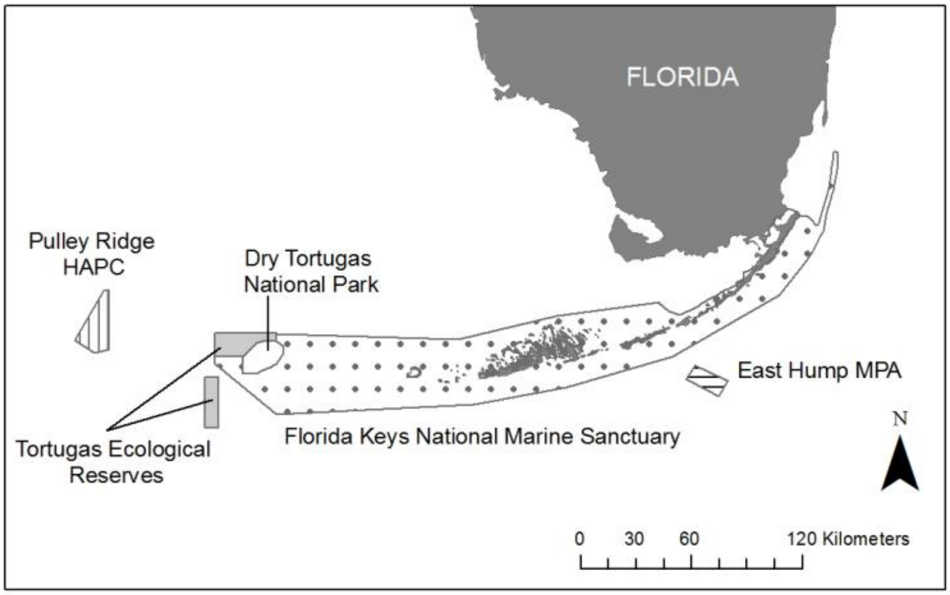


Fig. 2.2. Southern Florida MPAs.

3.1.2. Holistic progress

Overlapping federal jurisdictions obfuscate U.S. national strategies for achieving ecosystem-based management goals. Given the sectoral authorities of federal agencies, the shift in scientific perspective toward ecosystem-based management outpaces legislative and regulatory progress. Typically Congress takes months or years to enact new legislation; likewise, the procedures federal agencies must follow to promulgate new regulations could take months or years. However, executive power allows the U.S. President to issue an executive order (EO), which can create legal requirements much more quickly than the passage of a legislative bill through Congress. In July 2010, EO 13547 (75 FR 43021) created the National Ocean Council and provided for a new National Ocean Policy, including the development of regional coastal and marine spatial plans. Although statutes were not amended, the EO requires multiagency planning across sectors for integrated, adaptive, ecosystem-based management. The policy focuses on ecosystem health, biodiversity, resiliency, conservation and sustainability, and improved scientific understanding of ecosystems like the GOM. Importantly, EO 13547 mandates that the U.S. is "cooperating and exercising leadership at the international level" (75 FR 43021). Many regional planning bodies, task forces, and other cross-cutting organizations now work collaboratively to design and provide comprehensive regional governance for living marine resources of the GOM region. In conclusion, progress is underway in the U.S. to alleviate problems that arise from fragmented federal authority.

3.2. Mexico's environmental policy progression

Mexico has a civil law system in which power of the federal government lies with the legislature. Civil law, much like international law, relies heavily on specific language of the statutes as they often take the form of codes to be followed in an exact manner. Precedence is not a factor in a judicial decision in a civil law system as the statutory codes are written so explicitly that it is highly unlikely that judges' statutory interpretations would differ. Therefore, in theory, the lack of variability in statutory interpretations in the Mexican legal system increases regulatory predictability and stabilizes expectations of regulated entities when compared to the common law system.

3.2.1. Governance regime shift

The Mexican federal government operated under hegemonic rule of a single party for most of its existence since the Mexican Revolution, which ended about 1920. The *Partido Revolucianario Institucional* (PRI) was the party in power until 2000. Over the course of several decades, Mexico's governance regime transitioned from electoral authoritarianism to democracy through electoral reform by uncoordinated opposition to the hegemonic power (Diaz-Cayeros and Magaloni 2001; Schedler 2002). Democratic consolidation culminated with the 2000 elections when PRI was defeated for the first time. Under a democratic regime, Mexico began the process of decentralization and increased attention to environmental policy.

3.2.2. Environmental decentralization

Mexico's democratization has enabled and catalyzed the more recent process of environmental decentralization. Decentralization of environmental policy and regulatory authorities enables a bottom-up governance mechanism to function in concert with top-down governance of the federal government (see section 5 for further discussion). Sustainable and protective environmental policy necessitates a blend of governance mechanisms because many environmental policy solutions require substantial local input from scientific, public policy, and resource management perspectives. Mexico's overarching environmental decentralization statute, *Ley General del Equilibrio Ecológico y la Protección al Ambiente* (LGEEPA; General Law of Ecological Equilibrium and Environmental Protection; 1988 and 1996), provides for municipalities to have environmental regulatory authority unless specifically retained under federal or state jurisdiction and also supports public participation in local government processes (Rivera-Arriaga and Villalobos 2001; Assetto et al. 2003). As a result, all Mexican states now have environmental laws, but implementing regulations and enforcement capabilities are weak (Rivera-Arriaga and Villalobos 2001). Other primary environmental statutes and regulations include *Ley Federal del Mar* (Federal Law of the Sea; 1986), *Ley General de Vida Silvestre* (LGVS; General Law of Wildlife; 2000), *Ley General de Pesca y Acuacultura Sustentables* (LGPAS; General Law of Sustainable Fisheries and Aquaculture; 2007), *Ley Orgánica de la Administración Pública Federal* (Organic Law of Federal Public Administration; 1976), *Ley General de Desarrollo Forestal Sustentable* (General Law of Sustainable Forest Development; 2003), and *Norma Oficial Mexicana* (Mexican Official Standard) 059-SEMARNAT-2010 (NOM

059 2010), which lists threatened and endangered species, and *Norma Oficial Mexicana* 022-SEMARNAT-2003 (NOM 022 2003), which specifically protects mangrove species (Bezaury-Creel 2005; SEMARNAT 2006).

Environmental decentralization in Mexico is a work in progress as the traditional centralized power continues to dominate local governance regimes. The longstanding centralized and authoritarian government regime left persistent impediments to implementation of environmental policies and regulations at the state and local levels. For example, environmental enforcement and policy decision-making remain centralized within the federal government because of extremely limited local financial capacity and local regulatory involvement (Assetto et al. 2003). A shift in federal environmental policy toward eliminating sector-based management likely improves conservation and sustainable management of natural resources, but policy integration at the federal level may also hinder development and implementation of local environmental regulations.

Just as lingering features of centralism do not facilitate a diffusion of power, some aspects of Mexican traditional culture may temper environmental decentralization. A prime example is the false dichotomy between democratization and *caciquismo*, a sociopolitical custom of systemic intermediation by an individual or a clique. Democratization theoretically counters Mexico's longstanding *caciquismo*, but reformation of politics and governance creates enough instability to fuel continuity of *caciquismo* to some extent, which could have a culturally stabilizing effect thus reinforcing its governance role (Pansters 2005; Zárate Hernández 2005). Decentralization reformation results in increased local authority, but in Mexico, the persistent, albeit waning, presence of *caciquismo* may dissuade the public from seeking or retaining control over environmental issues. Thus, decentralization may not always foster a culture that touts equitable public participation, particularly on a local scale. As seen in other developing countries undergoing environmental decentralization, Mexico faces the challenge of employing environmental governance standards without eliminating culturally accepted practices (Batterbury and Fernando 2006).

Mexican federal agencies have been reorganized several times resulting in a division of authority over living marine resources, but most environmental agencies, including *Comisión Nacional de Áreas Naturales Protegidas* (CONANP) that regulates protected areas, fall within the *Secretaría de Medio Ambiente y Recursos Naturales* (SEMARNAT). An exception is the regulatory agency for fisheries, *Comisión Nacional de Acuacultura y Pesca* (CONAPESCA), which lies within the *Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (SAGARPA). Unfortunately, legal compliance is not strong, and environmental enforcement is weak and ineffective, particularly at local levels, because of insufficient funds, lack of monitoring capability, low fines, and lack of expertise and equipment (Rivera-Arriaga and Villalobos 2001; Bezaury-Creel 2005; Fragas and Jesus 2008). Inherently and unfortunately, weak enforcement foments weak compliance, which stifles regulatory effectiveness. Institutional framework is in place at the federal level for effective conservation and management of living marine resources, but political will does not provide ample support of policy implementation to match the governance structure. Moreover, Mexican federal agencies have some overlapping jurisdictions; therefore, federal agencies do not always cooperate well (Bezaury-Creel 2005). Finally, although continued environmental decentralization has potential to lead to some fragmented regulatory authority, Mexico's *Comisión Interseceretarial para el Manejo Sustenable de Mares y Costas* (CIMARES) may guide governance away from regulatory fragmentation via interagency planning for sustainable management of living marine resources.

CIMARES was created in 2008 and includes not only SEMARNAT but also secretariats that govern fisheries, tourism, navigation, security, and other coastal and marine issues (CIMARES 2010).

3.3. Cuba's environmental policy in a socialist regime

Cuba implements a hybrid of the common and civil law systems that is influenced by communism. The single-party government operates within a socialist framework and has a president (often referred to as a dictator) and a Council of State, which governs the nation when the popularly elected National Assembly of the People is not in session (Bauer et al. 2012). The Cuban legal system reflects socialist ideals because the laws are intended to provide not only a regulatory role but also a dynamic, evolutionary role in society (Salas 1985; Evenson 1998). During the evolution of Cuba's government and legal system throughout long-lasting efforts to sever ties with Spain, the U.S. influences in Cuba were ubiquitous (Pérez 2003). To support repeated annexation attempts, most Cubans modeled many aspects of governance and life after those of the U.S. Historically, many Cubans were educated in the U.S., which enhanced similarities between the two countries as such educational influence shaped several professional practices, including law. Because of Cuba's intimate history with the U.S., the Cuban legal system has similarities to the common law system despite the frequent reliance on written code as the primary source of law. For example, in lieu of a jury system as in the U.S., Cuba's legal system has lay judges and professional judges, the latter being elected, as opposed to Mexico's civil system, which does not have any form of popular legal participation (Salas 1985; Bauer et al. 2012). Although Cuba's economic crisis triggered some bureaucratic decentralization in the 1990s, environmental policymaking in Cuba is still centralized for the most part (Whittle and Rey Santos 2006; Cruz and McLaughlin 2008). As a result, policy implementation in Cuba typically avoids bureaucratic delays that often occur in decentralized nations, such as the U.S. and Mexico.

3.3.1. Environmental legislative context

Despite environmental legal reformation that lagged that of most other countries by 20 to 30 years, Cuba has some of the most impressive ecological communities in the GOM and wider Caribbean region. Biodiversity of living marine resources remains high partially because of Cuba's long-term political and economic isolation, which has precluded prolificacy of destructive practices such as overfishing and rapid coastal development. Nevertheless, decades of environmentally damaging land use practices and other anthropogenic pollution have degraded many natural resources and ecological communities; interestingly, most damage occurred before the end of the Cuban Revolution (Whittle and Rey Santos 2006).

Beginning with a speech at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, President Fidel Castro led Cuba through a period of environmental legislative reform in the early 1990s (Whittle and Rey Santos 2006; Evenson 1998). Cuba amended its constitution, enacted laws, promulgated regulations, and developed policies to promote sustainable development and environmental protection throughout the 1990s. During the same time period, a governmental reorganization caused a shift in authority for such legislation and policies with the creation of a cabinet-level agency focused solely on environmental protection—the *Ministerio de Ciencia, Tecnología y Medio Ambiente* (CITMA), within which are several environmental agencies and institutions (Whittle and Rey Santos 2006). CITMA's organic act, *Ley 81 del Medio Ambiente* (Law 81; 1997) was passed in 1997, three years after the creation of CITMA. Law 81 addresses many environmental issues, notably including coastal zone management and protected areas, and instituted a major reconstruction of Cuban environmental law (Evenson 1998).

Although CITMA is the agency with most authority over environmental resources, three other cabinet-level agencies have jurisdiction over some marine resources. The *Ministerio de la Industria Pesquera* (MIP) regulates fisheries, the *Ministerio de la Agricultura* houses the *Empresa Nacional para la Protección de la Flora y la Fauna* (ENPFF), which manages many protected areas, and the *Ministerio de la Industria Basica* regulates oil and gas extraction including offshore petroleum deposits. CITMA has made great progress in designing new environmental policies and legislation, and in several cases Cuba now has more stringent environmental mandates than the U.S. or Mexico. For example, Cuba's legal requirements for environmental impact assessment require avoidance, minimization, and mitigation of adverse environmental impacts, but the U.S. environmental impact assessment legislation only calls for analysis of alternatives without requiring any protective actions (Whittle and Rey Santos 2006). CITMA has developed comprehensive environmental law, and the challenges now are policy implementation and regulatory enforcement to make sustainable environmental protection a reality in Cuba. Indeed, as demonstrated by CITMA's rapid progress, Cuba's environmental legislative reform has been the primary tool used to transform society to one aiming to protect and sustainably manage environmental resources.

3.3.2. Perpetuating environmental conservation and protection

In Cuba, economic recovery comes at the expense of environmental protection. For example, an increase in tourism is boosting the nation's economy; yet, without comprehensive enforcement of environmental legislation, increases in pollution and environmental degradation may ensue. Unfortunately, Cuba lacks substantial resources for environmental monitoring and enforcement despite the enactment of progressive decrees aimed at protecting the environment. Hindrances to technological modernity, such as the lack of full access to the internet, also affect the nation's ability to maintain connectivity and exchange information with other countries. Although Cuba faces many challenges as a result of technological deficiencies and weak funding, the nation makes great progress with few resources. Government planning is a top priority in socialist regimes; therefore, Cuba focuses on design of policies and governance frameworks, including those in the environmental arena. Effective public participation and enforcement are deterministic features that could influence successful implementation of Cuba's strong environmental legislative framework. Cuba's increased information sharing and participation in trinational intiatives, conferences, and workshops will enhance the ability of the Gulf-facing nations to protect and sustainably manage GOM living marine resources (Alzugaray 2006).

3.4. International governance

The United Nations Convention on the Law of the Sea (UNCLOS 1982) is the most comprehensive international law that applies to the entire GOM. Although the U.S. is the only GOM nation that has not ratified UNCLOS, compliance with most UNCLOS provisions is considered a requirement under customary international law. UNCLOS provides for juridical zones that are consistently applied by the three Gulf-facing nations. The Western and Eastern Gaps (see Fig. 2.1) are the only areas of high seas where international legal provisions related to the high seas and the extended continental shelf apply. Many other international treaties also apply to GOM resources; however, not all three countries are parties to all treaties so a lack of consistency creates a challenge for international coordination. Table 2.1 lists international treaties that apply to living marine resources in the GOM.

UNCLOS encourages international cooperation regarding living marine resources and protection and preservation of the marine environment of semi-enclosed seas, such as the GOM, with consideration of features that are characteristic of the region (UNCLOS art. 123, 197 1982; Alexander 1999; Goodwin 2011). The language, however, is not strong enough to require specific implementation procedures (McLaughlin 2008), and the requirement is simply to make an effort either directly or through a regional organization to coordinate activities on an international scale. Historically, few efforts have been made in the GOM to manage transboundary living marine resources on an international scale through federal cooperation of the U.S., Mexico, and Cuba (Cruz and McLaughlin2008). However, several non-federal organizations have programs or efforts in place to address shared resources of the GOM region (see section 5). The blowout of the BP Deepwater Horizon oil well in April 2010 focused international attention on the GOM. As a result, the new U.S. National Ocean Policy, per EO 13547, requires international cooperation and leadership from the U.S. government. A resulting example of international law stemming from EO 13547 is the Agreement between the United States of America and the United Mexican States Concerning Transboundary Hydrocarbon Reservoirs in the Gulf of Mexico (2012), which is an oil and gas treaty geographically focused on the maritime boundary region of the GOM. The national and international attention on the state of living marine resources in the GOM has created a political climate that encourages international cooperation, which is key to successful conservation and management of transboundary resources.

Table 2.1
Chronologically ordered international conventions concerning GOM species and habitat conservation and management as ratified by nations bordering the GOM.
Sources: Díaz-Briquets and Pérez-López 2000; CIMARES 2010; DeBey 2011.

Treaty[a]	**U.S.**	**Mexico**	**Cuba**
Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere (Western Hemisphere Convention)	✓	✓	
International Convention for the Regulation of Whaling (ICRW)	✓	✓	
Convention on the High Seas (CHS)	✓	✓	
International Convention for the Conservation of Atlantic Tunas[b]	✓	✓	
Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention)	✓	✓	✓
Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention)	✓	✓	✓
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	✓	✓	✓
Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries[b]	✓		✓
Convention on the Conservation of Migratory Species of Wild Animals (CMS)			✓
United Nations Convention on the Law of the Sea[c] (UNCLOS)		✓	✓
Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (Cartagena Convention)	✓	✓	✓
Agreement on Cooperation for the Protection and Improvement of the Environment in the Border Area (La Paz Agreement)	✓	✓	n/a[d]
Protocol for Specially Protected Areas and Wildlife in the Wider Caribbean Region to the Convention for the Protection and Development of the Marine Environmental of the Wider Caribbean Region (SPAW Protocol)	✓		✓
Convention on Biological Diversity (CBD)		✓	✓
North American Agreement on the Environmental Cooperation (NAAEC)	✓	✓	n/a[e]
Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (Compliance Agreement)	✓	✓	
Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (Fish Stocks Agreement)	✓		
Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC)	✓	✓	

[a] This table does not include several other ocean treaties, such as those related to pollution, that do not focus expressly on conservation and management of living marine resources and habitats. Legal citations for listed treaties are in Literature Cited.
[b] These treaties lack widely used abbreviations. ICCAT refers to the Commission, not the Convention.
[c] The U.S. has not ratified UNCLOS but has accepted most provisions as customary international law.
[d] A bilateral treaty between the U.S. and Mexico.
[e] A trilateral treaty among Canada, the U.S., and Mexico.

In addition to international treaties, many informal international agreements, which are not legally binding, exist regarding living marine resource conservation and management. Several relate to living marine resources in the GOM, but few involve Cuba. Three bilateral international fishery memoranda of understanding (MOUs) exist between the U.S. NMFS and Mexico's CONAPESCA. Of the three MOUs, two are applicable to the GOM—one regarding the MEXUS-Gulf research program and one concerning information exchange (DeBey 2011). Also, in 1994 the U.S., Mexico, and Canada signed the North American Agreement on Environmental Cooperation (NAAEC; 1993), which complements and coincided with the North American Free Trade Agreement (1993). The NAAEC created the Commission for Environmental Cooperation, a trinational organization that addresses shared environmental issues such as MPA networks. The same three nations also signed an MOU in 1995 to create the Canada/Mexico/U.S. Trilateral Committee for Wildlife and Ecosystem Conservation and Management, which focuses on cooperation and coordination to conserve and manage species and ecosystems (DeBey 2011). The U.S. Department of the Interior and Mexico's SEMARNAT signed an MOU in 1995 focusing on cooperation regarding natural protected areas, among other issues (ELI and CMDA 2011). In February 2012, the U.S.'s ONMS and Mexico's CONANP signed an MOU to foster a cooperative relationship regarding conservation, administration, and management of MPAs, including transboundary networks (SEMARNAT and NOAA 2012). All three GOM-facing nations are members of the Intergovernmental Oceanographic Commission Sub-Commission for the Caribbean and Adjacent Regions, which falls within the United Nations Educational, Scientific and Cultural Organization (UNESCO) (DeBey 2011). Also, the U.S., Mexico, and Cuba are all members of the Western Central Atlantic Fishery Commission, which is governed by the United Nations Food and Agricultural Organization and aims to encourage conservation and rational, sustainable management of transboundary fishery resources among other goals (DeBey 2011).

3.5. Comparison of legal systems in GOM region

Although substantial differences exist between the civil and common law systems, the U.S., Mexico, and Cuba have comparable sources of national law, and such sources are hierarchically aligned consistently among the three countries. Stemming from the concept of federalism, constitutional law is the most powerful and authoritative in each Gulf-facing nation. Each country has, in declining order of power, federal laws, state or provincial laws, and county, local, and/or municipal laws, regulations, or codes. Although legal similarities exist, the division of power varies among the three countries. The U.S. states have more domestic legal authority than the Mexican states or Cuban provinces. Accordingly, the Mexican and Cuban federal governments maintain broader authorities than the U.S. federal government. For example, the U.S. states have domestic control and sovereign authority over waters and submerged lands to a specified distance (3 nmi for most states; 9 nmi for Texas and Florida’s Gulf coast) offshore. In contrast, Mexico and Cuba do not grant domestic authority to states over coastal waters or submerged lands, which remain under federal control per their constitutions.

Despite the difference in division of authority among federal and state governments, most authority for implementation of national environmental law lies with federal agencies for each of the three nations. However, the nations differ in their structuring of the federal government from the perspective of distribution of authority among federal agencies. The U.S. federal government is highly fragmented with overlapping, disconnected, and divergent authorities among many different agencies that regulate living marine resources. Goals of achieving efficiency and effectiveness within the U.S. federal government are challenging given the limited statutory authorities of individual regulatory agencies. Dispersion of similar or shared authorities among multiple agencies hinders legislative and regulatory processes and progress, especially for holistic concepts, such as ecosystem-based management, that require intense interjurisdictional cooperation. The Mexican and Cuban federal governments are much more centralized, which facilitates legislative and regulatory progress in many respects. Centralized regulatory control facilitates design and implementation of a single, effective approach to management, regulation, and enforcement. Given Mexico's democratization and Cuba's communist influence, Cuba's federal government is more centralized than Mexico. The more centralized governments typically have more expedient legal processes whereas legislative progress in the U.S. can be very lengthy, and the successive regulatory promulgations often require compliance with several statutes and coordination among many federal agencies thus lengthening the bureaucratic timeframe.

Despite the legal differences among the Gulf-facing nations, each nation has a solid legislative framework in place aimed at protecting living marine resources within the respective EEZs. Each nation's environmental legislation could be improved, however, to achieve sustainable ecosystem-based management. New policies requiring international collaboration, innovative funding mechanisms for enforcement and monitoring, and mandatory information sharing are legislative needs shared by the U.S., Mexico, and Cuba. Differences in legal systems pose no major hurdle because the three federal governments acknowledge the shared need for sustainable living marine resources. International law encourages and requires international cooperation regarding conservation and management of living marine resources (UNCLOS art. 117-120 1982). Continued trinational collaboration through existing and new legislative vehicles will increase efficiency and effectiveness with which the three nations protect and manage transboundary resources.

4. Place-based management

Transboundary living marine resources would benefit from coordinated, place-based management on the scale of the large marine ecosystem. Ideally, ecosystem-scale, place-based management for the GOM region would consist of a network of MPAs, which would be linked through geographic, ecological, and management connections. Place-based management is a common concept with different degrees of implementation. Specific terms and their definitions and interpretations vary by country and by stakeholder. For the purposes of this analysis, place-based management is discussed in terms of direct goals for conservation and sustainable management of living marine resources and their habitats. Many legal and policy vehicles exist in federal and international regimes that focus on other issues, such as point and non-point pollutants, that supplement ecosystem-based management, but such mechanisms are beyond the scope of this analysis.

Legally and empirically, various perceptions of protected areas challenge international efforts to implement spatial tools effectively. Fortunately, the International Union for the Conservation of Nature (IUCN) is global environmental organization that, among other things, has policy in place to encourage consistent interpretation and understanding of place-based management. The IUCN defines an MPA as “any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment” (Kelleher 1999). Additionally, the IUCN defines a protected area network to be “a collection of individual protected areas that operates cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfill ecological aims more effectively and comprehensively than individual sites could alone," and the IUCN specifically identifies an MPA network as a system "to connect and protect those areas needed to bolster ecosystem functioning so that the overall health of the ocean is not jeopardized by human uses" (Brock et al. 2012).

Despite the IUCN's attempt to create a global standard for the definition of an MPA or MPA network, many nations have their own legal definitions that vary slightly. The U.S. has a definition specific to MPAs: "any area of the marine environment that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (EO 13158). Mexico and Cuba each have one federal agency that regulates most terrestrial and aquatic protected areas; therefore, Mexico and Cuba each have one definition for all protected areas. Mexico's LGEEPA defines protected areas to be "…original environments that have not been significantly altered by human activity or that require to be preserved and restored" (LGEEPA art. 3 1988 and 1996). In Cuba, Law 81 declares protected areas to be "specially enshrined to protect and maintain biodiversity and natural resources, socially and culturally associated, to achieve the specific objectives of conservation" (Law 81 art. 8 1997). Note that the U.S. definition does not include designations according to international law or designations by other means; therefore, it is the most legally restrictive of the four definitions.

Beyond legal definitions, terminology creep and inconsistent use of terms hinder effectiveness of place-based management, especially in marine ecosystems. Various stakeholders misinterpret the umbrella term "marine protected area," which has led to creation and use of new terms to avoid perpetuation of unsupported stigmas. The biggest myth associated with MPAs is that they are all no-take areas, also known as marine reserves, meaning that all fishing activities are prohibited. On the contrary, not all MPAs are no-take areas. In an effort to clarify the often misunderstood definition of an MPA and to dissolve associated stigmas, MPA practitioners have coined and used many other terms. Ironically, attempts to clarify terminology increased confusion because there is no umbrella term with a standard definition. Instead of using standardized terminology as submitted by the IUCN, the field has been inundated by many other general terms that include, but are not limited to, marine managed area, marine conservation area, marine wilderness, and marine reserves. Inconsistent terminology, legal and otherwise, may exert confounding effects on trinational marine spatial planning.

Furthermore, each country in the GOM region has programs and tools in place aimed at integrated coastal and ocean management, which takes into account watershed impacts, MPAs, and other spatial planning concepts. The three countries are in different stages of the integrated management process. As with other cross-jurisdictional efforts, Cuba is the leader in the GOM region regarding integrated coastal zone management plans and organizations, likely due in part to Cuba's fewer bureaucratic hurdles and more centralized regulatory structure. Legal instruments that enabled Cuba's rapid progress in integrated management are Law 81, *Decreto-Ley 212-2000* (Decree-Law 212; 2000), and *Acuerdo 3139 del Comité Ejecutivo del Consejo de Ministros* (CECM 3139; 2001). Decree-Law 212 created zones and imposes robust restrictions on coastal development (Houck 2000). Permanent structures are prohibited in the coastal zone, and the zone of protection, which extends inland 20-40 m from the coastal zone, allows only non-permanent structures and some agriculture (Gebelein 2012). However, monitoring and enforcement may still be concerns for Cuba's integrated management and watershed plans. For example, Cuba's *Sistema Nacional de Áreas Protegidas* (SNAP) has a mandate for using geographic information systems, but SNAP is understaffed and has technological limitations regarding geospatial analysis.

Mexico has a land and sea use planning effort, specifically *Ordenamiento Ecológico Marino y Regional del Golfo de México y Mar Caribe*, which is broad and identifies potential targets for improved resource protection and management. The legal basis for the land and sea use planning is the 2003 LGEEPA regulation (2003). However, there is no comprehensive legal framework to support integrated coastal and ocean management in Mexico (Bezaury-Creel 2005; CIMARES 2010). Mexican law solely provides sectoral regulatory authority, which limits the government's ability to develop regulations for integrated coastal zone management. However, some integrative policy tools are available. Regulations exist not only for MPAs but also for ecological zoning programs, which spatially distribute economically productive activities at federal, state, and municipal levels (Bezaury-Creel 2005). Additionally, CIMARES developed a *Política Nacional de Mares y Costas de México* (CIMARES 2010), which is an important progressive step toward developing a foundation for a legal instrument to require integrated management for sustainable living marine resources.

Finally, the U.S. has recently begun efforts for coastal and marine spatial planning (CMSP), which is an ecosystem-based, place-based management tool intended to combine activities that fall within various agency jurisdictions (see section 4.2) for the purpose of collaborative planning and management of multiuse ocean areas. The legal basis for CMSP is EO 13547. CMSP is expected to reduce the redundancy of planning efforts by agencies that have overlapping jurisdictions by incorporating multi-use (non-sectoral) zoning into regional, integrated, cross-jurisdictional plans. Although in very different stages of implementation, all three federal approaches in the GOM region for integrated watershed, coastal, and ocean management have merit as valuable place-based management tools.

4.1. Categories of place-based management

In addition to different definitions and umbrella terms mentioned above, confusion arises from different categorization schemes for protected areas. The IUCN has defined seven categories of protected areas based on management objectives in an effort to standardize terminology further (Table 2.2). One type of IUCN protected area may be nested within another; for example, a protected seascape may have a portion designated as a strict nature reserve that requires more protective measures than the seascape. Although the IUCN categories include terminology describing types of protected areas, alphanumeric labels function to minimize nomenclature confusion as the IUCN categories are based on management objectives and uses allowed for each category. In addition to the IUCN's categories, UNESCO's Man and the Biosphere Programme (MAB) has an international committee that designates biosphere reserves, but they are not necessarily legally defined or designated MPAs (Kimball 2001).

Many countries, including Cuba, model their legal definitions of protected areas after the IUCN categories (Table 2.3; Dudley 2008). In addition to the management categories established by *Decreto-Ley 201* (Decree-Law 201; 1999) listed in Table 2.3, Decree-Law 201 also establishes three additional special classifications: Protected Areas of National Significance, Protected Areas of Local Significance, and Special Regions of Sustainable Development, which all fall within IUCN category VI (Estrada Estrada et al.

Table 2.2
IUCN protected area categories.
Source: Dudley 2008.

Category	Type	Management objectives
Ia	Strict Nature Reserve	Protect biodiversity & possibly geological & geomorphological features; strict control of human visitation, use, & impacts; self-sustaining without management but may require natural restoration
Ib	Wilderness Area	Natural forces dominate; allow self-reliant travel & indigenous ecological lifestyle; limited access
II	National Park	Protect large-scale ecological processes; allow zoned recreation; promote education; economic contributions through tourism
III	Natural Monument or Feature	Protect specific natural monument; small area with high visitor value; conserve cultural & spiritual values; protect biodiversity niches
IV	Habitat/Species Management Area	Protect particular species or habitat (fragments); requires active management; publicly accessible
V	Protected Landscape/Seascape	Protect integrity of interaction of people & nature over time; traditional management; scenic quality; recreational & tourism opportunities; broad, multiple values for protection; contains permanent settlement
VI	Protected Area with Sustainable Use of Natural Resources	Promote ecological, economic, & social sustainability; conservation & natural resource management with zoning; predominantly natural; maintain ecosystem services; includes protected area networks

2004; Gebelein 2012). However, many other countries, including Mexico and the U.S., have protected area definitions that do not align exactly with the IUCN categories (Table 2.3). Mexico's LGEEPA establishes a classification scheme that permits zoning in each category so they correspond indirectly to some IUCN categories, but management objectives do not include improvement of human ecology elements unlike some IUCN management objectives (Fragas and Jesus 2008). Similar to Cuba's additional classifications, Mexico has two additional classifications: state reserves or parks and municipal ecological preservation areas (Fragas and Jesus 2008). Protected areas in Mexico that do not fall within CONANP's jurisdiction are not included in the classification scheme. For example, CONAPESCA has authority to designate and protect fishery refuge areas. The U.S. does not have a classification scheme for protected areas, which is likely a result of the highly fragmented government structure, and therefore,

Table 2.3
Federal protected area categories of GOM countries.
Sources: Showalter and Schiavinato 2003; Estrada Estrada et al. 2004; Bezaury-Creel 2005.

Category	Corresponding IUCN category
CUBA	
Natural Reserve	Ia
National Park	II
Ecological Reserve	II
Outstanding Natural Element	III
Managed Floral Reserve	IV
Faunal Refuge	IV
Protected Natural Landscape	V
Protected Area of Managed Resources	VI
MEXICO	
Sanctuary	Ia
Biosphere Reserve	Ia for core zones; VI for buffer zones
National Park	II
Natural Monument	III
Protected Area of Natural Resources	VI
Protected Area of Flora and Fauna	VI
U.S.[a]	
National Marine Sanctuary	IV
Marine National Monument	V
National Park	II
National Seashore	V
National Wildlife Refuge	IV
National Estuarine Research Reserve	V
EFH, HAPC, fishery restrictions	n/a
Critical Habitat	n/a
No Activity Zone	n/a
National Historic Places	n/a

[a] Specific sites within a U.S. category type may correspond with different IUCN categories due to different site-specific management plans; corresponding IUCN categories listed generally align with most sites, but exceptions exist and are noted as "n/a."

protected area designations in the U.S. are not distinguished by management objectives as done with IUCN categories. Rather, protected areas in the U.S. carry labels, such as National Park, National Marine Sanctuary, No Activity Zone, and others, related specifically to terms and definitions in authorizing legislation (see section 4.2).

Related to vessel operation in EEZs, the International Maritime Organization (IMO) legally designates six other types of MPAs: routing measures, Special Areas, smaller areas within an EEZ that are not Special Areas, Particularly Sensitive Sea Areas (PSSAs), no-anchoring areas, and mandatory reporting systems within an EEZ (Kimball 2001; Hildreth 2008). Special Areas cannot receive specific pollutants from vessels, and PSSAs have broader protective measures and are still evolving in scope (Young 2007). However, because the IMO specifically oversees shipping and maritime traffic, IMO's designations do not have protection objectives related to conservation although PSSAs can account for stressors that do not originate from vessels. The only PSSA in the GOM region corresponds with the Florida Keys National Marine Sanctuary, and the Flower Garden Banks National Marine Sanctuary has three IMO-designated no-anchoring areas (Hildreth 2008).

Other MPAs designated by international law include those that are created by treaty provisions; however, the provisions do not mandate MPA designation. Of the treaties listed in Table 2.1, those best suited for international legal MPA designation from an ecosystem-based management perspective include Western Hemisphere Convention, Ramsar Convention, World Heritage Convention, Cartagena Convention and the associated SPAW protocol, CBD, and NAAEC (see section 5 for further discussion). However, none of these requires signatories to designate MPAs.

4.2. Federal regulatory agencies and laws

In the U.S., several agencies have authority over different types of MPAs according to different statutes. The broadest and most comprehensive statutory authorities for MPAs are held by ONMS and NPS in accordance with the NMSA and the Antiquities Act (16 U.S.C. § 431 et seq.), respectfully. Other agencies with authority over some types of place-based management in the GOM include NMFS, BOEM, BSEE, Environmental Protection Agency (EPA), USCG, and state resource agencies that share management responsibility (Table 2.4). Other legal mechanisms exist for creation of new MPAs in the U.S. that are not affiliated with a regulatory agency—the President can issue an EO to create an MPA independent of Congressional legislation; the President can issue a Proclamation exercising executive authority granted by the Antiquities Act; and Congress can pass a bill to enact legislation to establish an MPA. Once a new MPA is established through one of these vehicles, a federal regulatory agency, typically ONMS or occasionally NPS, delineates and manages the site. Although each federal agency operates independently according to different statutes, the agencies are expected to increase coordination through the mandatory CMSP process.

In Mexico, fewer agencies have regulatory authority over MPAs than in the U.S. (Table 2.5), but interagency cooperation is very weak. The main agency governing protected areas is CONANP, which is within SEMARNAT. However, *Procuraduría Federal de Protección al Ambiente* (PROFEPA), which is also housed within SEMARNAT, is responsible for enforcement in MPAs, which adds a layer of discontinuity because CONANP has no enforcement authority on site. Additionally, *Secretaría de Marina* (SEMAR) and SAGARPA also have regulatory roles within MPAs. SEMAR is also required to work with PROFEPA regarding regulatory enforcement for issues within MPAs (ELI and CMDA 2011).

Table 2.4
Summary of implementing legislation for U.S. MPAs.
Sources: Showalter and Schiavinato 2003; Hildreth 2008; ELI and CMDA 2011.

MPA Type	Legislative Vehicle for Designation	Designating Agency/Official	Legislative Vehicle for Management	Managing Agency
National marine sanctuary	National Marine Sanctuaries Act; Executive Order; Congressional act	Secretary of Commerce; President; Congress	National Marine Sanctuaries Act	ONMS
Marine national monument	Presidential Proclamation under Antiquities Act	President	Antiquities Act	ONMS & U.S Fish and Wildlife Service (FWS)
National park	Congressional act	Congress	Congressional act; National Park Service Organic Act	NPS
National seashore	Congressional act	Congress	Congressional act; National Park Service Organic Act	NPS
Essential fish habitat (EFH); HAPC; gear restrictions; spatial & temporal closures	Magnuson-Stevens Fishery Conservation and Management Act	Fishery Management Council	Magnuson-Stevens Fishery Conservation and Management Act	NMFS
Critical habitat	Endangered Species Act	NMFS; FWS	Endangered Species Act	NMFS; FWS
National wildlife refuge	Migratory Bird Conservation Act; Congressional act; Executive Order	Migratory Bird Conservation Commission; Congress; President	National Wildlife Refuge System Administration Act	FWS
National historic places (landmarks, sites, parks, etc.)	National Historic Preservation Act	NPS	National Historic Preservation Act	NPS; BOEM; BSEE
No activity zone, live bottom stipulations	Outer Continental Shelf Lands Act	BOEM	Outer Continental Shelf Lands Act	BOEM; BSEE
National estuarine research reserve	Coastal Zone Management Act	State & NOAA's Office of Ocean and Coastal Resource Management (OCRM)	Coastal Zone Management Act	State & OCRM

Note: This table does not include several other legislative instruments, such as those related to pollution, that do not focus on conservation and management of living marine resources and habitats. Legal citations are provided in Literature Cited.

CONAPESCA, which is within SAGARPA, regulates fisheries and has authority, including enforcement, over ocean areas regarding fishery restrictions. Place-based management within CONAPESCA, similar to place-based management under the U.S. authority of NMFS, deals with fishery regulations, such as spatial closures or gear restrictions. Therefore, CONAPESCA has sole authority over fishing restrictions, including no-take zones, even within MPAs thus restricting CONANP's authority (SEMARNAT 2006). LGPAS, which focuses on resource extraction, trumps LGEEPA; as a result, fisheries are managed for the purposes of maximizing production with disregard to environmental protection and conservation of living marine resources. However, CONAPESCA is directed to work with CONANP for place-based management despite apparent regulatory conflicts, but cooperation between agencies within SEMARNAT and SAGARPA is very weak if it occurs at all (SEMARNAT 2006; Fragas and Jesus 2008). SEMARNAT, using information from the *Comisión Nacional de Biodiversidad*, is responsible for protecting habitat for threatened and endangered species (SEMARNAT 2006). Official Mexican MPAs created under LGEEPA may or may not include no-take zones, and no-take zones can be established outside of MPAs in accordance with the LGVS (regarding protected species) or the LGPAS (regarding commercial species) (Bezaury-Creel 2005). Although both CONANP and CONAPESCA have official seats on CIMARES, CONAPESCA does not often attend CIMARES meetings and tends to withdraw from participation. Thus, weak or absent intragovernmental coordination; weak regulatory compliance; lack of financial, technical, and human resources; and absent or outdated management plans hinder realization of potential benefits of Mexican MPAs (Fraga and Jesus 2008). Combined with lingering effects of *caciquismo* and lack of local stakeholder involvement, regulatory difficulties persist. Because of regulatory disconnects between CONANP and CONAPESCA, few fishing restrictions exist in

Table 2.5
Summary of implementing legislation for Mexican MPAs.
Sources: Bezaury-Creel 2005; SEMARNAT 2006; ELI and CMDA 2011.

MPA type	**Legislative vehicle for designation**	**Designating agency/official**	**Legislative vehicle for management**	**Managing agency**
All federal protected areas	Declaration in *Diario Oficial de la Federación*	President	*Ley General del Equilibrio Ecológica y la Protección al Ambiente*	CONANP, PROFEPA, & SEMAR
Habitat for protected species	*Ley General de Vida Silvestre* & *Norma Oficial Mexicana 059-SEMARNAT-2001* (NOM-059)	SEMARNAT Secretary	*Ley General de Vida Silvestre* & NOM-059	*Dirección General de Vida Silvestre*, CONANP, & PROFEPA
Fishery refuge areas, no-take zones, & other fishery restrictions	*Ley General de Pesca y Acuacultura Sustentables*	CONAPESCA	*Ley General de Pesca y Acuacultura Sustentables*	CONAPESCA
Mangrove habitats	*Ley General de Desarrollo Forestal Sustentable* & NOM-022-SEMARNAT-2003	SEMARNAT Secretary or President	*Ley General de Desarrollo Forestal Sustentable*	*Comisión Nacional Forestal*, CONANP, & PROFEPA

Note: This table does not include several other legislative instruments, such as those related to pollution, that do not focus on conservation and management of living marine resources and habitats. Legal citations are provided in Literature Cited.

Mexican MPAs, thus exacerbating problems such as overexploitation, lack of compliance, and jeopardy of rare species populations.

In Cuba, the *Centro Nacional de Áreas Protegidas* (CNAP), within CITMA, manages the SNAP and the *Subsistema de Áreas Marinas Protegidas* (SAMP) but does not administer or manage specific sites directly (Estrada Estrada et al. 2004; Perera 2012). ENPFF, within the Ministry of Agriculture, directly manages most SNAP sites, including some nature reserves and many MPAs (Whittle and Rey Santos 2006; Perera 2012). Two other Cuban agencies have additional MPA responsibility (Table 2.6). Unlike Mexico’s conflicting structural relationship between CONANP and CONAPESCA, CNAP can designate no-take areas within an MPA with coordination of the MIP (Lindeman et al. 2003). In fact, CITMA, the MIP, and the ENPFF are jointly developing an MPA network (Whittle and Rey Santos 2006). Also, whereas the U.S. and Mexico do not have any standardized restrictions in their respective federal MPAs, Cuba has more centralized regulatory requirements. For example, Cuba prohibits mining activities within all MPAs (Dudley 2008). Two primary laws apply to MPAs in Cuba. Law 81 frames environmental management and defines CNAP and its objectives, and Decree-Law 201 more specifically defines CNAP's regulatory roles, including the category definitions discussed above in section 4.1 (Estrada Estrada et al. 2004; Gebelein 2012). The *Comité Ejecutivo del Consejo de Ministros* (CECM) creates and codifies MPAs using formal agreements as the legal approval instruments. For example, agreement CECM 4262 declared the first set of MPAs in 2001 (Estrada Estrada et al. 2004). However, few MPAs currently exist on Cuba's northwestern coast in the GOM because Cuban policies regarding living marine resources and MPAs are focused much more in Caribbean waters to the south.

Table 2.6
Summary of implementing legislation for Cuban MPAs.
Sources: Whittle and Rey Santos 2006; Gebelein 2012; Perera 2012.

MPA type	**Legislative vehicle for designation**	**Designating agency/official**	**Legislative vehicle for management**	**Managing agency**
Most official protected areas	CECM Agreements	CECM	Decree-Law No. 201 of the National System of Protected Areas; Law 81	ENPFF
No-take zones	Decree-Law 164	CNAP & MIP	Decree-Law 164	MIP
Coastal zone	Decree-Law 212	CITMA	Decree-Law 212	CITMA

Note: This table does not include several other legislative instruments, such as those related to pollution, that do not focus on conservation and management of living marine resources and habitats. Legal citations are provided in Literature Cited.

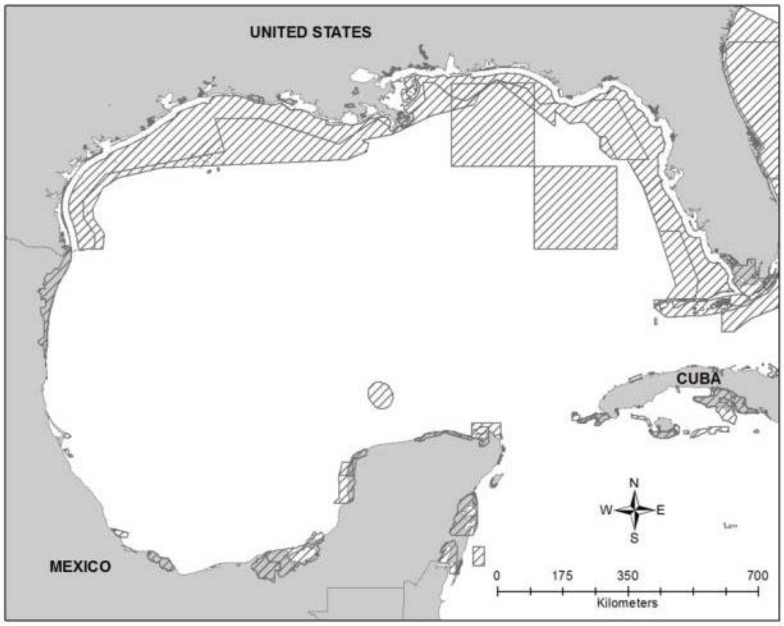
In addition to the specific legislation listed in Tables 2.4, 2.5, and 2.6, other legal requirements, notably including environmental impact analysis and consultations on protected species, must be met in each country before an MPA can be officially created. In the U.S., legal requirements stem from laws including, but not limited to, NEPA, the Energy Policy Act of 2005 (42 U.S.C. § 13201 et seq.), the Endangered Species Act of 1973, Magnuson-Stevens Fishery Conservation and Management Act, National Historic Preservation Act (16 U.S.C. § 470 et seq.), Historic Sites Act of 1935 (16 U.S.C. § 461 et seq.), Executive Order 13158 (2000), Executive Order 13089 (1998), and Executive Order 11593 (1971). Also, the Marine Mammal Protection Act of 1972 encourages protection of essential habitat for marine mammals. Most, if not all, of Mexico's and Cuba's additional procedural requirements are included in their environmental organic statutes: LGEEPA and Law 81, respectively.

4.3. Existing MPAs in the GOM

Although many MPAs exist throughout the GOM, the areal coverage of all MPAs collectively protects a small fraction of the GOM (Fig. 2.3). For the purposes of this study, only MPAs within federal waters will be addressed. Tables 2.7, 2.8, and 2.9 list the designated MPAs in the U.S., Mexico, and Cuba, respectively. For the U.S., the defined study scope eliminates consideration of many sites (well over 100) managed by state agencies or a combination of state and federal agencies. Most eliminated sites include state parks or other state protected areas and areas with federal authority including National Wildlife Refuges, National Estuarine Research Reserves, Padre Island National Seashore, Gulf Islands National Seashore, and critical habitats for the Gulf sturgeon (*Acipenser oxyrinchus desotoi*) and smalltooth sawfish (*Pristis pectinata*). However, many of the U.S. MPAs in state waters are member sites of the new Gulf of Mexico MPA Network that focuses on coastal and nearshore MPAs in the U.S. (NOAA 2011). As of

Fig. 2.3. Existing federal MPA coverage in the GOM region.
Data source: IUCN and UNEP-WCMC 2010.

A. MPAs managed by NMFS and other federal agencies.



B. MPAs excluding those designated by NMFS as fishery closures, gear restricted areas, and reef fish stressed areas.

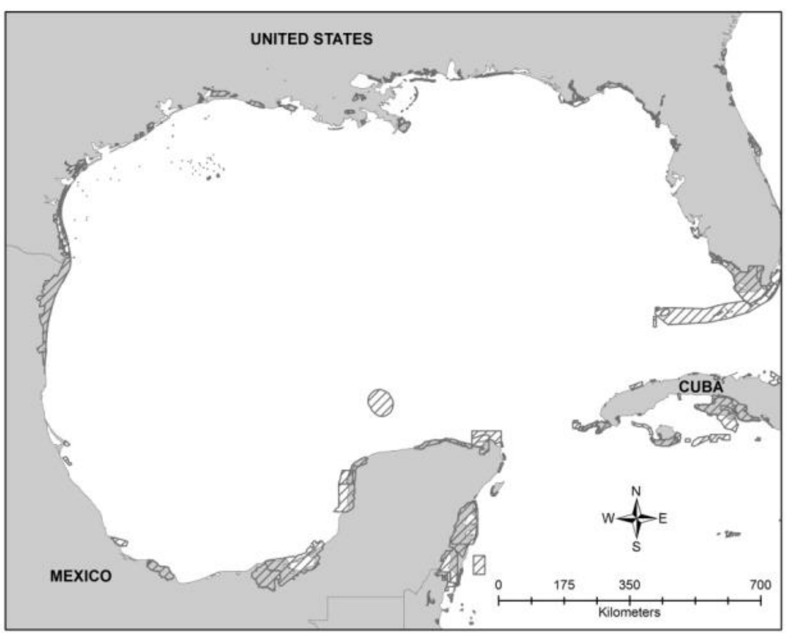


Table 2.7
MPAs in U.S. federal waters in GOM.
Sources: Coleman et al. 2004; 73 FR 72210; MMS 2008; IUCN and UNEP-WCMC 2010; MAB 2011.

Name	Federal category	Significance	Nearest state	Marine area (km^2)	Jurisdiction
Florida Keys National Marine Sanctuary	National marine sanctuary	National, international (PSSA)	Florida	9947	ONMS
Flower Garden Banks National Marine Sanctuary	National marine sanctuary	National, international (International No-Anchoring Area)	Texas	146[a]	ONMS
Dry Tortugas National Park	National park	National, international (UNESCO-MAB Biosphere Reserve)	Florida	261	NPS
Dry Tortugas National Park Research/Natural Area[b]	Fully protected research/natural area	National	Florida	168	NPS
Tortugas Ecological Reserve[c]	Ecological reserve	National	Florida	518	ONMS
Western Sambo Ecological Reserve[c]	Ecological reserve	National	Florida	31	ONMS
Critical habitats for elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals[d]	Critical habitat	National	Florida	3442	NMFS
USS *Hatteras*	National historic place	National	Texas	n/a	BOEM, BSEE, Navy
Southwest Florida Seasonal Trawl Closure	Managed fishery area	National	Florida	8787	NMFS
Shrimp/Stone Crab Separation Zones	Managed fishery area	National	Florida	597	NMFS
Alabama Special Management Zone	Managed fishery area	National	Alabama	2442	NMFS
Texas Closure	Managed fishery area	National	Texas	98,719	NMFS
Tortugas Shrimp Sanctuary	Managed fishery area	National	Florida	12,526	NMFS
Reef Fish Stressed Area	Managed fishery area	National	All	166,007	NMFS
Reef Fish Longline/Buoy Gear Restricted Area	Managed fishery area	National	All	247,982	NMFS
Madison Swanson Fishery Reserve	Managed fishery area	National	Florida	394	NMFS
Steamboat Lumps Fishery Reserve	Managed fishery area	National	Florida	357	NMFS
East and West Flower Garden Banks HAPC[e]	HAPC	National	Texas	141	NMFS

Table 2.7 Continued

Name	Federal category	Significance	Nearest state	Marine area (km²)	Jurisdiction
Florida Middle Grounds HAPC	HAPC	National	Florida	1194	NMFS
EFH	EFH	National	All	Varies	NMFS
Other HAPCs	HAPC	National	All	Varies	NMFS
NAZ	NAZ	National	All	Varies	BOEM & BSEE
Stipulation blocks	Stipulation blocks	National	All	Varies	BOEM & BSEE

[a] If proposed expansion plan is approved, the sanctuary would increase in size (NOAA 2010).
[b] This research/natural area is wholly within the Dry Tortugas National Park and complements the Tortugas Ecological Reserve.
[c] This reserve is wholly within the Florida Keys National Marine Sanctuary.
[d] Much of the critical habitat is within the Florida Keys National Marine Sanctuary and the Dry Tortugas National Park.
[e] This MPA is wholly within the Flower Garden Banks National Marine Sanctuary.
n/a = data not available.

March 2011, there are 33 MPAs in U.S. federal waters in the GOM (NOAA 2011). Although much of the northern (U.S.) GOM has some type of MPA designation, the majority of the area has place-based management by NMFS, which typically involves only fishery restrictions as opposed to more comprehensive ecosystem-based management (Fig. 2.3). Fig. 2.3A shows all areas that are managed even if only for one very specific purpose, such as restricting use of one gear type for harvesting one particular species of a federally managed commercial fishery. Fig. 2.3B delineates the spatial extent of comprehensive MPAs that are managed for a variety of activities. In addition to the MPAs listed in Table 2.7, NMFS regulates several seasonal closures, such as Riley's Hump off Florida, and species-specific seasonal restrictions (Coleman et al. 2004). Just as fishery restrictions vary from site to site, management plans for national parks and national marine sanctuaries are site-specific and do not have standard activity restrictions among sites.

However, MPAs designated by BOEM do have standard restrictions. BOEM has authority to designate a No Activity Zone (NAZ) as a stipulation in oil and gas leases to protect

Table 2.8
MPAs in Mexican federal waters in GOM.
Sources: Bezaury-Creel 2005; IUCN and UNEP-WCMC 2010; MAB 2011; CONANP 2012.

Name	**Federal Category**	**Significance**	**Nearest State**	**Marine Area (km^2)**
Área de Protección de Flora y Fauna Laguna Madre y Delta del Río Bravo	Protected area of flora and fauna	National, international (UNESCO-MAB Biosphere Reserve; Ramsar site)	Tamaulipas	3079
Santuario Playa de Rancho Nuevo	Sanctuary	National, international (Ramsar site)	Tamaulipas	0.30
Área de Protección de Flora y Fauna Sistema Arrecifal Lobos-Tuxpan	Protected area of flora and fauna	National	Veracruz	306
Manglares y humedales de Tuxpan	n/a	International (Ramsar site)	Veracruz	68.7
Parque Nacional Sistema Arrecifal Veracruzano	National park	National, international (Ramsar site)	Veracruz	522
Sistema de Lagunas Interdunarias de la Cuidad de Veracruz	n/a	Local, international (Ramsar site)	Veracruz	1.41
Reserva de la Biosfera Los Tuxtlas	Biosphere reserve	National, international (UNESCO-MAB Biosphere Reserve)	Veracruz	n/a
Laguna Sontecomapan	n/a	International (Ramsar site)	Veracruz	89.21
Reserva de la Biosfera Pantanos de Centla	Biosphere reserve	National, international (Ramsar site)	Tabasco	3027
Área de Protección de Flora y Fauna Laguna de Términos	Protected area of flora and fauna	National, international (Ramsar site)	Campeche	1588
Chenkán Turtle Beach	n/a	International (Ramsar site)	Campeche	1.0
Reserva de la Biosfera Los Petenes	Biosphere reserve	National, international (UNESCO-MAB Biosphere Reserve; Ramsar site)	Campeche	1819
Parque Nacional Arrecife Alacranes	National park	National, international (UNESCO-MAB Biosphere Reserve; Ramsar site)	Yucatán	3337.7
Reserva de la Biosfera Ría Celestún	Biosphere reserve	National, international (UNESCO-MAB Biosphere Reserve; Ramsar site)	Yucatán	193.46
Reserva de la Biosfera Ría Lagartos	Biosphere reserve	National, international (UNESCO-MAB Biosphere Reserve; Ramsar site)	Yucatán	64.2
Reserva Ecologíca Estatal El Palmar	Ecological conservation area	State, international (Ramsar site)	Yucatán	n/a

Table 2.8 Continued

Name	Federal Category	Significance	Nearest State	Marine Area (km^2)
Reserva Estatal de Dzilam	Ecological conservation area	State, international (Ramsar site)	Yucatán	n/a
Área de Protección de Flora y Fauna Yum Balam	Protected area of flora and fauna	National, international (Ramsar site)	Quintana Roo	1001.5
Reserva de la Biosfera Tiburón Ballena	Biosphere reserve	National	Quintana Roo	1460

Note: CONANP manages all national MPAs listed in this table.
n/a = data not available.

Table 2.9
MPAs in Cuban federal waters in GOM.
Sources: SNAP 2010; MAB 2011; Gebelein 2012.

Name	Federal category	Significance	Nearest province	Marine area (km^2)	Jurisdiction	Legal approval
Guanahacabibes	National park	National	Pinar del Río	159.5	CITMA*	CECM 4262/01
Península de Guanahacabibes	Protected area of managed resources	National, international (UNESCO-MAB Biosphere Reserve)	Pinar del Río	4037[a]	JA*	CECM 6871/10
Los Pretiles	Ecological reserve	National	Pinar del Río	346.5		CECM 7233/2012
Banco de San Antonio	Natural landmark	National	Pinar del Río	741		CECM 7233/2012
Rincón de Guanabo	Protected natural landscape	Local	Ciudad de la Habana	51	OLPP	CECM s/n/30-6-01
Laguna del Cobre-Itabo	Protected natural landscape	Local	Ciudad de la Habana	50	OLPP	CECM s/n/30-6-01
Laguna de Maya	Faunal refuge	Local	Matanzas	40	ENPFF	CECM 6871/10
Bacunayagua	Ecological reserve	Local	Matanzas	45	Turismo-Cubanacán	CECM 4089/01
Cayos de las Cinco Leguas	Faunal refuge	Local	Matanzas	1.44	ENPFF	CECM 4262/2001
Cayo Mono-Galindo	Ecological reserve	National	Matanzas	167	ENPFF	CECM 6803/10

[a] This area includes marine portions on both sides of the peninsula so the amount within the GOM study area is likely considerably smaller than this figure.

topographic features that provide rare marine habitat. Bottom-disturbing activities are prohibited within 152 m of NAZs, which are managed and enforced by BOEM and BSEE. In the northwestern GOM alone, there are NAZs (not itemized in Table 2.7) for 39 sites: 29 Fathom Bank, 32 Fathom Bank, Alderdice Bank, Appelbaum Bank, Aransas Bank, Baker Bank, Big Dunn Bar Bank, Blackfish Ridge Bank, Bouma Bank, Bright Bank, Claypile Bank, Coffee Lump Bank, Diaphus Bank, Dream Bank, East Flower Garden Bank, Elvers Bank, Ewing Banks, Fishnet Bank, Geyer Bank, Hospital Bank, Jakkula Bank, MacNeil Bank, McGrail Bank, Mysterious Banks, North Hospital Bank, Parker Bank, Rankin Bank, Rezak Bank, Sackett Bank, Sidner Bank, Small Dunn Bar Bank, Sonnier Banks, South Baker Bank, Southern Bank, Stetson Bank, Sweet Bank, and West Flower Garden Bank (MMS 2008). In the northeastern GOM, BOEM has stipulation blocks for live bottom in the area of Viosca Knoll and the Alabama Pinnacles and much of the continental shelf off western Florida (BOEMRE 2011). No bottom-disturbing activities are allowed in areas with live bottom with low- and high-relief features.

Mexico and Cuba have federal waters that extend to the shoreline per their respective constitutions (SEMARNAT 2006; Whittle and Rey Santos 2006); therefore, all estuarine and marine sites are included within the Mexican and Cuban EEZs. Like most U.S. MPAs, Mexican and Cuban MPAs have site-specific management plans. Spatial data are not available for MPAs resulting from areas restricted from certain fishing activities in Mexico and Cuba. CONAPESCA lists permanent and temporal fishery closures by species, and specific spatial data are not available for such closures; rather, closures in GOM waters are listed by proximity of the coastal state. CONAPESCA does have authority to create fishery refuge areas, but few, if any, exist to date (ELI and CMDA 2011). Therefore, no areas protected by Mexico’s CONAPESCA or Cuba’s MIP are included in Table 2.8 or Table 2.9, respectively.

5. Governance mechanisms for trilateral place-based management in the GOM region

Sustainable transboundary living marine resources require sustainable transboundary governance, particularly in the GOM region that includes three very different sovereign nations. The ideal governance regime for effective creation of a collaborative, international network of MPAs throughout GOM would involve a combination of governance concepts: blended approaches, cooperative regional organizations, federal authorizing legislation, and international legal instruments. Blending governance approaches is critical for successful place-based management on a regional scale in the GOM. The "top-down" approach is typically directed by national priorities, and the "bottom-up" approach is based on local priorities and concerns (Wilcock 1995). Additionally, market-based governance applies economic tools, such as incentives, environmental property rights, and valuation of public trust resources. Top-down governance involves federal laws and regulations and the accompanying mandatory management, procedures, and public policy processes performed by authorized agencies. A major benefit common to most top-down approaches is standardization of procedures, such as set timelines for accomplishing tasks and reaching milestones. The U.S., Mexico, and Cuba all have procedures for involving local stakeholders in environmental decision-making. Stakeholder involvement is especially important for contentious issues, such as no-take zones of MPAs. A 2008 effort in the U.S. to create a network of MPAs in the GOM failed due, in part, to lack of stakeholder support from fishermen (Pendleton et al. 2010). Stakeholder involvement is a steering component of MPA policy-making at the confluence of top-down and bottom-up approaches.

Bottom-up governance is community-based, often voluntary, and locally empowering. The bottom-up approach focuses on specific local issues; therefore, frequent and clear communication is critical. Effective communication may be more important for the bottom-up approach than it is for the top-down approach because there are no standard modes of anticipated communication that apply to every local community. The bottom-up approach is a method to engage the most affected stakeholders, including fishermen, divers, the oil and gas industry, conservationists, and more, and to ensure that local management objectives and priorities are nested within regional plans. Relationship development through a blended governance approach promotes conflict resolution and educational outreach to ensure stakeholders' understanding of how national priorities and local priorities and concerns can be integrated effectively.

Regional and international organizations, both governmental and non-governmental, have important roles in development of international marine policy as effective governance extends beyond the governments. The CEC leads initiatives and publishes guidance related to designing and assessing MPA networks in North America (Brock et al. 2012). The Gulf of Mexico Alliance (GOMA) brings together the U.S. GOM states to work together on shared environmental issues. GOMA is considering expanding the organization to include the Mexican GOM states as well (ELI and CMDA 2011); ideally, depending on the status of the political climate, the Cuban GOM provinces would eventually join the organization for comprehensive representation throughout the region. The Gulf of Mexico Large Marine Ecosystem Project, which is a Mexican-U.S. program that previously included Cuba, focuses on ecosystem-based management strategies, including tools such as an MPA network (GoM-LME 2011). Academic institutions and non-profit organizations, such as the Harte Research for Gulf of Mexico Studies at Texas A&M University-Corpus Christi, Mote Marine Laboratory, and the Gulf of Mexico University Research Collaborative, also focus on Gulf-wide research. Research institutions can use sound science to entice maturation of political will to favor ecological protection, conservation, and preservation over polluting and extractive activities that alter ecosystems, reduce biodiversity, and hinder ecological connectivity. The various projects and goals of such organizations operate synergistically to improve regional governance in the GOM and influence development of effective legal tools for trilateral place-based management on an ecosystem scale.

From the legal perspective, creation of IGOMMPAN must be grounded in federal legislation that authorizes MPA creation and management in each country. Because the U.S. distributes overlapping and fragmented statutory authorities among many federal agencies, the ideal legislative choice for authorizing IGOMMPAN in the U.S. is more complicated than it is in Mexico or Cuba. However, the NMSA is likely the most comprehensive federal legislative instrument in the U.S. to support IGOMMPAN. A compelling reason to propose the NMSA as the chosen legislative instrument is the mandatory cooperation with other federal agencies, such as NMFS and BOEM, that have statutory authorities over different types of MPAs, such as EFH and NAZs, respectively. Therefore, a national marine sanctuary designation and management plan takes into account multiple uses, which also supports the ongoing CMSP efforts. Unfortunately, a statutory moratorium currently prevents designation of new national marine sanctuaries by the Secretary of Commerce (Hildreth 2008), but that does not prevent an existing sanctuary from expanding. For example, the Flower Garden Banks National Marine Sanctuary issued a draft expansion plan, which would increase the protected area in the northwestern GOM (NOAA 2010). Moreover, a national marine sanctuary can also be designated by Executive Order or Congressional act, as shown in Table 2.4, which is an important consideration while the aforementioned moratorium remains in place. Another strong legal vehicle for designating an MPA network is the Antiquities Act, which allows for designation by Presidential Proclamation.

In practice, MPAs authorized by NMSA, Antiquities Act, Executive Order, or Congressional act could have equally robust management given effective interagency cooperation.

Legislative choices for Mexico and Cuba are much simpler because they have centralized federal management of all protected areas as discussed in section 4.2. Although a few secondary statutes and agencies have some authority over MPAs, the legal frameworks clearly point to the primary statutes and managing agencies—CONANP, within SEMARNAT, as authorized by LGEEPA in Mexico, and CNAP, within CITMA, and ENPFF, within the Ministry of Agriculture, as authorized by Law 81 in Cuba. In Cuba, the CECM issues specific agreements to designate new MPAs, which are managed by ENPFF directly and by CNAP collectively via SNAP.

The identification of international legal requirements would strengthen creation and continuing management of IGOMMPAN. A new trilateral treaty among the U.S., Mexico, and Cuba specifically designed to support creation and management of IGOMMPAN would be the clearest and most effective international legal tool, but negotiations of a new treaty could introduce delays that could be avoided by opting to use mechanisms under existing international law. More importantly, negotiation of a new international treaty between the U.S. and Cuba is currently legally and politically unrealistic. Of the existing treaties (see Table 2.1), most are specific to certain groups of species or to portions of the GOM; therefore, such treaties are not optimal legal instruments for implementing an ecosystem-based management tool such as an IGOMMPAN. Treaties that have not yet been ratified by the three GOM countries are likely not efficient avenues for creating internationally binding mechanisms. NAAEC is associated with the North American Free Trade Agreement; therefore, NAAEC intentionally excludes Cuba. UNCLOS, although not ratified by the U.S., has many provisions that are considered customary international law and, thus, binding. However, UNCLOS does not have specific provisions related to MPAs beyond requiring conservation and management measures for living marine resources in an EEZ (Young 2007); therefore, other treaties that focus more narrowly on protected areas would be more effective.

5.1. Applicable treaties that lack ratifications

If ever ratified by all three GOM nations, the following treaties would be possible vehicles for creation of IGOMMPAN:

- Western Hemisphere Convention
- SPAW Protocol
- CBD

The Western Hemisphere Convention (lacking Cuba's ratification) focuses on creating national legislation for protected areas and establishing such areas to protect all species, with an emphasis on migratory birds and rare species, and their natural habitats; the treaty also promotes international cooperation. Because the U.S., Mexico, and Cuba all have national legislation authorizing creation of protected areas, the Western Hemisphere Convention may not have a vital role, even with Cuba's ratification, beyond international cooperation. However, the regional SPAW Protocol and the global CBD would be effective means of international law for implementing an IGOMMPAN. The SPAW Protocol (lacking Mexico's ratification) applies to the Wider Caribbean Region, which includes the GOM, and focuses on ecosystem-based conservation of rare and fragile species, habitats, and ecosystems, and it identifies criteria for establishing protected areas, protective measures, management, and international cooperation among other items. Because the SPAW Protocol developed from a framework convention (Cartagena Convention), includes an action plan, and specifies measures for planning, management, and enforcement, the protocol is the most advanced environmental agreement for protected areas (Goodwin 2011). The SPAW Protocol also specifically requires creation of a network of protected areas (SPAW Protocol art. 7 1990). CBD (lacking the U.S.'s ratification) applies globally and aims to conserve biodiversity and specifically identifies national protected areas as an appropriate tool for comprehensive conservation and protection. Although the CBD identifies appropriate policy tools, it has not succeeded in generating an acceptable international response to reduce biodiversity loss (Goodwin 2011).

5.2. Applicable treaties with necessary ratifications

To create a legally binding IGOMMPAN, results of the international legal analysis identify three good candidates:

- Ramsar Convention
- World Heritage Convention
- Cartagena Convention

All three GOM countries have ratified all three treaties, which focus on place-based management without spatial or species-specific restrictions or preferences. Although the Ramsar Convention focuses on wetlands using a broad definition that includes nearshore marine areas and coral reefs, the treaty might not be ideal for an MPA network that includes offshore sites without tidal flats, mangroves, or coral reef features only below 6 m of water depth. Most notably, the Ramsar Convention would exclude the listing of Flower Garden Banks National Marine Sanctuary, which is a cornerstone site of IGOMMPAN. The World Heritage Convention has a focus on sites with existing or potential tourism value, and it does not focus on ecological values such as connectivity and biodiversity conservation without a tourism component (Young 2007). Also, the World Heritage Convention targets pristine sites, which would not include some IGOMMPAN candidate sites, and the treaty includes a delisting mechanism, which may not bode well for longevity of the complete network (Goodwin 2011). The Cartagena Convention encourages ecological protection and international cooperation with an emphasis on minimizing pollution; however, Article 10, which triggered the SPAW Protocol, is dedicated to specially protected areas for preserving ecosystems and habitats of depleted or rare species and information exchange regarding such areas. Although the Cartagena Convention lacks legally binding provisions, the treaty allows negotiations among the U.S., Mexico, and Cuba. Therefore, the Cartagena Convention is the international treaty under which creation of IGOMMPAN could most effectively and efficiently be established as a place-based tool for ecosystem-based management of transboundary living marine resources in the GOM region.

5.3. Suggested governance approach

If Mexico ratifies the SPAW Protocol, it would trump the Cartagena Convention as the ideal existing legal instrument for IGOMMPAN. Interestingly, the U.S. ratified the Cartagena Convention and the SPAW Protocol but not the CBD while Mexico ratified the Cartagena Convention and the CBD but not the SPAW Protocol. Cuba is the only country that ratified all three treaties that most strongly support an IGOMMPAN.

Finally, a trilateral MOU, among the U.S.'s ONMS, Mexico's CONANP, and Cuba's CNAP, could increase effectiveness of international cooperation by highlighting compliance with existing international legal instruments, particularly the Cartagena Convention as identified above, and by creating a trinational commission to establish and maintain an IGOMMPAN. Such a basis in international law would secure trilateral accountability and long-term cooperation regarding sustainability of shared living marine resources.

6. Challenges of cross-cultural collaboration

Living marine resources have a substantial role in historical, present-day, and future livelihoods of coastal residents and national economies, politics, and international relations for the U.S., Mexico, and Cuba. The sustainability of living marine resources of the GOM is integral to political progress, protection from natural and anthropogenic disasters, and economic and ecological stability and recovery processes. While the three countries typically agree on scientific bases toward achieving integrated management and sustainable populations, governance and culture in the three countries reflect various levels of progress toward ecosystem-based management.

Cuba leads the GOM region in efforts for integrated coastal and ocean management, likely because fewer bureaucratic hurdles exist. Cuba's governance regime and culture strongly reflect elements of socialism, which inherently considers human ecology. Cuba has integrated human activities, costs, and benefits into ecosystem-based management plans through environmental impact analysis and licensing. Given Cuba's current economic and technological struggles, the comprehensive integrated coastal zone management that minimizes adverse effects of development on coastal and ocean resources is impressive. Economically, Cuba needs to continue encouraging tourism, but environmentally, Cuba has fully recognized the importance of sustainable ecosystem services. Local involvement is part of public environmental policy, but stakeholder participation in practice is still evolving. However, the special local designations within SNAP will likely encourage local participation and help weave the concepts of place-based management and local empowerment into Cuban culture.

Although the U.S. governance regime does not have threads of socialism, the regulatory culture has longstanding and well accepted requirements and practices to include all citizens by encouraging regulatory transparency and public participation. Local involvement is strong in many areas of U.S. environmental policy, particularly regarding contentious issues such as establishing no-take zones in MPAs. Grassroots organizations are very well developed and effective at local and regional levels in the U.S. In some cases, such as the establishment and management of the Florida Keys National Marine Sanctuary, various stakeholder groups caused delays and changes to plans as a direct result of the government considering and addressing concerns from different users (Suman et al. 1999).

Non-governmental environmental organizations are growing in Mexico, which will facilitate local participation in Mexico's environmental policymaking. Although Mexico's environmental decentralization is underway, its effectiveness and efficiency are not keeping pace with institutional reorganizations within the federal government. Mexicans have strong traditional ties to history and culture that penetrate all levels of society, which have a noticeable role in slowing the evolution toward increased public participation, local stakeholder involvement, and horizontal and vertical coordination among regulatory agencies. *Caciquismo* culture and corruption continue to pervade Mexican politics and government structure to varying extents despite democratization and decentralization processes. As a result, Mexico generally continues to implement conservation through top-down approaches despite some attempts to start utilizing bottom-up concepts as required by decentralization processes (Fragas and Jesus 2008). However, the *Área de Protección de Fauna y Flora Yum Balam* is an excellent example of an MPA that was created as a product of persistent local efforts seeking federal protection for ecosystems and Mayan culture (Poot Balam 1998). Unfortunately, since the creation of the Yum Balam protected area in 1994, government authorities have increasingly ignored local expertise and excluded locals from participation in management decisions (Berlanga and Faust 2007).

This decline of local involvement after establishing a protected area indicates that Mexico should increase decentralization efforts to ensure long-term community involvement with place-based management.

Relationships among the U.S., Mexico, and Cuba are improving, but continued and increased international coordination is necessary for successful cross-cultural collaboration. The relationship between the U.S. and Cuba has oscillated in a declining sinusoidal fashion over the last century. To some extent, many Cubans embraced U.S. hegemony and cultural imperialism in the past. However, the U.S. economic embargo has made technological progress difficult for Cubans. Cultural imperialism and economic sanctions are not compatible with collaborative management of transboundary living marine resources in the GOM region. Although the embargo remains in place, recent U.S. policy encourages academic and educational exchanges (The White House 2011), and occasionally U.S. government scientists have been approved to interact with Cuban scientists to coordinate ecosystem-based management strategies for the GOM region (Boom 2012). Recently, U.S. scientists from academia and non-governmental organizations have collaborated more frequently with Cuban scientists to address environmental concerns regarding shared living marine resources (Machlis et al. 2012). The Environmental Defense Fund, a U.S.-based non-governmental organization, has been working with Cuban scientists since 2000 (Peterson et al. 2012), and it continues to pave the way for improved U.S.-Cuban relations regarding environmental issues. The relationship between Mexico and Cuba has shifted gradually since Mexican independence, when the newly sovereign Mexico viewed Cuba as a security threat. Most of Mexico’s relations with Cuba have been influenced by potential relations with third-party countries, such as Spain. As Mexico has strengthened its foreign policy with the U.S., Mexican-Cuban relations have deteriorated slightly, but diplomatic interactions have improved in recent years. The U.S.-Mexico relationship is the strongest in the GOM region. Several bilateral organizations work closely on many issues, including ecosystem-based management and place-based management in the GOM.

Although trilaterally-based science and policy share challenges discussed in bilateral contexts, trilateral relationships exist and continue to develop in the GOM region. Several trinational workshops and meetings have occurred among different organizations in the last several years, and the Trinational Initiative for Marine Research and Conservation in the Gulf of Mexico and Western Caribbean represents a group of scientists and policy makers from the U.S., Mexico, and Cuba who have met five times since 2007 (Nash and McLaughlin 2012; Trinational Initiative 2013). Increased trilateral collaboration and coordination based on sound science will create an atmosphere that cultivates improved cross-cultural understanding in the GOM region.

7. Call for expansion of collaborative international governance

The 2010 BP Deepwater Horizon oil spill focused global attention on the GOM. While international efforts were already underway to protect the GOM, the anthropogenic disaster increased concern for GOM living marine resources and, accordingly, resulted in more available resources for and attention to ecosystem-based management and protection. Hence, the political climate and state of the GOM living marine resources provide ripeness and nexus for the IGOMMPAN policy proposal. IGOMMPAN would protect biological connectivity, species aggregations, biodiversity, rare and sensitive habitats, and ecological functions. Functional redundancy can be realized through a stepping-stone approach to place-based management. Connectivity protection using a stepping-stone approach will ensure ecosystem resiliency if an anthropogenic or natural disaster reduces or eliminates any ecosystem functions in a particular location. Ecosystem resiliency is also critical for chronic threats, such as pollution, overfishing, climate change, and invasive species. IGOMMPAN would distribute and, thus, reduce and mitigate ecological risk (Pendleton et al. 2010).

For long-term maintenance, IGOMMPAN should be framed by well-founded international governance. The Benguela Current Commission is a well-known example of successful international governance based on trinational cooperation regarding shared resources of a large marine ecosystem. The Commission was established in 2007 to address fishery resources, rare species, and transboundary ecosystem processes, and Angola, Namibia, and South Africa plan to ratify the Benguela Current Convention by December 2012 (Cochrane et al. 2009; BCC 2011). The Benguela Current Commission's systematic progress regarding international policies to protect a shared large marine ecosystem could serve as a model for the GOM region.

Although there is not yet an international commission for the GOM, the recent MOU between ONMS and CONANP (SEMARNAT and NOAA 2012) is expected to increase government collaboration for coordinated management of MPAs in shared waters such as the GOM. The momentum of policies supporting IGOMMPAN could be utilized to include Cuba in collaborative activities. A trilateral MOU would be an important initial policy tool to establish and maintain a comprehensive IGOMMPAN. As proposed in section 5, the MOU would be most effective if based on existing international law—the Cartagena Convention was identified as the treaty that would best support IGOMMPAN based on the treaty's scope and ratifications by the U.S., Mexico, and Cuba. Following the strategic example of international governance of the Benguela Current large marine ecosystem, the MOU could also establish an international commission to establish and oversee IGOMMPAN and lead to a new trilateral treaty.

Results of policy analyses presented in this chapter identify the need for a convergent approach initially based on existing law, and possibly leading to a new treaty, to establish and maintain long-term transboundary management of IGOMMPAN. Continued trinational collaboration among scientists, regulators, and managers and sustainable local involvement are prerequisites for successful implementation of IGOMMPAN. An effective IGOMMPAN would be based on the large marine ecosystem disregarding political boundaries. Collaborative management of shared living marine resources would enable expedient and coordinated responses to threats through information exchange portals. An important long-term objective would be to link IGOMMPAN to neighboring ecosystems, such as the Caribbean Sea large marine ecosystem, including the Mesoamerican Barrier Reef, and eventually contribute to a global network of MPAs to ensure sustainable functionality of marine ecosystems worldwide.

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CHAPTER 3

INTERNATIONAL GULF OF MEXICO MARINE PROTECTED AREA NETWORK: A CONNECTIVITY SNAPSHOT

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Format: *Marine Policy* used as format.

Abstract

Transboundary living marine resources in the Gulf of Mexico region utilize habitats in waters of the United States, Mexico, and Cuba. Four well-studied cornerstone coral reef sites—Florida Keys, Flower Garden Banks, Veracruz Reef System, and Alacranes Reef—are major nodes for biological connectivity. Selected coral and fish species that occur at these four sites are explored herein in the context of Gulfwide connectivity via stepping-stone habitats throughout the continental shelf. Ecological connectivity is a compelling driver of place-based management. To implement a spatially explicit network of protected areas to preserve biological connectivity, connectivity in the human dimension is also critical. Marine protected area practitioners from the United States, Mexico, and Cuba collaborated in an effort to create an international marine protected area network in the Gulf of Mexico. Trinational collaborators identified 32 design parameters and 36 candidate sites to include in the network. Candidate sites demonstrate biophysical connectivity and can be linked through standardized governance methods for sustaining human and environmental health and well-being.

1. Introduction

The Gulf of Mexico (GOM) is a semi-enclosed, international sea that comprises a large marine ecosystem. Hard-bottom areas provide rare, important high-biodiversity habitats on the GOM's continental shelf. Several such areas are afforded federal protection by the United States (U.S.), Mexico, or Cuba. Transboundary living marine resources inhabit federal waters of all three nations, but the region lacks corresponding transboundary protection, conservation, and management for sustainable use of shared resources. This chapter addresses Gulfwide ecological connectivity and presents the progress of the trinational community of scientists and marine protected area (MPA) practitioners as they collaborate to protect shared transboundary resources through place-based management.

2. Shared coral reef resources

True coral reefs are not prevalent throughout the GOM, but major coral reef ecosystems occur in each of the four quadrants of the GOM. Areas with true coral reefs include the Florida Keys and Dry Tortugas off southern Florida, the Flower Garden Banks on the outer continental shelf off Texas and Louisiana, the Lobos-Tuxpan and Veracruz Reef Systems off the Mexican state of Veracruz, the Campeche Bank Reefs (including Alacranes Reef) on the shelf west of the Yucatán Peninsula, and reefs off northwestern Cuba (Tunnell 2007a; Fig. 3.1). The following discussion is a biogeographic comparison of several coral and fish species as they occur in each of the most studied GOM cornerstone coral reef communities: Florida Keys, Flower Garden Banks, Veracruz Reef System (VRS), and Alacranes Reef, which is the largest and northernmost of the Campeche Bank Reefs.

Analysis of species abundance, behavior, life history traits, and probable larval sources and sinks of several coral and fish species provides insight regarding ecological connectivity of coral reef ecosystems throughout the GOM. Ecological connectivity in the form of demographic connectivity occurs as biological linkage resulting from geographical movement of organisms between habitat sites during any life stage. Four coral species and four fish species were chosen for a detailed comparative analysis of their occurrence and ecological roles at each of the four sites based on a literature review. The species were selected as important species representing groups of species that collectively have important functional roles in coral reef ecosystems or are good indicators for ecosystem health assessment. The selected coral species, all scleractinians,

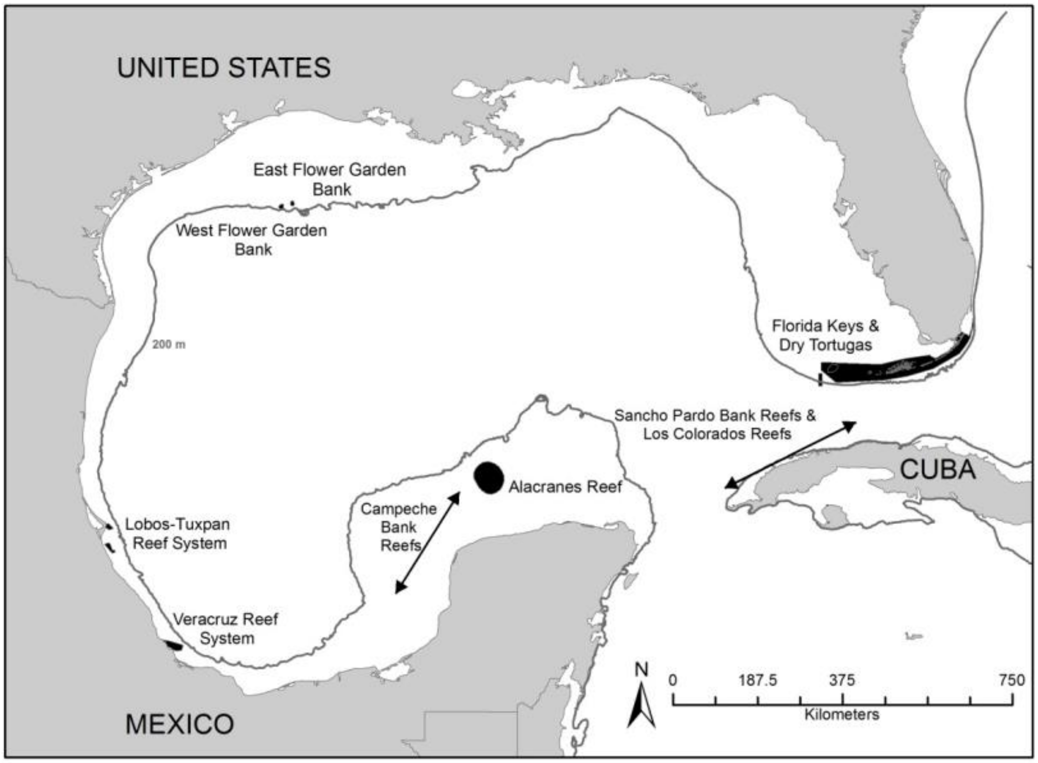

Fig. 3.1. Areas with true coral reefs in the Gulf of Mexico.
Adapted from: Nash and McLaughlin 2012.

are elkhorn coral (*Acropora palmata*), great star coral (*Montastraea cavernosa*), smooth brain coral (*Diploria strigosa*), and the non-native, invasive orange cup coral (*Tubastraea coccinea*). The selected fish species are redlip blenny (*Ophioblennius macclurei*), princess parrotfish (*Scarus taeniopterus*), black grouper (*Mycteroperca bonaci*), and the non-native, invasive complex of the red lionfish (*Pterois volitans*) and the devil firefish (*P. miles*) (*P. volitans* and *P. miles* are distinguishable genetically but not morphometrically [Hamner et al. 2007]). The invasive species were chosen because they are good surrogates to represent connectivity patterns of less prolific, indigenous species with similar life history characteristics.

2.1. Four cornerstone sites

Coral reef ecosystem health and coverage are declining globally. Typically, the healthiest coral reefs are the most remote and, accordingly, the least anthropogenically affected. Of the four cornerstone sites selected for this analysis, the healthiest coral reefs are those located farthest offshore—Flower Garden Banks and Alacranes Reef. The Florida Keys and the VRS are both located relatively close to large human population centers and are heavily influenced by drainage from rivers and runoff from the adjacent land, which are drivers for moderate to large adverse ecological impacts (Tunnell 2007a).

Two physiographic features also generally characterize coral reefs in the GOM. Coral reefs in the northwestern GOM are submerged, but coral reefs in the southern and eastern GOM are typically emergent. Hence, the Flower Garden Banks site is the only completely submerged cornerstone site. Also, the western portion of the GOM continental shelf, where the Flower Garden Banks and VRS are located, is composed of terrigenous sediment, and the eastern portions of the shelf, where the Florida Keys and Alacranes Reef are sited, are broad areas with carbonate sediments. However, each site has distinctive features, which are discussed in the following descriptions.

2.1.1. Florida Keys

The coral reefs in the Florida Keys region comprise the third largest barrier reef system in the world (NOAA 2011a). Biscayne National Park, Florida Keys National Marine Sanctuary (FKNMS; established in 1991), and Dry Tortugas National Park collectively protect the reef ecosystem in the region. The coral reef and hard bottom coverage is over 140,000 ha and includes patch reefs, back reefs, reef flats, bank (or transitional) reefs, intermediate reefs, deep reefs, and outlier reefs along with seagrass beds and sandy, soft-bottom areas (Kelty 2004).

Within FKNMS, coral reefs are typically on the ocean side and constitute only 1% of the benthic habitat (Wheaton et al. 2001).

FKNMS has over 100 coral species, including scleractinians, octocorals, and fire corals (NOAA 2011a). Over the past several decades the Florida Keys have experienced a phase shift to algae-predominant reefs. Analysis of monitoring data since the mid-1990s indicates a trend of declining species richness of scleractinians, including a large loss of acroporids throughout FKNMS (Wheaton et al. 2001). Increasing sea surface temperatures and the related coral diseases are the major threats to the reefs in the Florida Keys and have increased since the mid-1990s (Causey 2008). Anthropogenic stressors, such as overfishing, sedimentation, habitat loss and degradation, nearshore eutrophication and pollution, and increased visitor use, also contribute to the continuing decline of the ecosystem. Despite continued presence of stressors, coral coverage at FKNMS increased from 2007 to 2009, which is indicative of some recovery (NOAA 2011b; Morrison 2012).

The Dry Tortugas region west of the lower Keys is thought to be a valuable larval source providing dispersal to the east and to the rest of the Keys via the Florida Current (Ault et al. 2006). The larval dispersal theory combined with the decline in populations of the snapper-grouper complex led to the no-take marine reserves in the Dry Tortugas region, which were implemented in 2001 and cover about 56,600 ha (Ault et al. 2006) . Several species, both targets and non-targets of fisheries, have increased in abundance and size since the reserves were established (Ault et al. 2006).

2.1.2. Flower Garden Banks

In the northwestern GOM many banks with high-biodiversity communities formed on top of salt diapirs. The Flower Garden Banks, located about 185 km off the Texas and Louisiana coasts, are well known sites in this region that host healthy coral reefs with massive coral boulders and low algal biomass. The Flower Garden Banks are the northernmost coral reefs of the contiguous U.S. The coral reef caps occur at water depths of 17 to 46 m (Schmahl et al. 2008). The Flower Garden Banks National Marine Sanctuary (FGBNMS), established in 1992, currently protects East and West Flower Garden Banks and Stetson Bank. Stetson Bank is not a true coral reef and is not included in this analysis although it does have a coral community, albeit low in diversity. Efforts are underway to expand the sanctuary to include additional banks in the vicinity that have coral reef habitat (NOAA 2010). Additional protections of the banks include the Bureau of Ocean Energy Management's designation as a No Activity Zone, the National Marine Fisheries Service's designation as a Coral Essential Fish Habitat and Habitat Area of Particular Concern, and the International Maritime Organization's first international no-anchor zone (Hickerson et al. 2008; Schmahl et al. 2008).

Compared to FKNMS, the FGBNMS reefs are healthy and have high coral coverage, with approximately 50% in shallow areas and up to 70% in deeper areas (Hickerson et al. 2008; Monaco et al. 2008). The site is much smaller than the Florida Keys, however, with only 268 ha of coral reef coverage (Tunnell 2007a). Although the coral coverage is high, the species richness of corals is low with less than 40 species present in the sanctuary, which is about a third as much as on most Caribbean reefs (Schmahl et al. 2008; NOAA 2012a). The predominant coral species is *Orbicella* (formerly *Montastraea*) *annularis*, which covers up to 40% of the Flower Gardens reefs (Monaco et al. 2008). Based on recent molecular analysis, the *O. annularis* complex, which includes *O. annularis*, *O. franksi*, and *O. faveolata*, was moved from family Montastraeidae to family Merulinidae and assigned to the genus *Orbicella* (Budd et al. 2012). Unlike the other three cornerstone GOM sites, the FGBNMS lacks shallow-water gorgonians, but a diverse community of gorgonians and antipatharians exists in waters deeper than 43 m (Pattengill-Semmens and Gittings 2003; Hickerson et al. 2008). FGBNMS's biotic zones are distinguished according to predominant species at different depths. Although slightly different nomenclature exists for zonation, common zones describing benthic habitat at FGBNMS in order of descending depth are: *Diploria-Montastraea-Porites* zone, *Madracis* zone, *Stephanocoenia-Millepora* zone, algal-sponge zone, transition zone, and nepheloid layer (Minnery et al. 1985; Rezak et al. 1985). Coral diseases do not seem prevalent historically at FGBNMS, and bleached corals tend to have a high recovery rate (Schmahl et al. 2008).

Similar to coral diversity, fish species richness is low, but fish biomass and abundances are high at FGBNMS, with higher abundances in general at the West Flower Garden Bank (WFG) than at the East Flower Garden Bank (EFG) (Pattengill-Semmens and Gittings 2003). Parrotfish species were the most abundant of the FGBNMS fish assemblage counted in transects (Pattengill-Semmens and Gittings 2003). Individual fish, particularly parrotfishes and groupers, are larger than average when compared to typical Caribbean reefs (Pattengill-Semmens and Gittings 2003). Fishing pressure is low because of remoteness and protective regulations. Therefore, ichthyofaunal diversity and large average fish size at FGBNMS is not expected to change substantially over time as a result of direct anthropogenic stressors, but climate change may cause a shift in the community corresponding to species' thermal tolerances. Scientists have been monitoring FGBNMS for decades, and the coral reef ecosystem has been stable and resilient since monitoring began in the early 1970s (Gittings 1998).

2.1.3. Veracruz Reef System

The VRS is located in the southwestern GOM near the city of Veracruz. VRS was declared Mexico's first National Marine Park in 1992 (Rangel Avalos et al. 2008). The VRS has about 4662 ha of coral reef coverage, and live scleractinian coverage is about 17% (Horta-Puga 2003; Tunnell 2007a). Many of the VRS reefs are emergent platform reefs, and some have associated islands. The outflow of the Jamapa River just south of the city separates the VRS into two groups. The northern group occurs near the city and includes 13 reefs: 8 emergent platform reefs, 2 submerged bank reefs, and 3 fringing reefs (Tunnell 2007b). The southern group is close to Antón Lizardo, a fishing village south of Veracruz and the Jamapa River, and consists of 12 emergent platform reefs (Tunnell 2007b).

The Jamapa River brings freshwater and terrigenous sediment into the GOM, and the low salinity and high sedimentation create unsuitable conditions for corals in the area between the two groups. The VRS reefs, especially those very near shore and the city of Veracruz in the northern group, have noticeably declined over the past several decades as a result of various adverse anthropogenic effects, such as sewage, runoff, port construction, ship groundings, and overfishing (Chávez et al. 2007). Despite the declining reef health, fish abundance is significantly higher in the northern group than in the southern group of reefs, but fish species richness does not vary between the two groups (Rangel Avalos et al. 2008). The difference in fish abundance could be a direct effect of overfishing given the close proximity of the fishing village of Antón Lizardo to the southern reefs, which likely experience greater fishing pressure than the northern reefs. The reverse is true for stony coral coverage in that the southern group has significantly more scleractinian cover than the northern group (Rangel Avalos et al. 2008). Twenty-seven stony coral species occur with a mean coverage of about 22% (Rangel Avalos et al. 2008). *Acropora* spp. and *Diploria* spp. are the most abundant corals in the VRS (Ronzón Rodríguez and Vargas Hernández 2007). Shallow-water gorgonians and sponges are present, and algae are abundant (Rangel Avalos et al. 2008). Coral diseases have been observed at all

VRS reefs (Rangel Avalos et al. 2008). Although VRS generally has worse environmental conditions than most other reefs throughout the wider Caribbean region, the extent of coral disease at VRS (4.8%) is about the same as reefs with fewer stressors (Carricart-Ganivet et al. 2011). To date, VRS has not undergone a mass bleaching event, which is likely because of the high turbidity that may minimize coral disease and bleaching conditions (Carricart-Ganivet et al. 2011).

2.1.4. Alacranes Reef

Alacranes Reef, also known as Alacrán Reef, is the largest and northernmost reef of the Campeche Bank Reefs, which are located in the southeastern GOM off the Yucatán Peninsula. Alacranes Reef is about 135 km off the northern coast of the Yucatán Peninsula (Aguilar-Perera et al. 2007). The site is a large emergent platform reef with a few mangroves and with 32,500 ha of coral reef coverage. Scleractinians constitute a little over 11% of the benthic habitat (Tunnell 2007a; Acosta González and Arias González 2011). The 24 species of stony coral are distributed differently among the three reef zones: windward reef, central lagoon, and leeward reef (INE 1996). Of the stony corals, *Orbicella annularis* predominates the reef constituting half of the coverage although regional variations in predominance occur (del Socorro Rivas Solis 1990; Acosta González and Arias González 2011). The reef has five associated islands and a large lagoon with several small patch reefs (Liddell 2007). Mexico declared Alacranes Reef a National Park in 1994, and it has two core, no-take zones and a buffer zone in which fishing is allowed (Brulé et al. 2003; Aguilar-Perera et al. 2007). In 2006, Alacranes Reef was designated a UNESCO (United Nations Educational, Scientific and Cultural Organization) Biosphere Reserve (UNESCO 2011).

Like the Flower Garden Banks, Alacranes Reef is relatively healthy because it is far from shore, but algae predominate the benthic community (del Socorro Rivas Solis 1990; Acosta González and Arias González 2011). Also, Alacranes Reef is on a carbonate platform with negligible freshwater inflow or terrigenous sedimentation (Horta-Puga 2007). Because Alacranes Reef is located near the Yucatán Channel, it is in the path of many tropical storms and hurricanes, which can cause reef damage yet also quickly transport robust eggs and larvae. Nonetheless, Alacranes Reef continues to be one of the sites with highest fish species richness in Mexico (Arias González et al. 2011).

2.2. Coral species

Coral species richness is highest at FKNMS with over 40 stony coral species (NOAA 2011a). FGBNMS has over 30 scleractinians, and VRS and Alacranes Reef follow, each with less than 30 stony coral species (INE 1996; Rangel Avelos et al. 2008; NOAA 2012a). However, fewer studies have been conducted on Alacranes Reef than on the other four cornerstone sites; given the proximity to currents and the more speciose reefs of the Mexican Caribbean, Alacranes Reef likely has higher coral species richness than reported. All corals selected for this chapter are scleractinians, but the invasive orange cup coral is the only selected coral species that is non-reef-building and non-zooxanthellate. The three native species (elkhorn coral, great star coral, and smooth brain coral) are reef-building, zooxanthellate corals that contribute substantially to the reef's framework and structure.

2.2.1. Elkhorn coral

Acropora palmata is a yellowish-brown scleractinian that grows best in the surf zone and other shallow, unprotected waters, such as the windward side of reefs. In such areas, the coral branches are rounder and larger to survive the wave forces, whereas *A. palmata* that grows in deeper and more protected waters has a phenotypic variation of longer, flatter branches (Lirman 2000). Nevertheless, the branches are fragile and often break with strong wave action. However, *Acropora* spp. are among the fastest growing scleractinians with a growth rate up to 10 cm per year (Shinn 1966; Gladfelter et al. 1978), which allows for broken fragments to contribute to population sustainability as they grow into new colonies and for an individual colony to rapidly regenerate a lost branch. Studies show that *A. palmata* has adapted so well to physical disturbances that hurricanes can trigger a population expansion through regeneration from broken fragments (Fong and Lirman 1995). Hurricanes and other storm events may be means of connectivity by relocating fragments. The rapid growth rate and asexual reproduction, which also facilitate scientifically designed recovery, recolonization, and repopulation projects, are driving forces in the survival of *Acropora palmata* populations.

Acropora palmata also reproduces sexually via broadcast spawning, which occurs after the full moon in August. Egg and sperm bundles are released and float to the surface where they separate and mix with gametes from other colonies (Baums et al. 2005). Pelagic larvae are motile after about 3 days of development, and settlement occurs within 5 to 20 days (Baums et al. 2005). Therefore, larval transport via ocean currents is a probable mode of connectivity. However, within the Caribbean Sea, two distinct populations (western and eastern, with colonies in Florida and the Bahamas being part of the western population) have only slight range overlaps and little genetic mixing; as a result, self-recruitment is likely high (Baums et al. 2005). *Acropora palmata* in the GOM is likely part of the western Caribbean population, or the GOM population could be distinct from the western Caribbean population with the exception of that in the Florida Keys, which has the same genotype as the western Caribbean population. Genetic studies on samples from the FGBNMS, VRS, and Alacranes Reef have yet to be conducted.

Acropora palmata is one of the most important reef-building corals in the GOM region as a provider of structural stability for the reef and habitat for many species (Shinn 1976). Unfortunately, a drastic population decline began in the 1970s in the U.S. Virgin Islands (Grober-Dunsmore et al. 2006) and continued through the 1990s in the Florida Keys and other areas in the wider Caribbean. As a result, the U.S. lists *A. palmata* as Threatened, Mexico lists the species as Subject to Special Protection, the International Union for the Conservation of Nature and Natural Resources (IUCN) lists *A. palmata* as Critically Endangered, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) lists the species in Appendix II (Aronson et al. 2008; PROFEPA 2010). White-band disease, hurricanes, extreme cold spells, and other anthropogenic effects are causes for sharp declines in populations throughout the GOM and wider Caribbean region (Aronson et al. 2008; Causey 2008). At FKNMS and VRS, *Acropora palmata* was historically an abundant scleractinian and was one of the predominant species in the shallow portion (1-5 m) of the windward reef slope (Kühlmann 1975; Quintana y Molina 1991). However, its rapid population decline has left areas of dead coral likely resulting from increased algal coverage, sedimentation, ship groundings, and continental run-off at these nearshore sites. White-band disease type I has occurred annually since 1996 and is likely the main cause of the 88% loss of *A. palmata* coverage in FKNMS, and bleaching also occurred in 1997 and 1998 (Wheaton et al. 2001; Santavy et al. 2005). Although some population recolonization experiments show promise, there is no sign of *A. palmata* recovery at VRS (Rangel Avalos et al. 2008).

Despite the drastic declines of *A. palmata* at FKNMS and VRS, the population at Alacranes Reef is one of the largest and healthiest populations in Mexico. The distribution off the Yucatán Peninsula and in the Mexican Caribbean is relatively stable although it did experience some decline associated with the *Diadema antillarum* die-off in 1983-84 (Lessios et al. 1984; INE 1996; PROFEPA 2010). *Acropora palmata* comprises about 25% of the coral coverage on the windward side of southern Alacranes Reef, but the species is not found in large abundance on the leeward reef (del Socorro Rivas Solis 1990).

Although *Acropora palmata* most commonly grows in shallow waters up to 10 m in depth, it is present at FGBNMS where the shallowest parts of the reef occur at a depth of about 17 m (Schmahl et al. 2008; NOAA 2012a). *Acropora palmata* was first observed at FGBNMS in 2003 at 21.6 m on WFG's coral cap; the species was identified on the coral cap of EFG in 2005 at 23.5 m, which is the deepest record in the western Atlantic and Caribbean regions (Zimmer et al. 2006). The relatively recent discovery of the species at FGBNMS indicates that larval dispersal may have a critical role in connectivity given that the site is located far from other known occurrences. The recent occurrence at FGBNMS of *A. palmata*, which does not survive in water temperatures below 18°C, could also indicate a range expansion resulting from recent increases in sea surface temperatures (Schmahl et al. 2008). Fossil *A. palmata* at FGBNMS indicates that connectivity, likely via fragmentation and transportation, existed in the past as well (Schmahl et al. 2008).

2.2.2. Great star coral

Great star coral (*Montastraea cavernosa*), also known as giant or large star coral, forms green, brown, yellowish brown, or gray boulders with occasional pink or orange fluorescence and has large polyps (Humann and DeLoach 2002). *Montastraea cavernosa* occurs commonly on GOM reefs and can be found in a much broader depth range (as deep as 30 m) than *A. palmata*. In deep waters, *M. cavernosa* forms plates rather than boulders.

Montastraea cavernosa is the most conspicuous coral species and second most abundant scleractinian in the Florida Keys (Wheaton et al. 2001; Monaco et al. 2008). In FKNMS, *M. cavernosa* is common in the 10-to-60-m depth range and occurs in waters up to 90 m deep (Shinn et al. 1989). However, it has been subject to black-band disease and white plague since the mid-1980s through 2005 (Wheaton et al. 2001; Santavy et al. 2005; Causey 2008).

Montastraea cavernosa, along with the *Orbicella annularis* species complex, are predominant in deep portions of the coral reefs at FGBNMS, and *M. cavernosa* comprises about 13% of the FGBNMS coral coverage shallower than 45 m (Vize et al. 2005; Schmahl et al. 2008). *Montastraea cavernosa* is the first species to broadcast spawn during the mass spawning event at FGBNMS on the sixth, seventh, eighth, and ninth nights after the full moon in August about 8:30 pm (Schmahl et al. 2008). *Montastraea cavernosa* is a gonochoric coral, and females spawn after males (Vize et al. 2005). Surprisingly, WFG and EFG populations are genetically distinct (Atchison et al. 2008). Additionally, *M. cavernosa* is the third most abundant scleractinian sampled from oil and gas platforms in the vicinity of FGBNMS (Atchison et al. 2008).

Based on transect data collected at VRS, *M. cavernosa* is consistently one of the most abundant scleractinians at the site. Rangel Avalos et al. (2008) reported *M. cavernosa* as the third most abundant, and Horta-Puga (2003) reported it as the most abundant stony coral. *Montastraea cavernosa* is often the predominant species in the scleractinian assemblage on the windward and leeward reef slopes, particularly the deeper slope region, at VRS (Kühlmann 1975; Quintana y Molina 1991). The species distribution is slightly different at Alacranes Reef. *Montastraea cavernosa* is the most abundant coral species on the leeward side of southern Alacranes Reef and comprises about 25% of the coral coverage on that portion of the reef;

however, *M. cavernosa* comprises only about 10% of coral coverage on the windward reef (del Socorro Rivas Solis 1990).

2.2.3. Smooth brain coral

Smooth brain coral (*Diploria strigosa*), also known as common or symmetrical brain coral, forms green, brown, yellowish brown, or bluish gray smooth boulders, domes, or plates with rounded ridges (Humann and DeLoach 2002). Like *Montastraea cavernosa*, the species is very common at all four cornerstone GOM sites. In FKNMS, *D. strigosa* is commonly found at depths of 3-10 m but can occur in waters up to 40 m deep (Shinn et al. 1989). Unfortunately, black-band disease, hyperplasia, and white plague have affected *D. strigosa* at FKNMS, but the population has not suffered to the extent of that of *Acropora palmata* (Santavy et al. 2005).

Diploria strigosa is one of the most abundant corals at both WFG and EFG, and it is typically found in depths of 15-55 m (Bright et al. 1984). The only coral found in higher abundance in shallow areas of WFG is *Orbicella franksi*, and on EFG, *O. franksi*, *Porites astreoides*, and *M. cavernosa* are more abundant (Pattengill-Semmens and Gittings 2003; Vize et al. 2005). Like *M. cavernosa*, *D. strigosa* also comprises about 13% of the coral coverage shallower than 45 m at FGBNMS (Vize et al. 2005). *Diploria strigosa* margins increased by over a third from 2004 to 2005 at FGBNMS (Schmahl et al. 2008). Following the *M. cavernosa* spawning, *D. strigosa*, a broadcaster of egg and sperm bundles, spawns at FGBNMS about 9:00 pm on the seventh, eighth, and ninth nights after the full moon in August (Schmahl et al. 2008). *Diploria strigosa* is the only species that does not have a spawning window during which it is the only coral species spawning at FGBNMS, and its spawning does not end abruptly like the other mass spawning species (Vize et al. 2005). Unlike *M. cavernosa*, WFG and EFG samples of *Diploria strigosa* are genetically homogenous (Atchison et al. 2008). In the vicinity of

FGBNMS, oil and gas platforms host *D. strigosa*, which is the second most abundant scleractinian on platforms and appears to survive well in the full range of successional stages as determined by platform age (Sammarco et al. 2004; Atchison et al. 2008).

Diploria strigosa is also one of the predominant corals in the southern GOM (Quintana y Molina 1991). At VRS, it occurs in shallow portions of the windward and leeward reef slopes and in the reef flat (Kühlmann 1975). Although *D. clivosa* is more abundant than *D. strigosa* in that there are more colonies, *D. strigosa* colonies are larger in diameter than *D. clivosa* colonies at VRS (Ronzón Rodríguez and Vargas Hernández 2007). *Diploria strigosa* mortality rate is a good indicator of declining reef health in VRS lagoons (Ronzón Rodríguez and Vargas Hernández 2007). At Alacranes Reef, *D. strigosa* is the most abundant coral species on the windward side of the southern portion of the site, where it constitutes more than 22% of coral coverage at each of three different depths. The coral is the third most abundant scleractinian on the leeward reef (del Socorro Rivas Solis 1990).

2.2.4. Orange cup coral

Unlike many scleractinians, orange cup coral (*Tubastraea coccinea*), also known as sun polyp or sun coral, is ahermatypic and azooxanthellate. *Tubastraea coccinea* is a bright red, orange, or yellow polyp that forms colonies of various sizes (a few to hundreds of polyps per colony) (Humann and DeLoach 2002). The polyp stalk is usually darker than the bright yellow or orange tentacles. Because *T. coccinea* does not have zooxanthellae, it does not need light and is typically found in darker habitats, such as on pier pilings, oil platforms, reef caves, or even ship hulls. *Tubastraea coccinea* is a brooding scleractinian that releases planulae as opposed to *Acropora palmata*, *Montastraea cavernosa*, and *Diploria strigosa*, which are broadcast spawners that release gametes.

Orange cup coral is native to the Indo-Pacific and the eastern Atlantic, but is spreading throughout the Caribbean Sea and the GOM (Fenner and Banks 2004). The species was first recorded in the Caribbean in 1943 and was first observed in the GOM in the 1990s (Humann and DeLoach 2002). Currently *T. coccinea* is the most abundant scleractinian in the northern GOM (Sammarco et al. 2010). High fecundity and the capability of long-distance larval dispersal contribute to the invasion, which followed the pattern of the *Diadema antillarum* die-off but at a slower rate (Fenner and Banks 2004). Until recently, *T. coccinea* has been found in the GOM only on artificial surfaces, such as pilings, shipwrecks, and, particularly, oil platforms (Fenner 2001). Dispersal likely occurred via ship hulls and among platforms via currents. In the past decade, *T. coccinea* has spread beyond artificial surfaces to reefs and has been observed at FKNMS and FGBNMS (Fenner and Banks 2004). *Tubastraea coccinea* was documented on natural substrates for the first time in the GOM at EFG in 2002 at 24 m, and many colonies have been found in successive years at other banks in the northwestern GOM (Hickerson et al. 2008; Schmahl et al. 2008). *Tubastraea coccinea* first appeared at VRS on a Navy vessel that was sunk to become an artificial reef (T. Camarena Luhrs, personal communication). At Alacranes Reef, *T. coccinea* is known to occur at patch reefs (Rios-Lara et al. 2007), but data regarding initial observation of the invasion are not available.

Tubastraea coccinea could be a pioneer species because its abundance at shallow-water oil and gas platforms declines with increasing age of platforms (Sammarco et al. 2004). The opportunistic, non-indigenous species likely competes with native benthic species for space (Sheehy and Vik 2010). However, because *T. coccinea* may be a pioneer species, it may not be as much of a threat to native species as other more invasive, non-native species that usurp benthic habitat throughout all stages of succession (Sammarco et al. 2004; Sammarco et al. 2010).

2.3. Fish species

Each of the four cornerstone sites has a fish assemblage with more than 200 species, many of which are represented at all four sites. Reported estimates of reef fish species richness for the cornerstone sites of the GOM are: 341 reef fish species at FKNMS, 280 at FGBNMS, 244 at VRS, and 279 at Alacranes Reef (Jeffrey et al. 2001; González-Gándara 2003; Schmahl et al. 2008). The following selected fish species occur at all four sites. They each have different life history characteristics, which may represent different modes of connectivity among the four quadrants of the GOM.

2.3.1. Redlip blenny

Redlip blenny (*Ophioblennius macclurei*) is a small, territorial algivore that is associated with coral or rock and typically lives in or near crevices for protection from predators. It inhabits areas with high wave action and can adhere to the hard substrate with its pectoral fins. The redlip blenny is 5 to 10 cm long with a blunt head and typically dark brown body with red lips but occasionally occurs as a pale morph that has a white body and reddish-brown head. Males and females are both very territorial and protect areas that are about 0.5 m^2 in February and March and areas half that size in May after recruitment. Males create nests, and females leave their territories briefly to lay adhesive eggs in the nest after selection by the male; males protect the spawning female and then fertilize the eggs. After hatching, larvae float to the surface and are transported by tides and currents for about 45 days before settlement. Recruitment may be limited by competition for habitat as opposed to larval supply. A redlip blenny with established territory has a life span of about one year. (DeLoach and Humann 1999)

Redlip blenny is known to occur at the four GOM cornerstone sites and is likely common at all sites (Hildebrand et al. 1964; Jaap 1984; González-Gándara 2003; Hickerson et al. 2008; Rangel Avalos et al. 2008). Of all combtooth blennies (Blennidae), redlip blenny is the only species commonly observed on reefs in Florida (Jaap 1984). Along with other small benthic fish, redlip blenny occurs on patch reefs and is also predominant on the reef flat of bank reefs in FKNMS (Jaap 1984). No additional site-specific data are available as no studies have been conducted to date on this cryptic species in the GOM. However, historically redlip blennies have been very abundant at Alacranes Reef (Hildebrand et al. 1964). Given the territorial behavior and inhabitation of crevices, redlip blenny abundance is assumed to be relatively stable and likely similar at the other three cornerstone sites as well. For the purposes of this chapter, redlip blenny behavior and life history characteristics are also assumed to be similar to those reported from other sites throughout the region as described in the preceding paragraph.

2.3.2. Princess parrotfish

Princess parrotfish (*Scarus taeniopterus*) is a large algivore that feeds by scraping algae off coral or rock using teeth fused into strong beaks. While feeding on algae, parrotfishes also consume some coral, usually dead but occasionally living (DeLoach and Humann 1999). As a result of foraging activity, princess parrotfishes are bioengineers because they contribute to the maintenance of a balance between coral and algae coverages on the reef and to the sedimentation regime.

Parrotfishes are protogynous hermaphrodites. Parrotfishes are broadcast spawners, and they typically spawn on the outer reef edge near prominent structures that are downcurrent. Princess parrotfish spawns all year long in early to mid-morning. Spawning behavior usually involves a terminal male with a harem of three to nine females. Fertilized eggs drift in currents for about 25 h, and larvae settle a few weeks later typically far from the spawning site. (DeLoach and Humann 1999)

The princess parrotfish usually lives in habitats with high coral cover and seagrass beds in depths up to 25 m (DeLoach and Humann 1999; Rocha et al. 2010). Unlike most parrotfish species, *Scarus taeniopterus* is somewhat territorial. Foraging groups typically stay within areas of about 80 to 415 m^2. Feeding and spawning occurs in the territories, but most individuals migrate to sleep in refugia in more complex habitats. Juveniles are associated with *Thalassia* and often occur in large feeding aggregations. (DeLoach and Humann 1999)

Princess parrotfish is common and abundant throughout its range, which is the western central Atlantic (Rocha et al. 2010). At FKNMS, *S. taeniopterus* is one of the most frequently observed reef fishes and is common in deep portions of the bank reef (Jaap 1984; Ault et al. 2006). After establishment of the Tortugas Ecological Reserves, princess parrotfish occurrence increased by about 33% (Ault et al. 2006). At FGBNMS, princess parrotfish is also one of the frequently observed fish species (Pattengill-Semmens and Gittings 2003). Although princess parrotfish have a longer average total length at EFG than at WFG, the abundance of juveniles is high at WFG (Pattengill-Semmens and Gittings 2003). However, princess parrotfish abundance declined starting in 2001 when compared to earlier years at both WFG and EFG (Pattengill-Semmens 2007). Princess parrotfish is reported as common at VRS and Alacranes Reef, but specific habitat preferences and abundances are not reported (Hildebrand et al. 1964; González-Gándara 2003; Rangel Avalos et al. 2008).

2.3.3. Black grouper

Black grouper (*Mycteroperca bonaci*) is a large, solitary carnivore that preys on fishes, crustaceans, and cephalopods. *Mycteroperca bonaci* is a protogynous, sequential hermaphrodite that migrates long distances annually to spawn in huge aggregations in traditional breeding grounds. Spawning aggregations usually occur at or before sunset during a full moon in the winter and in areas with promontories on outer reef shelves in waters over 30 m deep. Spawning can occur throughout the year but peaks in winter and early spring (Crabtree and Bullock 1998). Pelagic eggs hatch into pelagic larvae that drift in currents and tides for about 25 to 45 days before settling on oyster reefs in estuaries with high salinity (DeLoach and Humann 1999). DeLoach and Humann (1999) stated that black groupers can live up to 14 years, but Crabtree and Bullock (1998) found that they may live 33 years. Although black grouper is tolerant to habitat degradation, fishing that targets feeding and spawning aggregations has reduced the population by about 30%, and IUCN categorizes the species as Near Threatened (Ferreira et al. 2008).

The Florida Keys host a major fishery for groupers, and black grouper commercial landings are higher than landings for any other grouper in the Keys (Ferreira et al. 2008; Monaco et al. 2008). *Mycteroperca bonaci* at FKNMS is most commonly observed on the outer fringe of patch reefs and in deep waters of reef banks (Jaap 1984). Black grouper spawning aggregations occur in Florida waters in January through February in the 18-to-28-m depth range (Eklund et al. 2000; Brulé et al. 2003). Population declines in the snapper-grouper complex followed heavy fishing pressure on aggregations, which contributed to the implementation of no-take marine reserves. The black groupers within Tortugas Ecological Reserves have increased in occurrence, abundance, and size since the reserves were established (Ault et al. 2006). Outside the reserves, black grouper occurrence and abundance also increased, but the size of black groupers did not increase above the legal minimum catch size limit, which is indicative of ongoing fishing pressure (Ault et al. 2006).

Black grouper is one of the most heavily fished grouper species in the southern GOM as well; landings in the Campeche Bank area are second only to those of red grouper (*Epinephelus morio*) (Renán et al. 2001). Historically, the grouper fishery (including about 14 grouper species collectively) had higher landings by weight than any other fishery in the Yucatán area, but the red octopus (*Octopus maya*) fishery has exceeded the grouper fishery consistently in recent years (Salas et al. 2006). The sex ratio of the grouper population in the Campeche Bank area, where Alacranes Reef is located, is 1:3 or 1:4 (males to females) (Renán et al. 2001; Brulé et al. 2003). Relative to inshore and offshore samples, samples from the shallow waters of Alacranes Reef indicate that most individuals at the reef are smaller females (Brulé et al. 2003). Although sexually active individuals were observed throughout the year, spawning season at Campeche Bank is December through March with peak spawning in February (Renán et al. 2001; Brulé et al. 2003). Local fishermen reported black grouper spawning aggregations at four Alacranes Reef sites in December through February (Aguilar-Perera et al. 2007). Most piscivores, including black grouper, occur in the spur-and-groove portion of Alacranes Reef (González-Gándara et al. 1999).

Black groupers occur in lower abundance at FGBNMS and VRS than at FKNMS and Alacranes Reef (Pattengill-Semmes 2007; Rangel Avalos et al. 2008). However, observation frequency of black grouper at WFG and EFG increased substantially in the early 2000s despite a reduction in overall fish species richness during the same time period (Pattengill-Semmes 2007). Black grouper feeding or spawning aggregations have not been reported to occur at FGBNMS or VRS.

2.3.4. Lionfish

Red lionfish (*Pterois volitans*) and devil firefish (*P. miles*) (referred to collectively herein as lionfish) are invasive, solitary piscivores that are spreading rapidly throughout the western Atlantic, including Caribbean Sea and the GOM. *Pterois volitans*, like *Tubastraea coccinea*, is native to the Indo-Pacific, and *P. miles* has a native range including the Red Sea, Persian Gulf, and Indian Ocean (Morris and Whitfield 2009). Lionfish likely were introduced to the western Atlantic off the east coast of Florida during the 1980s possibly by multiple aquarists' releases (Morris and Whitfield 2009). Lionfish have invaded the western Atlantic off the U.S. east coast, the Caribbean Sea, and more recently, the GOM. Lionfish occupy reefs and also artificial habitats, such as oil and gas platforms (Sheehy and Vik 2010). Lionfish are one of the most abundant reef predators in the region (Morris and Whitfield 2009). The opportunistic carnivore has significant adverse impacts on recruitment of native reef fish species and, therefore, can have long-lasting adverse effects on coral reef community structure (Albins and Hixon 2008; Arias-González et al. 2011). Few natural predators of the venomous lionfish exist although occasional reports of groupers consuming lionfish may provide insight into ecosystem-based population control techniques (Maljkovic et al. 2008).

Unlike parrotfishes and groupers, lionfish are not hermaphroditic and spawn in pairs throughout the year about every four days (Morris and Whitfield 2009). Spawning frequency combined with sexually maturation within the first year contributes to the lionfish's high fecundity. Lionfish have floating egg masses from which pelagic larvae hatch, which are dispersed by currents, thus rapidly expanding their range (Hare and Whitfield 2003; Freshwater et al. 2009; Morris and Whitfield 2009). The female releases two gelatinous egg masses at the surface, and larval duration is about 26 days but might be as long as 40 days (Hare and Whitfield 2003; Morris and Whitfield 2009).

Although the lionfish was likely introduced to the western Atlantic off the east coast of Florida in the 1980s, the first observation in the FKNMS occurred in January 2009 off Key Largo (Schofield 2009). The first individual was collected, but several other lionfish were observed at FKNMS within six months of the initial sighting (Schofield 2009). The U.S. National Oceanic and Atmospheric Administration (NOAA) considers the lionfish invasion at FKNMS to be "Intermediate-Advanced" with hundreds being reported and removed from the site since they were first reported (Aguilar-Perera 2011; USGS 2013). At FGBNMS, lionfish were first reported in July 2011, and FGBNMS's policy is to remove any lionfish (NOAA 2012c). Lionfish first appeared at VRS in December 2011, and two more individuals were observed in March 2012 indicating that the invasion has now reached VRS (T. Camarena Luhrs, personal communication). Two individuals of *Pterois volitans* were observed at Alacranes Reef in December 2009 at about 38 m (Aguilar-Perera and Tuz-Sulub 2010). The larval source for the two lionfish at Alacranes Reef was likely Cozumel, where *Pterois volitans* was first observed in 2009 (Aguilar-Perera and Tuz-Sulub 2010). Between July 2010 and February 2011, about 260 lionfish have been caught by fishermen in the Alacranes Reef National Park (Aguilar-Perera 2011). Note that the arrival of lionfish in the southern GOM occurred about 20 years after the introduction of the invasive species off Florida. From Florida, larval transport likely occurred first to the Caribbean Sea then via the Caribbean Current and the Yucatán Current into the GOM.

Lionfish predation threatens the coral reef ecosystem's biodiversity and stability of the trophic cascade. As the aggressive predator removes herbivores from the ecosystem, increased algal growth and the concurrent phase shift from balanced coral reef ecosystems to those predominated by algae may be expedited. Lionfish have a direct role in the decline of several species of reef fish populations by consuming newly recruited juveniles, which can have drastic effects especially on fishery species such as the snapper-grouper complex (Morris and Whitfield 2009). The lionfish competes with native species for food, thus also contributing indirectly to declines in reef fish populations. Of particular importance is lionfish population control within protected areas, which have reef fish populations that are more vulnerable to population decline from invasive species because of management provisions, such as restricted fishing activity, that may hinder the efficiency of lionfish population control. Climate change could exacerbate the adverse effects of the bioinvasion by allowing for an expansion of range as sea surface temperatures rise creating additional habitat for the lionfish. Unfortunately, given the high fecundity, high dispersal tendency, and occurrence at depths exceeding 350 m (T. Shirley, TAMUCC, personal communication), lionfish eradication may not be possible in the GOM (Albins and Hixon 2008). However, trinational efforts are underway to minimize the invasion's impacts on the ecosystem by removing individuals upon sighting, organizing lionfish derbies, and encouraging local restaurants to promote lionfish as a desirable seafood item.

3. Ecological connectivity

As implied by the above discussion of species co-occurring at the four cornerstone sites, ecological connectivity exists throughout the GOM region. The major currents, gyres, and eddies and storm events in the GOM form transportation highways for larval dispersal among the four cornerstone sites. Coral larvae connectivity model results have interannual variability throughout most of the GOM (Schill et al. 2012). Exceptions include regular connectivity, albeit with disregard to any density dependence, mortality, and fecundity functions, near the Yucatán and Florida Currents, which transport larvae among sites near Mexico's Yucatán Peninsula, Cuba's northwestern coast, and the Florida Keys. Furthermore, the stepping-stone layout of hard-substrate habitats on smaller, sub-regional scales strengthens Gulfwide connectivity through provision of habitat suitable for spawning aggregations, recruitment, feeding aggregations, and other important life-history events and behaviors. Much of the following discussion focuses on passive biological connectivity of the selected coral and fish species, but many highly migratory species, such as sea turtles, whale shark (*Rhincodon typus*), and cetaceans, also represent important pathways of demographic connectivity through juvenile and adult migrations and movement patterns throughout the GOM. Generally, given the stochastic nature of ecological connectivity via larval transport in the GOM, place-based protection of key habitats is a salient tool for preservation of ecological connectivity and resiliency in the GOM. Regardless of the life stage or connectivity mechanism, maintenance of demographic connectivity is critical for sustainable, ecosystem-based management of transboundary living marine resources and for population and community resilience following natural or anthropogenic perturbations (Nash and McLaughlin 2012).

3.1. Connecting cornerstones

The four cornerstone coral reef sites in the GOM likely experience variable degrees of connectivity that are not always bidirectional. Therefore, some sites would benefit from protection more than others. Similarity of faunal communities, proximity to major currents, exposure to storm events, and proximity to shipping channels and oil and gas platforms contribute to connectivity for species with life history characteristics that allow for transport of eggs, larvae, and adults on appropriate spatiotemporal scales among suitable habitats on the GOM's continental shelf. Spawning strategies, buoyancy of eggs, pelagic larval duration, horizontal and vertical larval swimming behavior, proximity of larval source to currents, frequency and intensity of storm events, and distance to suitable recruitment habitat are important considerations for assessment of connectivity via larval dispersal. Self-recruitment and recruitment from nearby sites may be more common than long-distance larval dispersal (Cowen et al. 2006), but even a small amount of larval dispersal contributes to regional demographic connectivity. Typically, successful larval dispersal for most species occurs over distances of 50 to 100 km (Cowen et al. 2006). In the GOM, stepping-stone connectivity may occur over such distances among habitat sites that are located between each of the four cornerstone GOM sites. Also, strong currents and storm events may directly transport eggs and larvae over longer distances directly among the cornerstone sites for some species.

3.1.1. Water circulation

Several currents and water circulation features have substantial roles in connectivity within the GOM. First, the Yucatán Current brings eggs and larvae from the Caribbean Sea into the GOM. Upon entering the GOM through the Yucatán Channel, most water continues into the center of the GOM and forms the Loop Current. The anticyclonic Loop Current intrudes into the eastern GOM to variable extents depending on seasonality and atmospheric and oceanic conditions. The Loop Current also extends farther into the northwestern GOM where it unpredictably sheds large anticyclonic eddies that travel to the west and southwest (Sturges and Leben 2000). As the anticyclonic eddies move west, they generate smaller cyclonic eddies that are typically located on the continental shelf of Texas and in the western Campeche Bay (Vázquez de la Cerda 2004). Large, deep, cyclonic frontal eddies to the east of the Loop Current have a role in anticyclonic eddy shedding and also contribute to the formation of the very consistent Tortugas eddies (Le Hénaff et al. 2012). Unlike the Loop Current, its cyclonic frontal eddies extend to deep waters, which enables vertical connectivity; similar cyclonic frontal eddies have a connectivity role in the Campeche Bank area (Le Hénaff et al. 2012). Eddies, in addition to major currents, are important conveyers of biological organisms throughout the GOM. For example, eddies can deliver entrained planktonic organisms to the FGBNMS from the Loop Current's surface waters. An eastward flow from FGBNMS to FKNMS, however, is only occasional as opposed to the regular westward flow, and Mississippi River freshwater inflow may prevent survival as larvae are transported from west to east (Lugo-Fernández 1998). Alternatively, hurricane activity can transport organisms from FGBNMS to FKNMS; therefore, such connectivity is possible especially considering that the FGBNMS mass coral spawning occurs during hurricane season (Lugo-Fernández et al. 2001). Finally, the Loop Current next turns to the east and flows out of the GOM via the Florida Current through the Straits of Florida. The Florida Current delivers warm water and entrained nutrients and early life stages to the Florida Keys from the Caribbean via the GOM's Loop Current. A series of counterclockwise gyres immediately north of the Florida Current circulates water between the Keys and the Florida Current as it becomes the Gulf Stream in the Atlantic Ocean (Causey 2008).

From the Yucatán Current, some water moves from the water masses destined for the Loop Current and proceeds to the west off the northern coast of the Yucatán Peninsula. The water moving to the west is entrained into a seasonal cyclonic gyre in the Bay of Campeche (DiMarco et al. 2005; Carrillo et al. 2007). In addition to the small cyclonic eddies mentioned above, the outer boundary of the large, cyclonic gyre is a plausible source of biotic exchange throughout the southern GOM, via the water exchange with adjacent, smaller, anticyclonic coastal eddies, and the center of the Bay (Salas-Pérez and Granados-Barba 2008). The gyre and associated eddies transport planktonic organisms from Alacranes Reef to VRS. Opposing along-shelf currents in the fall and winter off Tabasco and Veracruz generate offshore transport, which lowers the salinity in the southern Bay of Campeche as a result of freshwater inflow from the Coatzacoalcos and Grijalva-Usumacinta Rivers (Zavala-Hidalgo et al. 2003). During the fall and winter, the organisms likely have higher survivability when transported north of the low-salinity zone from the freshwater inflow. In the southwestern GOM, the wind-induced Western Boundary Current moves northward over the continental shelf in the western GOM from April or May to August and southward from September to March (Zavala-Hidalgo et al. 2003; Salas-Pérez and Granados-Barba 2008). Hence, the Western Boundary Current provides bidirectional transport of water and materials between southern and northern portions of the western GOM. In late summer there is a one-month lag when currents reverse on the western GOM shelf (Zavala-Hidalgo et al. 2003). Thus, the current reversals off the Tamualipas and Texas coasts do not coincide exactly; during the interim when the current is northward off Tamualipas and southward off Texas, offshore transport occurs at the confluence of the opposing along-shelf currents (Zavala-Hidalgo et al. 2003). Current velocities in the southern GOM during winter "nortes" range from 80 to 100 cm/s, which are substantially faster than summer, fall, and spring velocities, which are typically 30 to 60 cm/s (Salas-Pérez and Granados-Barba 2008). In the northern GOM, the Western Boundary Current and offshore transport supply a large anticyclonic gyre off Texas (Sturges 1993), which completes connectivity between VRS and FGBNMS.

3.1.2. Faunal links

FGBNMS represents the healthiest and most isolated coral reef system in the GOM. FGBNMS is 1270 km from FKNMS, 980 km from VRS, and 690 km from Alacranes Reef (Schmahl et al. 2008). As aforementioned, hurricanes and other tropical storms move water and entrained organisms very quickly throughout the GOM and could be occasional vehicles of connectivity between distant sites. Brooding corals at FGBNMS are 100% differentiable genetically from those at FKNMS (Sammarco et al. 2004). Brooders at FGBNMS are likely self-seeding, connected to populations in the southern GOM, or a result of a combination of self-recruitment and a Mexican larval source. Larval dispersal from Mexico to FGBNMS likely occurs via the Western Boundary current, as described above, and is supplemented by the shelf-edge eddies. Additionally, a shelf-edge current moves eastward during spawning season, which likely provides larval connectivity between WFG and EFG (Lugo-Fernández 1998). According to drifter data, the majority of pelagic larvae may be transported by eddies and other currents locally but remain in the northwestern GOM, thus likely contributing to self-seeding populations at FGBNMS and to dispersal to nearby banks and platforms in the vicinity (Lugo-Fernández et al. 2001). Other drifters travelled south and reached Veracruz and the Bay of Campeche in about 90 days indicating that pelagic larvae could be dispersed hundreds of kilometers in many directions from FGBNMS (Lugo-Fernández et al. 2001). Note that the species discussed in this chapter have pelagic larval durations that are considered long but are approximately half the time, at best, of the typical drifter travel time from FGBNMS to VRS or Alacranes Reef. Whether drifter travel routes and times are representative of larval dispersal remains to be proven. Nonetheless, several stepping stone habitats between FGBNMS and the southern GOM could provide smaller scale connectivity as seen among sites within FGBNMS. Within FGBNMS, apparent connectivity is primarily with abovementioned eastward current flows (Lugo-Fernández et al. 2001). Therefore, WFG is likely a larval source for EFG, and EFG could be a larval source for other hard banks and reefs that are farther east in the northwestern GOM.

VRS likely has less frequent connectivity with other reef systems in the eastern GOM and Caribbean because it lies beyond the path of direct currents, such as the Yucatán and Loop

Currents, connecting other sites (Rangel Avalos et al. 2008). Because of the lower likelihood for regular connectivity at VRS, it probably functions more as a sink rather than a source on a Gulfwide scale. Support for such a hypothesis is that the lionfish invasion reached VRS last of the four cornerstone sites. Because the lionfish arrived at VRS only five months after its first observation at FGBNMS, the two western cornerstone sites are likely more connected to each other than to FKNMS or Alacranes Reef as a result of the Western Boundary Current and associated eddies. However, occasional eddies that interact to exchange and circulate in the Bay of Campeche can transfer biological material between the central GOM and the coastal VRS (Salas-Pérez and Granados-Barba 2008). Campeche Bank Reefs, including Alacranes Reef, most likely provide larval supply to VRS via some smaller-scale currents and eddies in the southern GOM. Other Campeche Bank Reefs south of Alacranes Reef provide stepping-stone connectivity via the cyclonic gyre in the middle of Bay of Campeche. The high similarity of fish faunas of VRS and Campeche Bank supports the hypothesis that surface currents in the central and northern portions of Campeche Bay connect the two reef areas (Hildebrand et al. 1964).

Fish faunas of the Florida Keys and Alacranes Reef have been very similar throughout time, but connectivity between the two sites is likely a result of common connectivity with Caribbean fishes via the Yucatán Channel as opposed to direct exchange via surface currents connecting the Keys with Alacranes Reef (Hildebrand et al. 1964). Thus, as related to the faunal connectivity within the GOM, FKNMS is likely a sink for many species, but it could provide longer-term connectivity as a larval source to the Caribbean populations, which likely have many stepping-stone habitats that ultimately may provide pelagic eggs and larvae to the Yucatán Current for entry into the GOM. Finally, Alacranes Reef and FGBNMS also have similar fish faunas (Hildebrand et al. 1964), and these two sites may be connected more directly by dispersal via the Yucatán Channel and the Loop Current and by surface currents and eddies that circulate in the center and western portions of the GOM.

Rapidly expanding ranges of invasive species, such as orange cup coral and lionfish, may provide the basis for a conceptual dispersal model throughout the GOM (Cowen et al. 2006; Freshwater et al. 2009; Morris et al. 2009). Invasive species may be good surrogates for studying dispersal of native species with similar life histories. As demonstrated by the invasive orange cup coral discussed in this chapter, artificial hard surfaces, including oil and gas platforms, shipwrecks, pilings, and other structures, create an additional means of connectivity by providing a hard surface to which many benthic organisms, such as some scleractinians, attach. Thousands of oil and gas platforms exist throughout the GOM, and they may be important anthropogenic supplements to the existing natural network of coral reef habitats. Scleractinian survey results indicate that 10 species (plus one hydrozoan) occur on GOM platforms near FGBNMS in waters up to 36 m deep (Sammarco et al. 2004). *Madracis decactis* and *Diploria strigosa* were the predominant hermatypic corals represented in the data; *Montastraea cavernosa* and *Tubastraea coccinea* were also present (Sammarco et al. 2004). Genetic connectivity for broadcasters that spawn annually, such as *M. cavernosa* and *D. strigosa*, may be weaker than genetic connectivity for year-round brooders such as *Madracis decactis* and *Tubastraea coccinea* (Atchison et al. 2008). Annual spawners have pelagic eggs and larvae that can move throughout the GOM region depending on surface currents at that single time per year whereas species that have pelagic larvae year-round may have more dispersal opportunity with the help of several different current patterns and velocities throughout the year.

The four cornerstone coral reef communities of the GOM have faunal similarities that are likely connected to varying degrees on different spatial and temporal scales. The four coral species and four fish species discussed have generally similar affinities for the four sites as demonstrated by abundances, life histories, and behaviors. The most unusual example is *Acropora palmata*, which has declined at FKNMS and VRS, remained relatively stable at Alacranes Reef, and recently appeared at FGBNMS. This indicator species shows the sensitivity of coral reef ecosystems to anthropogenic effects as nearshore sites have a declining abundance of *A. palmata* because of deteriorating water quality. Also, climate change may contribute to the appearance of *A. palmata* at FGBNMS. The more common *Montastraea cavernosa*, *Diploria strigosa*, and invasive *T. coccinea* seem to have more similar distributions and abundances at the four cornerstone sites. Each of the four fish species has relatively long pelagic larval duration, which makes them likely candidates for connectivity via oceanic currents. The territorial redlip blenny would benefit from larval dispersal, especially to locations that provide unoccupied habitat. The princess parrotfish is known to settle far from the spawning location, which indicates that connectivity via dispersal of eggs and larvae is typical for the species. Because black grouper has a long migration to spawn in aggregations, the role of connectivity is inherently proven because the species occurs at sites other than the aggregation sites. Finally, the lionfish invasion has been mapped over time and matches the path of oceanic currents that likely distributed its eggs and larvae throughout the GOM and wider Caribbean region. Many other species occur at each of the four cornerstone sites, and the connectivity represented by the eight species described is a representation of widespread connectivity of coral reef communities throughout the GOM region.

3.2. Smaller scale ecological connectivity

Ecological links among the GOM's four cornerstone sites have been demonstrated on smaller scales linking additional sites, which supports the theory that rare, hard-substrate habitats provide “stepping-stone” connectivity throughout the GOM region. Cross-shelf currents occur in spots throughout the GOM continental shelf and certainly connect coastal, nearshore, and offshore shelf habitat sites. Offshore currents, eddies, and gyres can deliver organisms to hard substrate sites, including artificial reefs, on the continental slope and in deeper waters. For the purposes of this chapter, the following discussion focuses on regional connections in federal waters of the GOM continental shelf.

The strongest ecological connectivity to the wider Caribbean region occurs at sites that are adjacent to the major currents: Yucatán Current, Loop Current, and Florida Current. Northwestern Cuba has many emergent reefs and islands that are collectively exposed to all three major GOM currents. The northern portion of Guanahacabibes Gulf has the well-developed Sancho Pardo Bank reefs, and the Colorados Archipelago, which consists of about 160 small keys to the northeast of Guanahacabibes Gulf, is a geomorphologic hybrid of bank and barrier reefs that parallels much of the northwestern coast of Cuba (González-Sansón and Aguilar-Betancourt 2004). In contrast to the coastal VRS, the reefs of the Cuban GOM exhibit high biodiversity and are healthy, albeit overfished, because of few anthropogenic impacts in the area (González-Sansón and Aguilar-Betancourt 2004). Given the proximity to the currents and the southeastern location, the Cuban reefs are likely the most ecologically connected to Caribbean reefs. Although water generally flows to the northeast, a countercurrent to the Yucatán Current exists near Cabo de San Antonio, a countercurrent near the coast of the region moves to the southwest, and a coastal countercurrent to the Florida Current moves water westward (González-Sansón and Aguilar-Betancourt 2004; Le Hénaff et al. 2012). Such countercurrents allow bidirectional connectivity to reefs off southern Cuban and throughout the Caribbean Sea. Anticyclonic circulation between the Loop Current and the northwestern Cuban reefs provides year-round water exchange (González-Sansón and Aguilar-Betancourt 2004). The Florida Current runs between northern Cuba and FKNMS, both of which receive organisms entrained in the three major currents. The reefs of northwestern Cuba and FKNMS are linked indirectly via shared Caribbean connections, but direct connectivity across the Florida Straits is very infrequent because of the strength of the Florida Current. As indicated by larval dispersal and recruitment models, mutton snapper (*Lutjanus analis*) larvae from spawning aggregations off northwestern Cuba undergo longshore transport to supply recruits to northern Cuba and the Bahamas but rarely traverse the Florida Current (Paris et al. 2005).

In the northeastern GOM, several sites facilitate regional connectivity between FKNMS in the eastern GOM and FGBNMS in the western GOM. Several areas with fishery restrictions exist off the western coast of Florida. A few of these areas provide hard-bottom habitat, including important spawning grounds for some fish species, and serve as stepping stones for motile species. Tortugas Ecological Reserve, Riley's Hump, and Pulley Ridge are examples to the west of FKNMS and Dry Tortugas National Park. Off northwestern Florida, such areas include the Florida Middle Grounds Habitat Area of Particular Concern, Steamboat Lumps Fishery Reserve, and Madison-Swanson Fishery Reserve. Off the Alabama and Mississippi coasts, a group of drowned reefs called the Pinnacles hosts bathymetrically high, hard-substrate habitats in deep waters of the otherwise featureless outer continental shelf. Faunal similarities among the hard-substrate habitats indicate that stepping-stone ecological connectivity is supporting diverse communities throughout the northeastern GOM.

The region in the northwestern GOM where the Flower Garden Banks are located has many other similar banks that formed on underlying salt diapirs. The bathymetrically high banks lie on the mid and outer continental shelf and have geological and biological connections. Some banks are too deep for reef-building corals, but others have healthy coral populations. Most of the approximately 200 banks have surficial features that provide habitat for a diverse community of invertebrates and fish. FGBNMS advisory council has recommended a boundary expansion including the addition to the sanctuary of nine sites: Horseshoe Bank, McGrail Bank, Geyer Bank, Bright Bank, Sonnier Bank, Alderdice Bank, MacNeil Bank, Rankin Bank, and 28 Fathom Bank (NOAA 2012b). The purpose of the sanctuary expansion is to further support and protect the existing ecological connectivity in the northern GOM.

Southwest of the salt diapir region in the northwestern GOM is another collection of hard banks in the terrigenous region of the continental shelf in the western GOM. Many of the South Texas Banks, also known as snapper banks, are geolocated, but little is known about the biotic assemblages (Nash et al. 2013). The series of snapper banks continues south into Mexico where there are several submerged habitat sites with topographic relief off the coast of Tamaulipas (Hildebrand et al. 1964). The Tamaulipas Banks, unlike the South Texas Banks, are not specifically geolocated and have not been explored geologically or biologically. The South Texas Banks, and perhaps the Tamaulipas Banks as well, are relict barrier islands and Pleistocene coralgal reefs, and some of the banks still have living corals (Rezak et al. 1985; Belopolsky and Droxler 1999), which supports the concept that the sites have important roles as connectivity stepping stones even if they are lesser known than other connectivity routes. Farther south the Lobos-Tuxpan Reef System is offshore from Tuxpan, which is about 255 km north of VRS and just south of Tampico. The Lobos-Tuxpan Reef System is similar to VRS with emergent reefs and islands, and the system provides stepping-stone coral reef habitats for pelagic eggs and larvae and motile adults that move from VRS along the Western Boundary Current that connects the southern and northern portions of the western GOM.

The Campeche Bank Reefs are emergent and submerged bank reefs located near the edge of the continental shelf west of the Yucatán Peninsula. Alacranes Reef is the northernmost, largest, and most studied reef on the Campeche Bank, and accordingly, Alacranes Reef is the only formally protected site on the Bank. The reefs have high biodiversity with abundant scleractinians, gorgonians, sponges, and coralline algae, and inter-reef connectivity throughout the expansive Campeche Bank appears high (Jordán-Dahlgren 2002). Acroporids were predominant in the shallow areas historically and are recolonizing the reefs faster than at VRS, probably because of the healthier environment on the outer continental shelf of the Campeche Bank (Jordán-Dahlgren 2004). Upwelling in the western portion of the Yucatán Channel may hinder larval dispersal from the Caribbean to the Campeche Bank Reefs, and the low-salinity environment in the southern Bay of Campeche is a seasonal barrier to connectivity between the Campeche Bank Reefs and VRS (Jordán-Dahlgren 2004). Nonetheless, occasional connectivity exists as evidenced, for example, by the gorgonian populations in the two southern GOM areas. Campeche Bank Reefs have higher richness and abundance of gorgonians than VRS, but all gorgonian species at VRS are found on the Campeche Bank as well (Jordán-Dahlgren 2002). Thus, Campeche Bank Reefs are likely a source and VRS a sink for gorgonians in the southern GOM. The westward decreasing gradient of gorgonians is indicative of infrequent larval transport, which is enough to maintain demographic connectivity between the southwestern and southeastern GOM reefs. Interestingly, no shallow-water gorgonians are in the FGBNMS (Etnoyer 2009), but that may be because of a lack of suitable habitat (i.e., shallow or emergent reefs) as opposed to an absence of larval transport mechanisms. Finally, the higher similarities of gorgonian and other populations between the Campeche Bank Reefs and the Caribbean reefs (Jordán-Dahlgren 2002) are likely the result of proximity to the Yucatán Current, which, despite the variable upwelling along the northeastern Yucatán Peninsula, is the main conduit for larval transport from Caribbean reefs.

The rarity of important hard-bottom habitat on the GOM continental shelf limits colonizing opportunities for species that would likely experience distribution shifts in response to increasing water temperatures and other changing climatological variables. Hence, climate change effects may be greater in regions with more habitat discontinuity, which is another compelling reason to implement place-based protection in a network array. Also, given the increased storm intensity concurrent with climate change (Karl et al. 2009), more opportunities may arise for rapid delivery of eggs, larvae, and other life stages via tropical storms and hurricanes in the GOM. Rapid delivery facilitates connectivity of species with short pelagic larval durations or low fecundities and enables connectivity over larger regions for species with longer pelagic larval durations. For example, the alignment of a hurricane path with the Loop Current could enable water movement across the entire GOM in only a few days. Periodic rapid larval transport may become a critical phenomenon given that intense storms are simultaneously capable of destroying or damaging important habitat sites in the storm path. Therefore, protecting ecological connectivity through an MPA network is increasingly valuable in the face of climate change to secure resiliency while also recognizing shifting species distributions and other structural and functional changes (CEC 2012).

4. Trinational connections among MPA practitioners

Ecological connectivity can be preserved by protecting a network of habitat sites. Ongoing efforts to protect the GOM's existing ecological connectivity have resulted in several meetings and collaborative efforts of scientists and MPA practitioners over the past several years

(Nash and McLaughlin 2012). Islands in the Stream and Beyond the Horizon forums were devoted to discussions and collaborations about MPA networks (Ritchie and Keller 2008; Beyond the Horizon 2011). More recently, in July 2012, a trinational workshop focused on identifying network design parameters for creating the International Gulf of Mexico Marine Protected Area Network (IGOMMPAN). The workshop was held in Boca del Río, Veracruz, Mexico, in which 39 MPA practitioners from the U.S. (9), Mexico (30), and Cuba (3) participated. A pre-workshop survey was administered to maintain some consistency and conceptual similarities to previous efforts that focused on: 1) MPA capacity building throughout the Caribbean region (Gombos et al. 2011), and 2) network of nearshore MPAs in the U.S. GOM (Young and Stadler 2012). Some MPA practitioners involved in those efforts also participated in the 2012 trinational workshop, which helped maintain a common thread with ongoing initiatives. According to survey results, the biggest ecosystem-based challenges common to GOM MPAs are overfishing, climate change, non-point source pollution, and invasive species. Regarding the human dimension, survey responders identified several policy benefits and hurdles associated with the creation and maintenance of IGOMMPAN (Table 3.1).

Workshop participants focused on ecosystem-based problems and policy issues. Workshop outcomes, as discussed below, include identification and weighting of design parameters and identification of candidate sites for inclusion in IGOMMPAN.

4.1. Identifying network design parameters

The workshop's objective was to identify design parameters for IGOMMPAN, specifically targeting habitat sites that are critical for important life history stages, biodiversity conservation, and maintenance of ecological connectivity throughout the GOM region. Participants identified a total of 31 design parameters (Table 3.2) in several categories:

biological, geophysical, threats, management, political feasibility, environmental education and outreach, and cultural features.

Table 3.1
IGOMMPAN policy issues.

Benefits	**Challenges**
Information & resource sharing	Legal strategies
Coordinate protection of aggregations, corridors, & nursery habitats	Lack of communication
Better understand connectivity	Lack of time & interest
Better management & communication strategies	Lack of funding
Coordinate problem solving	Different work styles
Leverage for more resources	Lack of leadership
Establish GOM regional management plan	Political differences between Cuba & U.S.
Eliminate redundant efforts	U.S.'s commercial, economic, & financial embargo on Cuba
Improve public outreach ability	Language translation

Note: Survey data are on file with the author.

Additional discussions also focused on identifying species and sites that are critical for maintaining ecological connectivity and spawning aggregations and scientific experts who could provide more information. While aiming to address major regional concerns through application of design parameters, participants endeavored to identify IGOMMPAN candidate sites that demonstrate biophysical connectivity and that can be linked through standardized governance methods for sustaining human and environmental health and well-being.

4.2. Candidate sites

Workshop participants decided to include most of the existing MPAs in GOM waters and some currently unprotected or underprotected hard banks and reefs as IGOMMPAN candidate sites (Table 3.3; Fig. 3.2). Rather than protecting a fraction of important habitat sites as is often

Table 3.2
IGOMMPAN design parameters.

Parameter	**Rank of importance**[a]
Coral presence/coverage	1
Fish spawning aggregation sites	1
Nursery grounds	1
Sentinel sites for monitoring climate change	1
Best tourism practices	1
High biodiversity	2
Presence of protected species	2
Feeding aggregation sites	2
Areas with endemic species	2
Sites with high integrity	2
Best fishery practices	2
Proximity to known gyres and circulation mechanisms	3
Surveillance and enforcement programs	3
Feeding grounds	4
Sites critical for birds	4
Sites critical for marine migratory species	4
Site-specific political feasibility	5
Coastal development	5
Presence of submerged aquatic vegetation	6
High fragility	6
Presence of currents within a specific site	6
Contingency plans	6
Areas known to have marine mammals	7
Close to pollution sources	7
Hard substrate	8
Rugosity and relief	8
Environmental education and outreach	8
Ecosystem representativity	9
Presence of invasive species	10
Restoration activities	11
Presence of diseases	12
Presence of shipwrecks or other cultural features	13

[a] Ranking was determined by voting for importance levels for each parameter during the July 2012 workshop. A rank of “1” is the highest ranking, and “13” is the lowest.
Note: Data from July 2012 workshop are on file with the author.

Table 3.3
IGOMMPAN candidate sites.

	Site Name[a]	Site Number[b]	Relevant Habitat Types
United States	Florida Keys National Marine Sanctuary	1	Emergent coral reef system; barrier reef; islands; mangroves; seagrass beds
	Dry Tortugas National Park	2	Emergent coral reef system; barrier reef; islands
	Pulley Ridge Habitat Area of Particular Concern	3	Drowned barrier islands; diverse coral, algae, & fish communities; deepest coral reef ecosystem in the U.S. GOM
	Florida Middle Grounds Habitat Area of Particular Concern	4	Hard-bottom ridges; high coral & fish diversity compared to surrounding area
	Steamboat Lumps Fishery Reserve	5	Deep limestone terraces; deepwater coral system; abundant reef fish; grouper spawning site
	Madison-Swanson Fishery Reserve	6	Deep rocky outcrops; deepwater coral system; abundant reef fish; grouper spawning site
	Pinnacles[c]	7	Submerged hard-bottom bathymetric highs; relict reefs; abundant fish populations; probably spawning sites
	Northwestern Gulf of Mexico Reefs and Banks[c]	8	Coral communities; submerged hard-bottom bathymetric highs; deepwater corals; abundant sponges and reef fishes
	Flower Garden Banks National Marine Sanctuary	9	Coral reef; submerged hard-bottom bathymetric highs; deepwater corals
	South Texas Banks[c]	10	Submerged hard-bottom bathymetric highs; relict coral reefs & barrier islands; abundant gorgonians & reef fishes
Mexico	Tamaulipas Banks[c]	11	Submerged hard-bottom bathymetric highs; relict coral reefs & barrier islands; likely similar biology to South Texas Banks
	Área de Protección de Flora y Fauna Laguna Madre y Delta del Río Bravo	12	Mangroves; coastal dunes; beaches; lagoon; hypersaline estuary & wetland; abundant coastal & marine birds
	Santuario Playa de Rancho Nuevo	13	Nesting beach for Kemp’s ridley sea turtle
	Sistema Arrecifal Lobos-Tuxpan	14	Emergent coral reef system; fringing & platform reefs; islands
	Manglares y Humedales de Tuxpan	15	Mangroves; coastal wetlands; abundant coastal & marine birds
	Parque Nacional Sistema Arrecifal Veracruzano	16	Emergent coral reef system; fringing & platform reefs; islands
	Reserva de la Biosfera de los Tuxtlas	17	Mangroves; beaches; rocky shore
	Manglares y Humedales de Laguna Sontecomapan	18	Lagoon; mangroves; seagrass bed; abundant coastal & marine birds
	Reserva de la Biosfera Pantanos de Centla	19	Wetlands; mangroves; beaches; coastal plain; abundant coastal & marine birds
	Área de Protección de Flora y Fauna Laguna de Términos	20	Lagoons; swamps; abundant coastal & marine birds

Table 3.3 Continued

	Site Name[a]	Site Number[b]	Relevant Habitat Types
Mexico	La Playa Tortuguera Chenkán	21	Nesting beach for hawksbill and green turtles
	Reserva de la Biosfera Los Petenes	22	Wetlands; mudflats; mangroves; coastal dunes; brackish marshes; cenotes; seagrass beds; abundant coastal & marine birds
	Reserva de la Biosfera Ría Celestún	23	Lagoon; hypersaline estuaries; sea turtle nesting beaches; abundant coastal & marine birds
	Reserva Ecologíca Estatal El Palmar	24	Wetlands; sea turtle nesting beaches; abundant coastal & marine birds
	Campeche Bank Reefs[c]	25	Emergent and submerged coral reef systems; islands
	Parque Nacional Arrecife Alacranes	26	Emergent coral reef system; islands; abundant reef fishes
	Reserva de Dzilam	27	Coastal wetlands; coastal dunes; mangroves; marshes
	Santuario Playa Ría Lagartos	28	Nesting beach for hawksbill and green sea turtles
	Reserva de la Biosfera Ría Lagartos	29	Mangroves; coastal dunes; hypersaline estuary; marshes; abundant coastal & marine birds
	Área de Protección de Flora y Fauna Yum Balam	30	Mangroves; islands; coastal dunes; wetlands; abundant coastal & marine birds
	Reserva de la Biosfera Tiburón Ballena	31	Whale shark feeding grounds
Cuba	Reserva de la Biosfera Peninsula de Guanahacabibes	32	Lagoons; swamps; mangroves; cenotes; sea turtle nesting beaches; very diverse coral reef system
	Guanahacabibes National Park	33	Lagoons; swamps; mangroves; cenotes
	San Antonio Bank	34	Rocky bottom; coral reef system
	Ecological Reserve Mono-Galindo	35	Islands; coastal plains; mangroves
	Cayos de las Cinco Leguas Faunal Refuge	36	Islands; lagoons; estuaries; salt marshes; mangroves

[a] In counterclockwise order from Florida to Cuba.
[b] Site numbers correspond with mapped sites in Fig. 3.2.
[c] These sites are each complexes of several sites. They are also the sites that do not currently have formal protection.

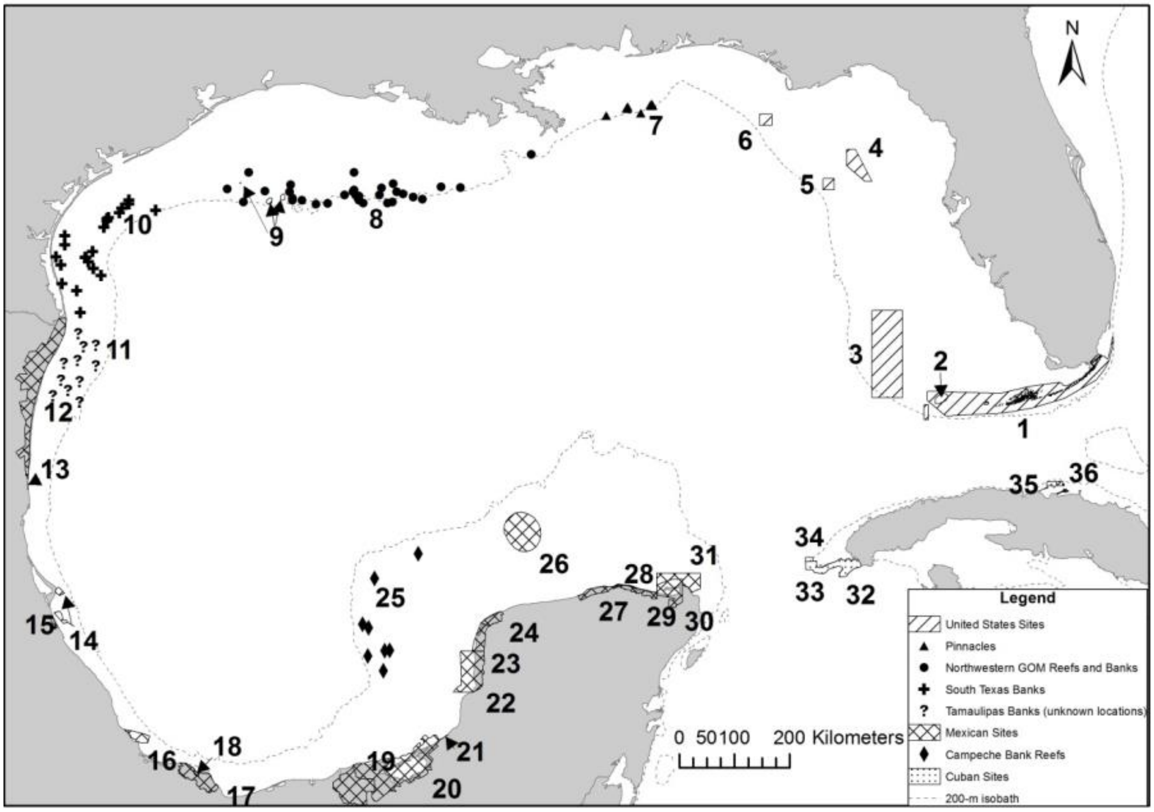

Fig. 3.2. IGOMMPAN candidate sites.

done with MPA design strategies (Botsford et al. 2009), the IGOMMPAN candidate sites are proposed for full protection and inclusion in the network. Because important hard-bottom habitats are rare on the GOM continental shelf (Nash and McLaughlin 2012), all such habitat sites contribute to the GOM's resiliency. Some of the submerged sites are somewhat physically isolated, remote, and relatively small. For example, the FGBNMS currently has three distinct protected areas that target habitat features that are physically separated. The discontinuity of hard-bottom habitats throughout most of the GOM's continental shelf supports the rationale to protect many small areas to preserve ecological connectivity and resiliency. Even small MPAs secure self-recruitment and larval retention, which sustains a robust population for larval dispersal. Therefore, several small MPAs could maintain demographic connectivity even with a low frequency of long-distance connectivity.

Workshop participants valuated design parameters at the candidate sites and some sites in the Mexican Caribbean. According to similar results of multivariate analyses (principal component, multidimensional scaling, and nearest neighbor clustering), the sites were grouped into five main categories: coral reefs (43%), estuarine or lagoon systems (28%), coastal wetlands (12%), turtle nesting beaches (5%), and important fishery habitats (12%). The most distinctive groups that most closely align with site values resulted from multidimensional scaling. Generally, the coral reef sites have the highest values and typically provide habitat for more species than the other categories. The group of estuarine or lagoon systems includes high-quality coastal wetlands and portions of the marine environment. The coastal wetlands group, although with lower values than the estuarine or lagoon systems, consists of a tight cluster of sites that does include some estuarine or lagoon features but those that are more affected by anthropogenic activities than the previous group. The last two groups, turtle nesting beaches and important fishery habitats, are close enough in value that results are mixed. Of the important fishery habitats, South Texas Banks consistently ranks at the low end while Pulley Ridge consistently ranks at the high end. The geographical separation of these two sites is notable, and the South Texas Banks and Pulley Ridge may be equally important in sustaining fisheries and diversity in their respective regions. Despite overall importance, each candidate site contributes noticeably to ecological connectivity of several to many important transboundary living marine resources in the GOM.

4.3. Next steps

Workshop participants agreed on action items to maintain continuity, communication, information sharing, and proactive strategies for establishing IGOMMPAN. All participants agreed that future IGOMMPAN meetings should occur in Mexico to facilitate logistics of trinational participation. Cuba's *Sistema Nacional de Áreas Protegidas* invited all participants to an MPA workshop to be held in Havana in July 2013. Mexico's *Comisión Nacional de Áreas Naturales Protegidas* offered office space for an IGOMMPAN communication coordinator, and the Gulf of Mexico Large Marine Ecosystem Project committed to hiring an individual for the position. The Harte Research Institute for Gulf of Mexico Studies will develop a web-based data portal for trinational information sharing among IGOMMPAN members. Several individual participants also volunteered for various activities such as designing outreach material, organizing educational tours, and coordinating with additional agencies.

Once IGOMMPAN is formally established, MPA practitioners' connectivity efforts should continue within and beyond the GOM. Within the GOM, natural ecological communities exist on the continental slope and in deeper waters—deep sites provide habitat for chemosynthetic communities and cold-water corals. Living marine resources have also established communities in, on, and around artificial reefs, including shipwrecks and thousands of oil and gas platforms. Ecological connectivity also clearly exists among IGOMMPAN sites and sites within U.S. state waters, the Mesoamerican Barrier Reef, and other sites throughout the wider Caribbean region and the western Atlantic Ocean. IGOMMPAN could easily link to other established networks: the U.S. nearshore Gulf of Mexico MPA network (NOAA 2012d), the Caribbean MPA Managers network (CaMPAM 2013), and the North American MPA Network (CEC 2011).

5. Conclusion

Ecological connectivity throughout the GOM is a dynamic process. Larval transport pathways and post-settlement movement patterns vary spatially and temporally depending on suitable habitat availability, unpredictable behavior of the Loop Current and associated eddy shedding, severe storms, and effects of anthropogenic activities. The four coral reef cornerstone sites are the most studied sites and among the healthiest, most robust coral reef communities of the GOM. As a result, they host many species that exhibit connectivity throughout the region. Hydrological models combined with species-specific knowledge are excellent bases for ecological connectivity scenarios, which are important tools needed to properly design protection and recovery plans aimed at sustaining productivity and building resiliency of coral reef ecosystems. Additional studies, particularly those focusing on larval dispersal, are needed to better map connectivity patterns in the GOM. Until technology for tracing and tracking larvae is cost-effective and reliable, genetic analyses should be conducted on more species using samples from coral reef communities throughout the GOM. Genetic connectivity of important representative species, such as those in this chapter, could be extrapolated to predict the degree of connectivity for assemblages consisting of species with similar life histories. Nonetheless, demographic connectivity of the eight species presented is a solid basis for creation of a network of protected habitats.

Within the GOM, efforts are underway to design an international network of MPAs to protect ecological connectivity. Although very little biological information exists for several of the “stepping-stone” sites, such as the South Texas Banks and the Tamaulipas Banks, better understanding of ecological connectivity would provide insight to scientists as they identify key habitat nodes that are critical to maintaining resiliency of the GOM in the face of chronic environmental stressors and episodic natural and anthropogenic disasters. Using the best available information, maintaining and increasing connectivity through place-based management on the scale of a large marine ecosystem could increase the likelihood of preserving biodiversity in a changing climate (Krosby et al. 2010). In the realm of human ecology, connections exist among scientists and MPA practitioners throughout the GOM region, and collaborative opportunities are expected to continue and strengthen as IGOMMPAN is formed and maintained.

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CHAPTER 4

SELECTING AMONG THE SOUTH TEXAS BANKS FOR PLACE-BASED PROTECTION USING A STATISTICALLY DERIVED ABIOTIC SURROGATE FOR BIODIVERSITY

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Format: *Marine Policy* used as format.

Abstract

Biodiversity data are critical for marine conservation planning, but biological surveys, particularly in offshore locations, are resource intensive and dependent on favorable conditions at sea. In areas with few biological data, abiotic variables are used as surrogates for marine biodiversity. The South Texas Banks are hard-substrate sites with bathymetric relief on the continental shelf in the northwestern Gulf of Mexico where biological data are sparse. High-resolution multibeam echosounder data were used to create a dataset of geomorphic variables to be used via multivariate statistical analyses as an abiotic surrogate for biodiversity patterns. The statistical approach produced a ranking tool to guide prioritization of future biological explorations and site selection for design of marine protected areas. A minimum of five of the South Texas Banks is proposed for place-based protection. Similar methodology can be applied to other regions of the Gulf of Mexico to identify sites for inclusion in the International Gulf of Mexico Marine Protected Area Network.

1. Introduction

Conservation planning and design of marine protected areas (MPAs) are dependent on biodiversity data for habitat mapping or understanding of spatial ecology. Marine biodiversity is difficult to quantify, particularly in offshore locations, given the paucity of biological survey data. Comprehensive biological assessments are resource intensive and are dependent on favorable field conditions. Hence, remotely sensed data and reconnaissance-level information can provide a relatively affordable means for identifying areas with high biodiversity through the use of surrogates (Zacharias and Roff 2000). Because biological data are often unavailable or inadequate, surrogates for biodiversity are critical for site selection for place-based management of living marine resources (Rodrigues and Brooks 2007).

On the seafloor, known biodiversity hotspots include areas with hard substrate and bathymetric relief, such as seamounts and other hard grounds (Anderson et al. 2011). Biodiversity increases with increasing habitat heterogeneity, which typically corresponds with geomorphic heterogeneity or complexity (Heap 2006; Buhl-Mortensen et al. 2010). Hard-substrate areas with bathymetric relief create structure and geomorphic heterogeneity on the seafloor, which results in greater diversity within biological communities that use geomorphic features for important behaviors such as foraging, shelter, and spawning aggregations. Certain geomorphic, structural, and environmental features and phenomena are known to correlate with habitat heterogeneity and high biodiversity in the marine environment. As a result, abiotic features can be used as proxies or surrogates for estimating biodiversity trends. Several studies have used abiotic surrogates that quantify environmental gradients (e.g., dissolved oxygen, salinity, temperature) and sediment compositional variables (e.g., sediment type, grain size) that directly relate to marine biodiversity patterns (Zacharias and Roff 2001; Stevens and Connolly 2004; McArthur et al. 2010; Anderson et al. 2011). Indirect gradient variables, such as depth, surficial complexity, and rugosity, also drive benthic biodiversity and spatial ecology (Collin et al. 2011). Finally, distinct geomorphic features on the seafloor, at individual and regional scales, are also surrogates for biodiversity (Williams et al. 2008; Anderson et al. 2011). Although most effective surrogates are based on combined biotic and abiotic data (Zacharias et al. 2001; Stevens and Connolly 2004; Rodrigues and Thomas 2007; Ban 2009), abiotic surrogates alone still provide useful information for identifying biodiversity hotspots or patterns in subtidal environments when biological data are absent or incomplete (Last et al. 2010).

Bathymetry and bathymetry-derived variables combined with geospatial identifiers are attractive surrogates for biodiversity as improving technology enables higher-resolution and more affordable data collection. Coarse bathymetric data have been used to identify hard grounds in the marine environment using rugosity as an indicator (Dunn and Halpin 2009). Depth is a primary factor affecting faunal distributions, but size, relief, and structural complexity of geomorphic features on the seafloor are also known indicators of biodiversity and distribution (Williams et al. 2009; Collin et al. 2011). High-resolution, multibeam echosounder bathymetric data can be used to generate a suite of quantitative variables to describe the seafloor and act as surrogates (Buhl-Mortensen et al. 2009). Moreover, multivariate statistical analysis of bathymetry-derived variables produces information about biodiversity and spatial ecology that conservation planners need to make well-informed decisions.

In the Gulf of Mexico (GOM), hard-substrate bathymetric highs create biodiversity hotspots on the continental shelf that consists mostly of unconsolidated sediments on a generally flat seafloor (Rezak et al. 1985; Rezak et al. 1990; Nash and McLaughlin 2012). Analytical subjects were hard grounds on the continental shelf off South Texas known as the South Texas Banks. Over 20 South Texas Banks have been identified, but few biological data exist (Nash et al. 2013a). Abiotic variables are not appropriate for predicting occurrence, distribution, or abundance of individual taxa (Stevens and Connolly 2004), but because geomorphic variables are appropriate surrogates for mesoscale biodiversity (Last et al. 2010), statistical analysis of such variables can elucidate biodiversity patterns and ecologically relevant zones (Verfaillie et al. 2009). Multivariate statistical analyses of spatial and bathymetry-derived variables were used to infer biodiversity patterns at the South Texas Banks.

Geomorphic features create the foundation of certain habitat types; therefore, identification of such features is fundamental for marine spatial planning in support of ecosystem-based management (Roff et al. 2003; Heyman and Wright 2011). Australia, which is a global leader in science, design, and implementation of MPAs, has already used geomorphic features and bathymetric data successfully to guide site selection for mesoscale conservation planning (Anderson et al. 2011). Similarly, the multivariate statistical approach described herein facilitates site selection for place-based protection of important habitats in the coralgal bank region of the continental shelf off South Texas. In support of the endeavor to create the International Gulf of Mexico Marine Protected Area Network (IGOMMPAN), this chapter culminates with a ranking tool to identify potential IGOMMPAN sites within the group of outer-shelf South Texas Banks.

2. Materials and methods

This study was designed to use high-resolution bathymetric data to aide in selection of high-biodiversity habitat sites for marine conservation planning. Methods were adapted from a previous statistical study of bathymetric highs in the salt diapir regions of the northwestern GOM using data describing the Flower Garden Banks and neighboring sites (Fig. 4.1; Nash et al. 2013b). A principal component analysis (PCA) model was used by Nash et al. (2013b) to predict the number of biotic zones at a site using six geomorphic variables.

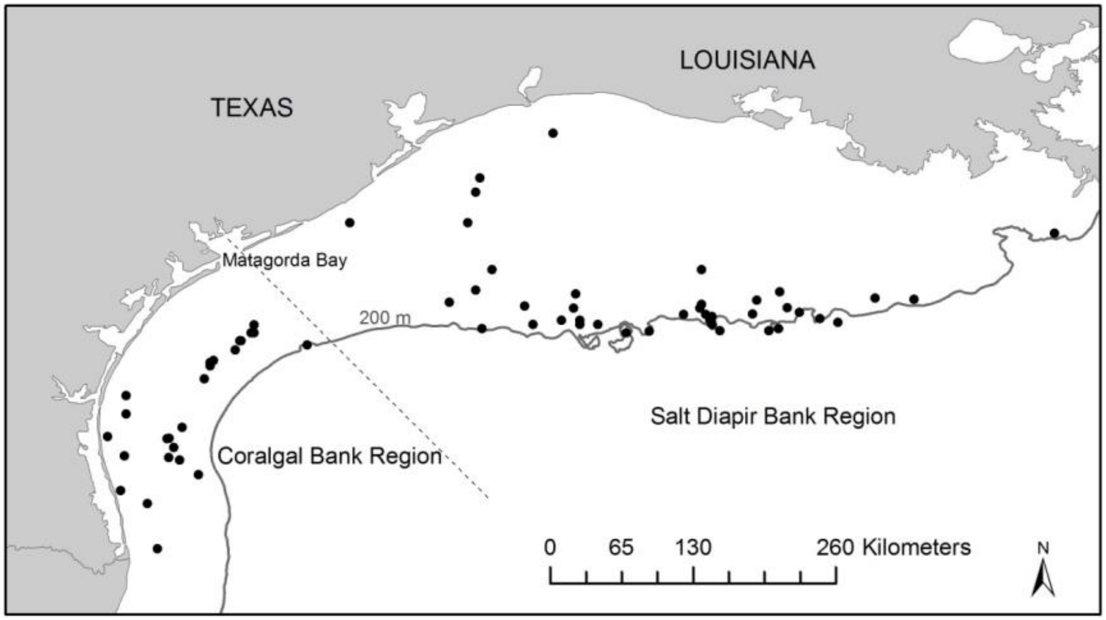

Fig. 4.1. Northwestern GOM hard banks. Nash et al. (2013b) performed a statistical analysis on selected sites in the salt diapir region. This chapter focuses on the study performed on selected outer-shelf South Texas Banks in the coralgal bank region.
Adapted from: Rezak et al. 1985 and Nash et al. 2013a.

In lieu of a pinnacle count used by Nash et al. (2013b), this study used rugosity as the sixth variable because the South Texas Banks do not have pinnacle features as do the salt diapir banks. Raw, high-resolution, multibeam bathymetric data were collected using a Kongsberg EM 710 0.5x1 shallow-water multibeam echosounder on the *R/V Falkor*, and those data were processed to remove spurious data using Caris HIPS and SIPS Version 7.1 software. Processed, georeferenced data were imported into ArcGIS® as ASCII grid files and converted to bathymetric rasters (raster resolution = 1 m) for use and analysis. Finally, multivariate statistical tests were run using Matlab®. For comparative purposes, the analysis for the salt diapir region was performed again using rugosity instead of pinnacle count. Data from the South Texas Banks were applied to the revised PCA loadings to gauge the accuracy of results. Next, independently of the salt diapir region model, 12 outer-shelf sites that were explored during the September 2012

South Texas Banks cruise were analyzed using multivariate statistical tests: nearest neighbor cluster analysis, multidimensional scaling (MDS), and PCA. Statistical results were analyzed and used to create a ranking tool to facilitate prioritization of future biological expeditions and to support decision-making processes regarding site selection for habitat protection in the South Texas Banks region of the GOM.

2.1. Study area

The marine landscape that comprises the South Texas Banks is roughly 15,000 km^2 within U.S. waters and likely continues to the south into Mexican waters where similar geomorphic features are known as the Tamaulipas Banks (Hildebrand et al. 1964). The coralgal bank region of the northwestern GOM's shelf lacks allochthonous salt sheets that underlie hard banks and reefs in the salt diaipir region (Berryhill 1986; Nash et al. 2013a). The South Texas Banks occur across the continental shelf between the Rio Grande and Brazos-Colorado shelf edge fans (Holcombe et al. 2010). Over 20 South Texas Banks have been identified, but biological data are scarce (Nash et al. 2013a). High-resolution bathymetric data existed only for a few of the South Texas Banks previously (Holcombe et al. 2010). The study area comprises the outer-shelf South Texas Banks, which are hard, carbonate banks thought to be drowned Pleistocene coralgal reefs on the continental shelf off South Texas (Rezak et al. 1985; Belopolsky and Droxler 1999; Holcombe et al. 2010). Habitats closer to the shelf edge typically have higher species richness and less environmental variability than nearshore sites (Zacharias and Roff 2001).

Analyses focused on 12 outer-shelf South Texas Banks, which occur in two geographical groups (Fig. 4.2). The northern group includes Baker, South Baker, Aransas, North Hospital, Hospital, and Southern Banks. The southern group consists of Dream Bank, Big Adam Rock, Small Adam Rock, Blackfish Ridge, Mysterious Banks (a complex of many banks), and a newly discovered unnamed bank. The newly discovered site may be of a different origin than the other South Texas Banks because it is deeper and closer to the shelf edge. Detailed bathymetric maps of the 12 sites are in the Appendix.

2.2. Expedition summary

A scientific party used the *R/V Falkor* of the Schmidt Ocean Institute to explore the continental shelf with the goal of mapping the South Texas Banks. The cruise occurred September 17-29, 2012, and the research team was composed of scientists from Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi, Rice University, and The University of Texas at Brownsville. The goals of the cruise were to confirm (or correct) locations of known sites, map the sites using a state-of-the-art multibeam echosounder system, perform video transects across ecologically and geologically interesting site features, and collect biological and geological specimens. The video transects and benthic and sediment samples were conducted using Deep Sea Systems International's Global Explorer MK3, a remotely operated vehicle (ROV).

Target locations were based on coordinates from literature (Nash et al. 2013a). Several sites could not be located with published coordinates—Bad Mud Bank, Small Dunn Bar, Big Dunn Bar, Little Adam Rock, Little Mitch Bank, Four Leaf Clover, and East Bank. Other sites, such as 9 Fathom Rocks and Steamer Bank, were located at different coordinates than described in the literature. Additionally, the East Breaks site, which is farther to the east and deeper than all other sites, was not sought based on timing and logistics of the cruise plan. Finally, a serendipitous discovery of a previously unknown site was made southeast of the Mysterious

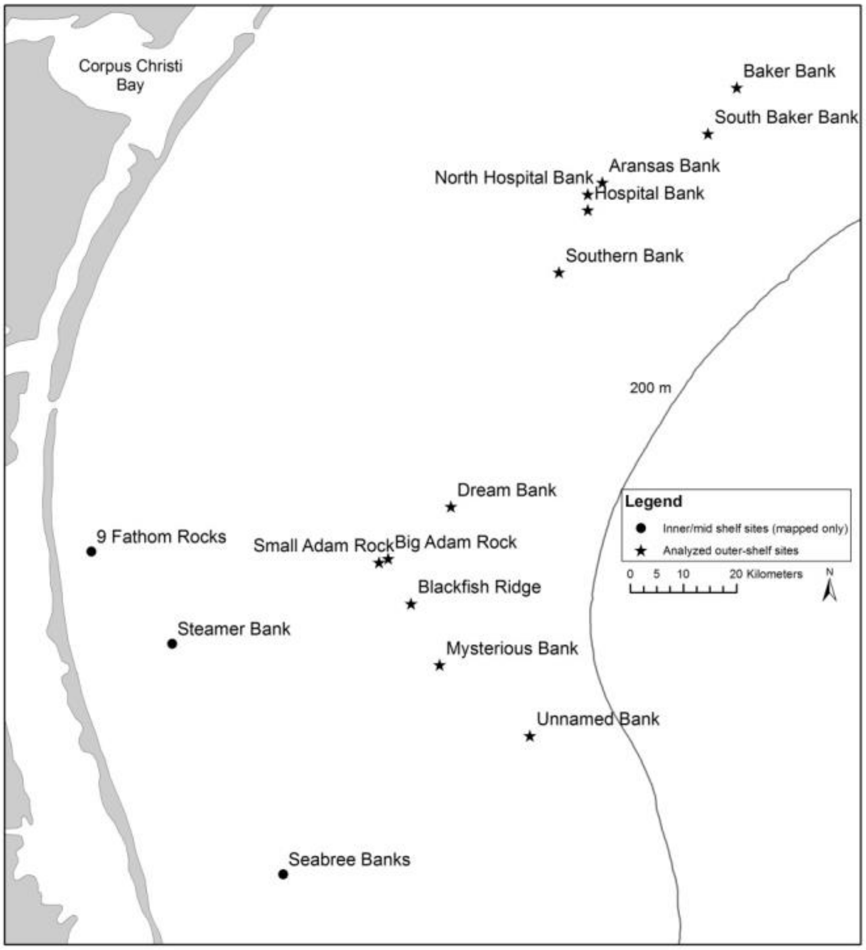

Fig. 4.2. Study area with sites explored in 2012. Inner- and mid-shelf sites (dots) were located and mapped but excluded from the statistical analysis. Outer-shelf sites (stars) are targets of the analysis presented in this chapter.

Banks complex near the shelf edge. The site has not yet been officially named and is referred to in this chapter as Unnamed Bank. Correct coordinates for located sites are in Table 4.1.

Table 4.1
Sites explored during September 2012 expedition.

Site Name	Latitude	Longitude	Site components	Position on shelf
Baker Bank	27°45'00”N	96°14'00”W	5	outer
South Baker Bank	27°40'30”N	96°16'24”W	2	outer
Aransas Bank	27°35'30”N	96°27'00”W	1	outer
North Hospital Bank	27°34'30”N	96°28'30”W	1	outer
Hospital Bank	27°32'30”N	96°28'30”W	2	outer
Southern Bank	27°26'30”N	96°31'30”W	1	outer
Dream Bank	27°02'30”N	96°42'30”W	2	outer
9 Fathom Rocks	26°57'56”N	97°19'06”W	5	inner
Big Adam Rock	26°57'12”N	96°49'00”W	1	outer
Small Adam Rock	26°56'42”N	96°49'48”W	1	outer
Blackfish Ridge	26°52’36”N	96°46’36”W	1	outer
Steamer Bank	26°48’31”N	97°10’54”W	>52	mid
Mysterious Banks	26°46’06”N	96°42’00”W	>58	outer
Unnamed Bank	26°39’13”N	96°34’22”W	3	outer
Seabree Banks	26°25’06”N	96°59’34”W	>40	mid

Because of time constraints and occasionally rough seas, the ROV was deployed at only six sites: Baker Bank, Aransas Bank, Dream Bank, Blackfish Ridge, Mysterious Banks, and Unnamed Bank. Biological and geological specimens were collected at these sites with the exception of Mysterious Banks, where the persistent nepheloid layer greatly hindered visibility and, thus, sampling efforts. Sediment cores were collected only at four sites: Aransas Bank, Dream Bank, Blackfish Ridge, and Unnamed Bank. At Baker Bank, very loose, unconsolidated, thixotropic sediment prevented successful sediment sampling, and the poor visibility at Mysterious Banks inhibited the ROV pilot from collecting a push core at the site. Video transects were performed at the five sites (the ROV dive was aborted at Mysterious Banks because of the poor visibility), and analysis of various biological assemblages is currently underway.

2.3. Calculation of input variables

Six variables describing bank features were calculated in ArcGIS® and used as input to the statistical analyses (Table 4.2). The distance to the nearest neighbor was a simple measurement using the site coordinates that identify the center peak of a site (see Table 4.1) and the Haversine formula for great-circle distances on a sphere. The next three variables were calculated after defining site boundaries and extracting bathymetric data accordingly. Some sites are complexes with more than one component (e.g., Dream Bank comprises two distinct components); for such sites, individual polygons were created to bound each component, and variables were quantified collectively for all components combined at a single site. Regional depth was the mean depth of a 200-m buffer zone outside the polygons that defined site or site component boundaries. Shallowest depth was the crest depth or peak of a site. Area was the planimetric area of a site within defined boundaries. The rugosity measure was calculated using the Benthic Terrain Modeler (BTM) version 3.0 (Wright et al. 2012), which used a vector ruggedness measure (VRM) to describe variability in topography using a 3x3 neighborhood (e.g., Sappington et al. 2007). Rugosity is traditionally calculated as the ratio of three-dimensional area to planimetric area. However, a VRM quantifies three-dimensional dispersion of orthogonal vectors with reference to the landscape and is less correlated with slope. This rugosity index has a range of 0 to 1, with 1 being the most rugose. A terrace was defined as a flat area bounded by steep slopes. To quantify terraces at each site, the depth range was divided into 1-m intervals, and total area was calculated for each interval by counting the number of pixels, each of which represents 1 m^2. Hypsometric curves (percentage of area v. depth) were plotted for each site, and the peaks on the curves were identified as terraces. Three-dimensional images of the sites in ArcScene® aided in observation of the terraces identified in the hypsometric plots.

Table 4.2
Geomorphic data for selected South Texas Banks.

Site name	**Distance to nearest neighbor (km)**	**Regional depth (m)**	**Shallowest depth (m)**	**Area (km^2)**	**Rugosity (0 to 1)**	**Terrace count**
Baker Bank	9.22	74	58	1.39	0.00187	3
South Baker Bank	9.22	85	62	0.21	0.00250	4
Aransas Bank	3.08	73	59	0.51	0.00143	4
North Hospital Bank	3.08	71	57	1.42	0.00193	5
Hospital Bank	3.71	77	58	2.41	0.00182	4
Southern Bank	12.16	82	59	1.02	0.00203	5
Dream Bank	14.55	84	68	2.07	0.00129	4
Big Adam Rock	1.61	68	60	0.51	0.00092	3
Small Adam Rock	1.61	65	60	0.07	0.00068	2
Blackfish Ridge	9.26	75	61	1.36	0.00154	3
Mysterious Banks[a]	14.25	80	69	3.64	0.00090	0
Unnamed Bank	17.96	99	83	0.37	0.00324	2

[a] Entire site was not mapped. Data were minima.

2.4. Statistical analyses

First, the predictive model created for the salt diapir region (Nash et al. 2013b) was applied to the South Texas Banks. Because the biotic zone results were not correct for the South Texas Banks (see section 4.1), new statistical analyses were performed using only data from the South Texas Banks. Using Matlab®, three sets of multivariate statistical tests were performed using the data in Table 4.2 as input values. The hierarchical cluster analysis used a similarity matrix of standardized, Euclidean distances. Clusters were produced as a result of linkage distances (LD) calculated with an algorithm using Ward's minimum variance, and the dendrogram was produced using the nearest neighbor technique.

Next, a non-metric MDS without rotation was conducted using the same similarity matrix as was used for the cluster analysis. The MDS utilized two dimensions yielding a Kruskal's stress metric goodness of fit of 0.054. Two dimensions were initially chosen based on the MDS results in the salt diapir region; the low Kruskal stress (less than 0.1) confirmed that two dimensions were sufficient for explaining the variance in the data (Kruskal 1964).

The PCA was performed without rotation using the correlation matrix of the six variables. Principal components (PCs) 1 and 2 explained over 80% of the variance, which is even higher than those for the salt diapir regional model; hence, the remaining four PCs were not used for analysis. Finally, statistical results were interpreted to produce a grouped ranking of sites indicative of predicted biodiversity.

3. Theory

Because abiotic surrogates alone are not robust predictors of biodiversity or spatial ecology (Rodrigues and Brooks 2007; Ban 2009; Last et al. 2010), further analysis of video transects may be helpful to confirm the detected biodiversity patterns. Ground-truthing biodiversity patterns presents hurdles ranging from resource intensive surveys to difficulty of taxonomic identification based on video transects (McArthur et al. 2010). However, video-based ground-truthing is common and successful for validating acoustic surveys (Jordan et al. 2010). Once results are compiled for selected sites that were explored with the ROV, community compositions and site similarities could be used to refine the statistics-based method for ranking predicted biodiversity levels among the South Texas Banks. According to preliminary results of biological analyses, terrace size may strongly influence composition of fish assemblages (Lerma et al., The University of Texas at Brownsville, personal communication). Therefore, terrace area calculations could produce another important variable that could be a determinant in additional statistical analyses. Based on biological results from the six sites that were surveyed, additional information could be provided to adjust geomorphic variables to serve as indirect proxies for taxa-specific habitat (Wilson et al. 2007). The analysis could be taken a step further to suggest distributions of communities and taxa at each site based on combined bathymetric analyses and video transect results. Another potential complementary research project for existing and additional data would be using algorithms generated by machine learners to predict smaller-scale biodiversity and habitat classifications (Collin et al. 2011). Ultimately, mapped geomorphic features overlaid with biological data form comprehensive marine habitat maps that can be used to refine or develop conservation plans (Brown et al. 2011).

Depth, sediment composition, and topography are also good correlates for species composition as identified from video footage (Buhl-Mortensen et al. 2009). In the coralgal bank region of the shelf off Texas, however, sediment samples are difficult to collect at deep-water sites that require ROV-assisted sample collection. The nepheloid layer clouded vision, and the highly unconsolidated, thixotropic sediments often fell out of the corers thus preventing compositional analysis. A different technique for collection of sediment samples could produce better results for analysis and creation of another dataset.

Particular geomorphic features, including promontories, ridges, and edges, attract some fish species as they aggregate to spawn (Heyman and Wright 2011). Analysis of catch data and interviews of commercial and recreational fishermen could reveal locations and timing of the presence of gravid females and spawning aggregations at the South Texas Banks. Further analysis of the processed, high-resolution multibeam echosounder data could identify possible specific locations of spawning aggregations for some species. Biological surveys could be conducted based on spatiotemporal patterns of aggregations in the GOM region to determine which, if any, of the South Texas Banks provides critical habitat for populations that implement this reproductive strategy. Place-based protection of known spawning aggregations is an essential tool for sustainable fisheries management.

Finally, similar methods could be applied to other regions within the GOM, and perhaps in other seas, for MPA site selection. The Pinnacles region in the northeastern GOM off the coasts of Mississippi and Alabama includes submerged reefs and banks with steeply rising features. Because of the geomorphic features similar to those of the salt diapir region in the northwestern GOM, the model developed for predicting biotic zones (Nash et al. 2013b) would be a good choice for application to the Pinnacles using existing multibeam bathymetry (Gardner et al. 2000). The methodology presented herein for the South Texas Banks would be applicable to the Tamaulipas Banks, which are hard banks that are likely similar in origin and ecology as part of the same geophysical trend of the South Texas Banks that continues south along the shelf into Mexican waters (Hildebrand et al. 1964). Finally, in the southeastern GOM, many high-biodiversity reefs occur on the Campeche Bank off the western coast of the Yucatán Peninsula (Chávez et al. 2007). Because the Campeche Bank has both submerged and emergent reefs, other variables are likely important drivers of biodiversity and species distribution. For example, wave exposure affects community types in waters that are less than 50 m deep (Roff et al. 2003). To accommodate different physical profiles and resulting ecological communities of the Campeche Bank reefs, additional geomorphic surrogates for biodiversity should be quantified and analyzed using the multivariate statistical methodology used for the other portions of the GOM. For each of the regions described, mesoscale biodiversity patterns from statistical analyses could inform conservation planners and policy decision-makers regarding site selection for IGOMMPAN.

4. Results

4.1. Application of biotic zone model of salt diapir region

As a supplement to previous results in the salt diapir region (Nash et al. 2013b), the salt diapir sites grouped well using the rugosity variable in the additional PCA test as demonstrated by overlaid number of biotic zones from literature. An increasing number of biotic zones appeared as a trend corresponding to decreases in PC1 and PC2 (Fig. 4.3). Biodiversity typically increases with an increasing number of biotic zones, and previous studies at the sites in the salt diapir region confirm this pattern (Rezak et al. 1985). When the data from the outer-shelf South Texas Banks were applied to the PCA loadings of the model based on the salt diapir region, a trend of increasing biodiversity resulted as PC1 and PC2 decrease (Fig. 4.4). Because the original model was designed to predict the number of biotic zones, the model does not apply to the coralgal bank region since South Texas Banks likely all have three biotic zones (Rezak et al. 1985). Therefore, the previous model did not correctly predict the number of biotic zones at the outer-shelf South Texas Banks, but the comparable trend did indicate that a discernible biodiversity pattern would result from similar analyses catered to the South Texas Banks in the coralgal bank region of the outer continental shelf.

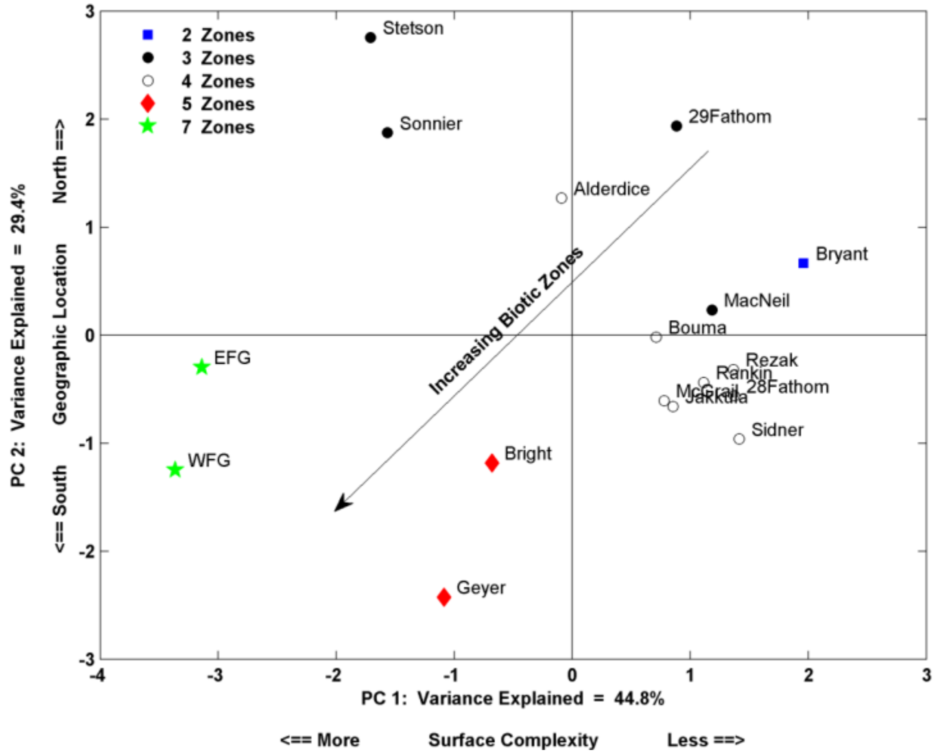

Fig. 4.3. PCA results for hard banks in the salt diapir region of the northwestern GOM.

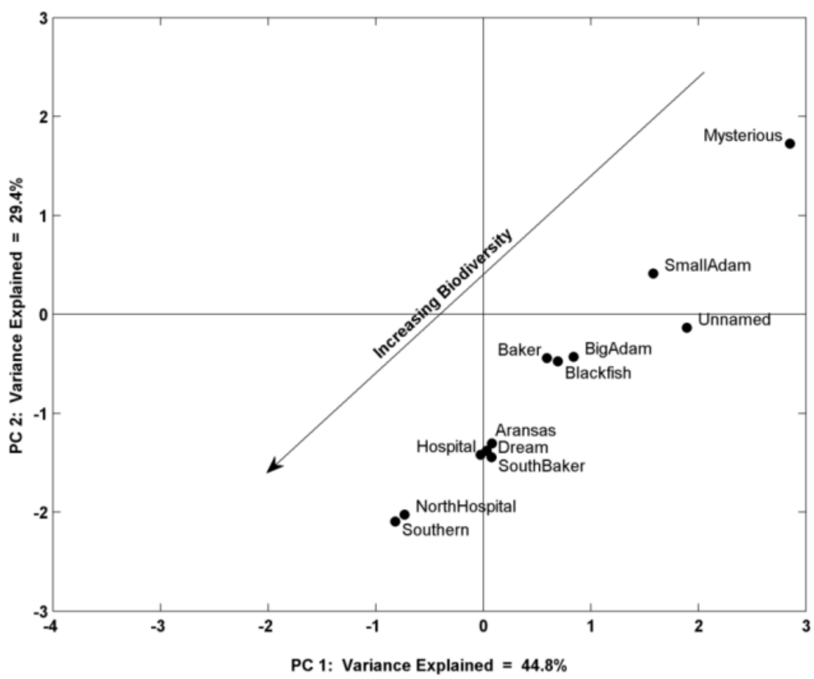

Fig. 4.4. Plot of South Texas Banks using PCA loadings from salt diapir region model.

4.2. Cluster analysis

Of the 12 outer-shelf South Texas Banks, three main groups resulted from nearest-neighbor, hierarchical cluster analysis that produced a dendrogram using Ward's minimum variance (Fig. 4.5). The largest cluster included Baker Bank, Blackfish Ridge, Aransas Bank, North Hospital Bank, Hospital Bank, South Baker Bank, Southern Bank, and Dream Bank. The two remaining groups were pairs, one of Big Adam Rock and Small Adam Rock and the other of Mysterious Banks and Unnamed Bank. Given the relational positioning of the three clusters and the values of the variables (Table 4.2), the dendrogram was interpreted to indicate that no single physiographic variable was driving the cluster results.

The large cluster was divided into three sub-clusters: 1) Baker Bank and Blackfish Ridge, 2) Aransas, North Hospital, and Hospital Banks, and 3) South Baker, Southern, and Dream Banks. Within the large cluster and among all sites in this study, Baker Bank and Blackfish Ridge (sub-cluster 1) were the most similar as demonstrated by the low LD of 0.7. The two sites had very close values for all six variables, which collectively produce the lowest LD in the dendrogram. The remaining sites in the large cluster (i.e., sub-clusters 2 and 3) were more similar, which is primarily because they all have four or five terraces and mid-to-high relative rugosity values. The regional and shallowest depths were also comparable among those six sites of the large cluster and may offer secondary explanation. Moreover, distance to nearest neighbor appeared to drive the separation between sub-clusters 2 and 3. Coincidentally, sites within sub-cluster 2 are geographically clustered as well (see Fig. 4.5). Dream Bank had a larger dissimilarity (LD = 2.66 compared to South Baker and Southern Banks combined) than other sites within sub-clusters with high terrace counts, which appeared to be driven by a much deeper crest depth than other sites within the large cluster.

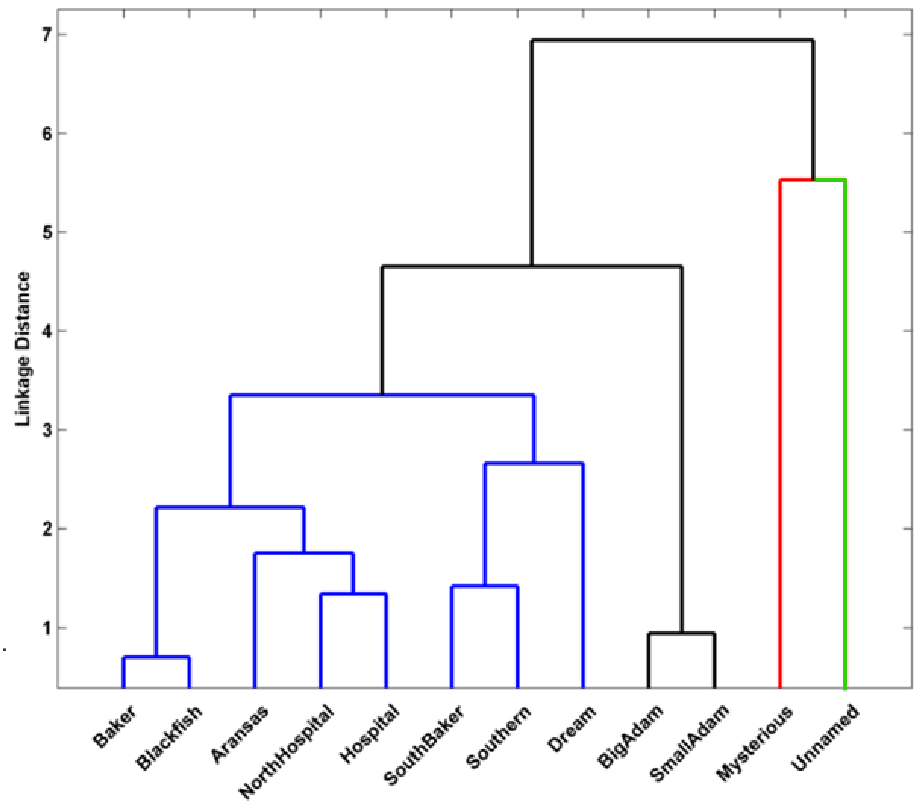

Fig. 4.5. Results of nearest-neighbor, hierarchical cluster analysis.

Big Adam Rock and Small Adam Rock are very close geographically (1.61 km) and are also the sites with the shallowest regional depths (68 m and 65 m, respectively) and lowest reliefs (8 m and 5 m, respectively). Therefore, their close pairing (LD = 0.94) distinctly separated from the other banks was expected.

The final group was a pairing for different reasons. Mysterious Banks and Unnamed Bank were loosely paired together (LD = 5.53) and were dissimilar to the other South Texas Banks as explained by several variables. These two sites are the southernmost sites off the Texas outer shelf. The Mysterious complex covers the largest area of the South Texas Banks, but it comprises more than 58 components, or distinct areas of hard substrate. The Mysterious Banks are individually very low in relief and exhibit no terrace features. The difference between the regional and shallowest depths for the Mysterious complex stems from the change in depth across the shelf more than the vertical relief at the site. Mysterious Banks have the lowest rugosity, and Unnamed Bank has the highest rugosity of the outer-shelf South Texas Banks. Unnamed Bank is the southernmost and deepest site in this study, and it is the site closest to the shelf edge.

4.3. Multidimensional scaling

The circled groups in the MDS plot (Fig. 4.6) were similar to those of the cluster analysis. The same eight sites of the large cluster previously described also grouped together in the MDS plot for similar reasons. The large group consisted of the most prominent sites. Big Adam Rock and Small Adam Rock were paired together as small sites in shallow water. Finally, the plot isolated Mysterious Banks and Unnamed Bank from each other and all other sites, which corresponded with the cluster dendrogram given the large LD between those two sites. The Mysterious Banks site appeared alone close to the x-axis probably because of its large areal coverage and very low relief even without taking into account the slope of the continental shelf. Unnamed Bank was isolated on the plot as well, which is explained by its location in deep water near the shelf edge and its high rugosity.

The two-dimensional patterns in the MDS plot elucidated some causal factors affecting clusters among the banks. Dimension 1 appeared to sort sites by depth, with higher values corresponding with deeper sites. Distance to nearest neighbor could be a secondary influence on dimension 1 values. Generally, sites with a positive dimension 2 value had relatively high rugosity whereas sites with a negative dimension 2 value had low rugosity. Overall, the MDS plot provided relational context among and within the groupings.

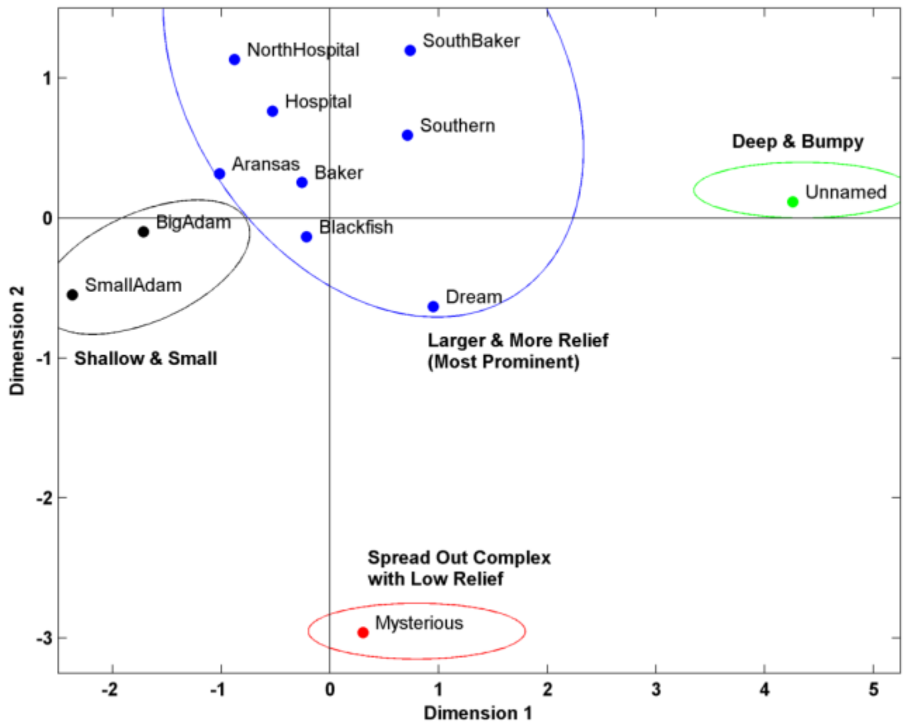

Fig. 4.6. Multidimensional scaling plot. Circled groups corresponded with cluster analysis results and represented zones of similarity.

4.4. Principal component analysis

The PCA plot (Fig. 4.7) was almost identical to the MDS plot (Fig. 4.6) with the exceptions of slightly different positioning for Aransas and Hospital Banks. Nonetheless, as with the cluster analysis and MDS results, the sites in the northern group of the outer-shelf South Texas Banks were more similar to each other than the sites in the southern group. The interpretation of plotted results was enhanced by quantifying the contribution of each variable to each PC (Table 4.3). Six PCs collectively accounted for all data variation, but similar to the MDS analysis, reduction of dimensions allowed most of the variance (greater than 80%) to be accounted for by the first two PCs. All remaining PCs explained much less of the total variance and had eigenvalues below one (Table 4.3), which indicated the eigenfunctions did not explain as

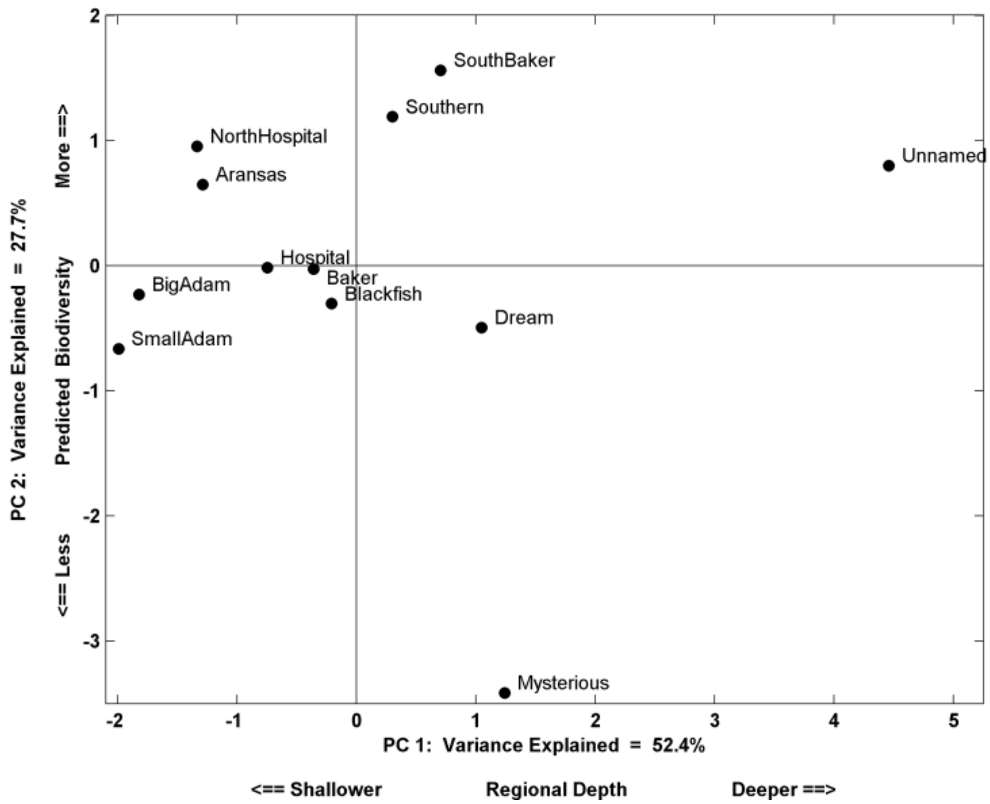

Fig. 4.7. PCA plot for outer-shelf South Texas Banks. Sites at the top of the plot have higher predicted biodiversity.

Table 4.3
PCA summary for outer-shelf South Texas Banks.

	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.14	1.66	0.82	0.22	0.13	0.03
Proportion of variance	52.4%	27.7%	13.7%	3.6%	2.1%	0.4%
Cumlative proportion	52.4%	80.1%	93.8%	97.4%	99.6%	100.0%
Distance to nearest neighbor	**0.517**	0.119	0.205	0.511	0.573	0.293
Regional depth	**0.543**	0.156	0.117	0.055	0.139	-0.803
Shallowest depth	**0.508**	0.138	-0.341	0.113	0.665	0.390
Area	0.071	**0.550**	0.745	0.289	0.222	0.069
Terrace count	0.174	**0.618**	0.512	0.415	0.354	0.167
Rugosity	0.380	**0.509**	0.103	0.683	0.187	0.291

much variance as a single variable (Jackson 1993). Similar to the MDS dimension 1, PC1 was generally aligned with the regional depth with substantial contributions from distance to nearest neighbor and shallowest depth. Therefore, PC1 accounted for bathymetric and geographical characteristics. PC2 was influenced most heavily by the remaining variables: planimetric area, terrace count, and rugosity. These three variables described physical features of a site, and they combined to distribute sites along the y-axis according to predicted biodiversity levels, where a greater PC2 value indicated greater biodiversity. An increasing biodiversity trend moving up the y-axis was expected based on site features and literature describing some biological characteristics (Rezak et al. 1985). Banks with more physical features and surface complexity are expected to support more biodiversity. For example, sites such as South Baker and Southern Banks have abundant epibenthic communities (Rezak et al. 1985) and, therefore, more biodiversity. In contrast, the Mysterious Banks complex has low relief and turbid conditions; as a result, the site supports only a limited epibenthic community (Rezak et al. 1985).

When compared to PCA results from the salt diapir region, different variables accounted for the statistical groupings. For example, PC1 from the two study areas was strongly influenced by different variables, with crest depth, or shallowest depth, being the only shared variable (Fig. 4.8). Area, terrace count, and rugosity also strongly influenced PC1 in the salt diapir region, but distance to nearest neighbor and regional depth strongly influenced PC1 in the South Texas Banks region. Generally, a shift in drivers of PC1 occurred from surficial features to depth and from proximity to the closest neighboring site. However, area, terrace count, and rugosity (all surficial features) were the driving variables of PC2 for the South Texas Banks region so the PCA results of the two regions had almost opposite emphases among variables contributing strongly to PC1 and PC2. Crest depth was an important factor of PCA results for both regions.

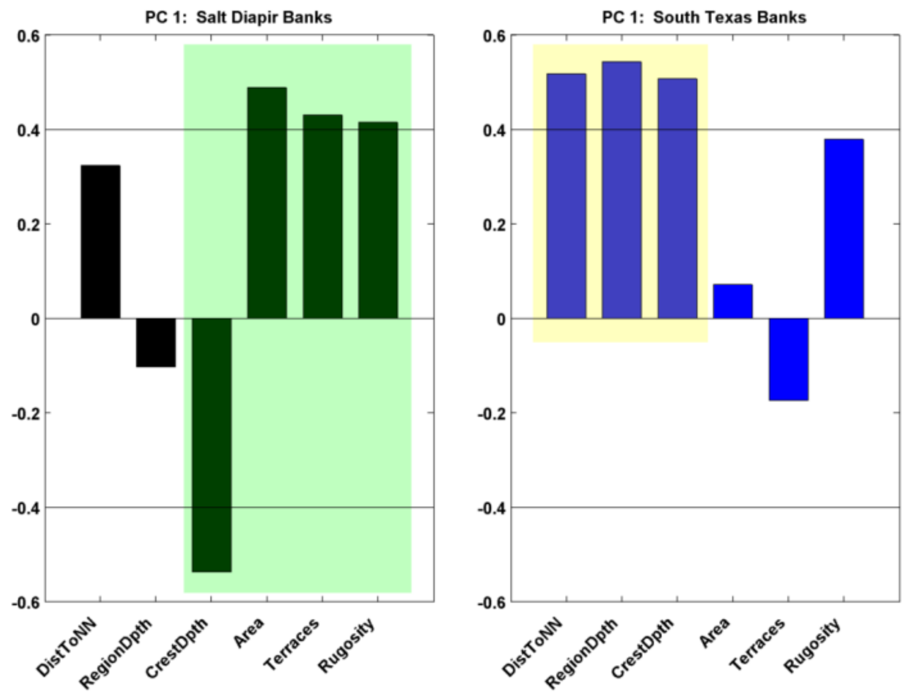

Fig. 4.8. Comparison of PC1 loadings from the salt diapir region and the South Texas Banks region. Variables that contributed substantially (>0.4 or <-0.4) are shaded in each graph.

5. Discussion

All three statistical analyses produced consistent results. The pairing of Big Adam Rock with Small Adam Rock reflected their shared small area, shallow depth, and close proximity to each other. The large grouping of all northern sites plus Dream Bank and Blackfish Ridge demonstrated that the combination of rugosity, area, and relief could be a good indicator of predicted biodiversity as PC2 increased. Mysterious Banks and Unnamed Bank were distantly related to each other and to all other sites in all analyses. The positions of the two sites plotted in the MDS and PCA results (Figs. 4.6 and 4.7, respectively) conformed to expected biodiversity levels at the sites based on the six variables and the ROV experiences at each site. The video transect at Mysterious Banks was aborted because of poor visibility. Mysterious Banks would be expected to have low biodiversity as a result of the very low relief combined with the presence of the nepheloid layer. The video transect analysis from Unnamed Bank is in progress. Several biological specimens were collected at Unnamed Bank, which was anecdotally indicative that the site may have high species richness. Relatively high biodiversity can also be inferred because Unnamed Bank had a rugosity that is the highest of all 12 sites and almost twice the mean. The conclusion that Unnamed Bank has a high predicted biodiversity is supported by two principles: 1) high rugosity is a good surrogate for high benthic biodiversity (Dunn and Halpin 2009), and 2) the benthos contributes to habitat heterogeneity increasingly with depth (Buhl-Mortensen et al. 2010).

5.1. Ecological connectivity and similarity

Primary geological variables previously have been reported to explain multivariate classification of deep-water habitat included depth and distance from the continental shelf (Williams et al. 2009). The neritic habitat sites in this study were comparable but included a different distance variable related to the nearest neighbor instead of the distance to the shelf edge or the shore. Unlike other research in which abiotic surrogates were used for biodiversity, inclusion of the distance to the nearest neighbor in this research introduced the concept of connectivity among sites. The tighter grouping of the northern sites could be indicative of more connectivity, which could be explained by the nearest neighbor distance. The northern group had a mean distance to nearest neighbor that was almost a third less than that of the southern group. Nonetheless, no apparent latitudinal gradient existed between the northern and southern groups because the statistical plots did not relate to geographical positions of the sites. Addition of environmental variables (e.g., salinity, dissolved oxygen, freshwater inflow, sedimentation, water temperature) that typically are aligned with latitudinal gradients would not likely alter the results significantly because environmental variables are relatively consistent, albeit with seasonal variations off South Texas, on the outer shelf at the spatial scale of analysis (Flint and Rabalais 1981; Zacharias and Roff 2001).

Geological connectivity was accounted for strictly by abiotic variables, and further statistical analysis incorporating biological results as proposed in section 3 could explain, at least in part, ecological connectivity. Geographically close sites have higher fish assemblage similarities than more separated sites because of foraging behavior of motile species and mesoscale connectivity even if habitat sites are not similar (Lindsay et al. 2008). Preliminary biological results had high similarities of fish diversity among assemblages surveyed at Baker, Aransas, and Dream Banks (Lerma et al., The University of Texas at Brownsville, personal communication). Statistical results of this study based on geomorphic variables also placed Baker, Aransas, and Dream Banks together in the large cluster, which indicated that the statistical methodology was valid in the coralgal bank region.

Further biological analysis showed that Baker and Dream Banks had higher fish assemblage similarity to each other than compared to that of Aransas Bank, which could be because Baker and Dream Banks have terraces that are larger than those at Aransas Bank (Lerma et al., personal communication). Ecological connectivity likely exists among the three sites, but the preliminary biological results did not support the concept that the degree of connectivity is directly proportional to geographical distance if suitable habitat is available. To the contrary, Baker and Aransas Banks were more similar to each other than to Dream Bank (Figs. 4.5, 4.6, 4.7). These results better support the connectivity theory because Baker and Aransas Banks are closer to each other and reside in the northern group whereas Dream Bank is in the southern group of sites (Fig. 4.2). Additional biological results (i.e., for other three sites with video transects and for additional taxa, such as corals, sponges, and mollusks) may produce different results for similarity and diversity indices. Alternatively, the relatively low rugosity of Dream Bank could be the causative factor in its statistical distance from other sites and its lower predicted biodiversity. Nonetheless, the high fish assemblage similarity among Baker, Aransas, and Dream Banks corresponded with the results interpreted herein that group the sites among those with larger size and relief and higher diversity epibenthic communities.

5.2. Ranking tool

The quantitative techniques used in this study based on geomorphic variables enabled detection of biodiversity patterns in the absence of comprehensive biological data. The inferred biodiversity trend (i.e., increasing with an increasing value of PC2 in Fig. 4.7) was used to create a ranking tool to 1) guide prioritization of future biological expeditions to collect more ground-truthing data at particular sites, and 2) select sites for place-based protection based on biodiversity and similarity patterns. The ranking of the 12 outer-shelf South Texas Banks were used to categorize the sites into three priority levels: high (PC2 > 0), medium (0 < PC2 < -1), and low (PC2 < -1) (Fig. 4.9). The sites in the high category included South Baker, Aransas, North Hospital, Southern, and Unnamed Banks. Medium category sites were Baker Bank, Hospital Bank, Dream Bank, Big Adam Rock, Small Adam Rock, and Blackfish Ridge. The low category site was Mysterious Banks. Future biological explorations and site selection for place-based protection are proposed most strongly for high-priority sites followed by medium-priority sites. When combined with available geomorphic data, additional biological surveys would provide the necessary information for composite marine habitat mapping, which supports not only MPA design and implementation but also the broader ecosystem-based management that is needed to ensure sustainable use of living marine resources (Cogan et al. 2009). Additional biological data collection is recommended for high- and medium-priority sites to further support conservation planning. Given that the ROV dive on Mysterious Banks was aborted, resource expenditures on further exploration at that site may not be advisable without data to predict the behavior of the nepheloid layer. Additionally, Mysterious Banks may not have ample biodiversity and rare or representative habitat to warrant special protection.

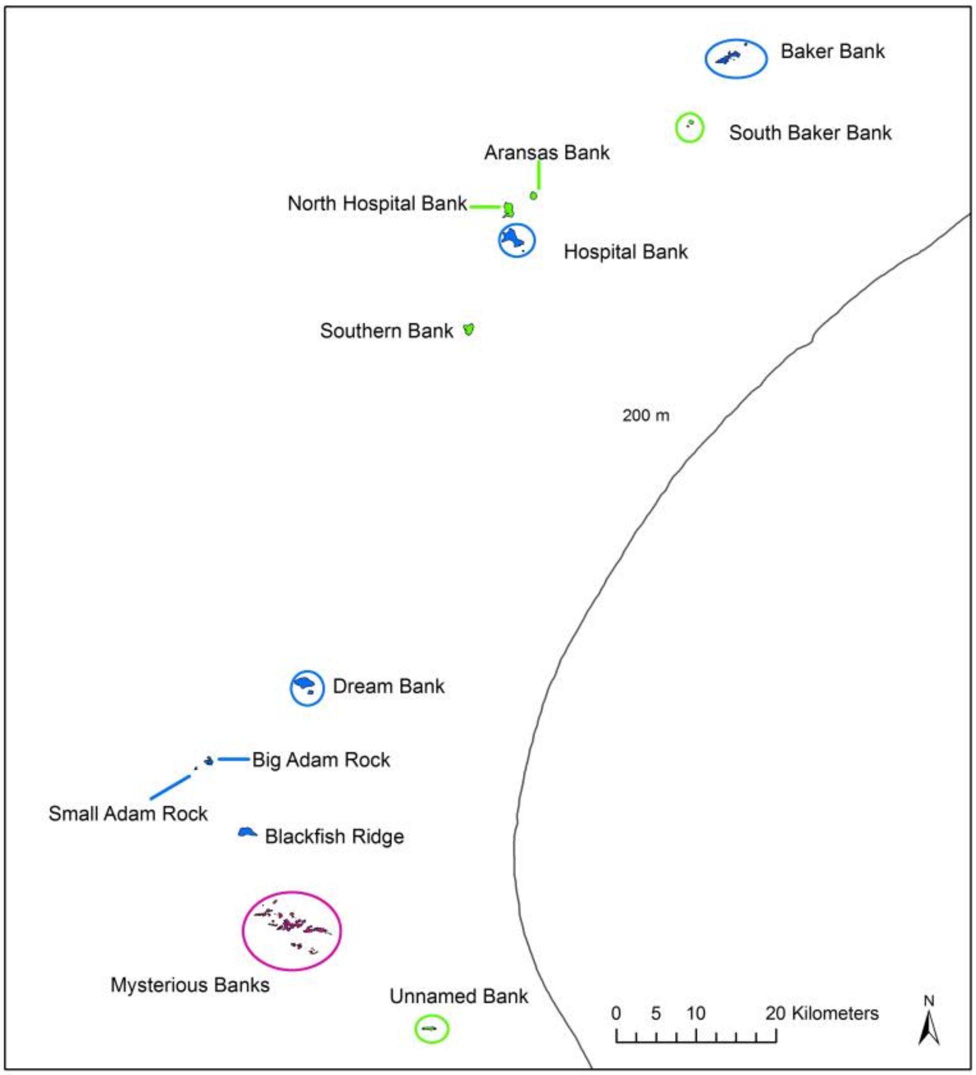

Fig. 4.9. Outer-shelf South Texas Banks according to category. High-priority sites are shown in green, medium-priority in blue, and low-priority in purple.

7. Conclusions

Analysis of high-resolution bathymetry collected for several South Texas Banks provided an increased understanding of the marine landscape in the coralgal bank region of the continental shelf off Texas. Geomorphic variables can act as surrogates to collectively group sites among the South Texas Banks as analogs for biodiversity. In the coralgal bank region of the shelf, the unpredictable nepheloid layer can hinder or prevent video surveys. This phenomenon exemplifies the importance of acoustic data collection and the use of abiotic surrogates for biodiversity. Nonetheless, ground-truthing biological surveys should be conducted to complement analyses using surrogates. The use of geomorphic surrogates supports ecosystem-based management in that all species – common, rare, and keystone – are inherently included in site selection as opposed to species-specific MPA design processes. The ranking tool proposed herein provides a suggested prioritization of future biological explorations and potential MPA designations for the South Texas Banks. At a minimum, South Baker, Aransas, North Hospital, Southern, and Unnamed Banks should be included in IGOMMPAN as a policy approach to protect biodiversity and preserve ecological connectivity throughout the GOM. Similar methodology could be used to identify prospective MPA sites in other regions of the GOM, including the Pinnacles area, Tamaulipas Banks, and Campeche Bank reefs.

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CHAPTER 5

CONCLUSION: POLICY AND SCIENCE SUPPORT CREATION OF THE INTERNATIONAL GULF OF MEXICO MARINE PROTECTED AREA NETWORK

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Format: *Marine Policy* used as format.

The Gulf of Mexico (GOM) is an international, semi-enclosed sea that embodies a large marine ecosystem. The United States (U.S.), Mexico, and Cuba each border the GOM and share transboundary living marine resources that use the sea throughout part or all of their life histories. The three nations also share ecological concerns regarding chronic stressors, such as overfishing and pollution, and episodic events, such as hurricanes and oil spills. Internationally shared resources and mitigation issues are most effectively managed through collaborative efforts, in both policy and science arenas. Trinational initiatives to protect and sustainably manage GOM living marine resources jointly are ongoing, albeit sporadically, through the efforts of federal agencies, non-governmental environmental organizations, and academia. Diplomatic, cultural, and technological hurdles hinder fluid communication and information exchange among scientists, resource managers, and policy decision-makers of the three nations, but progress continues to the credit of perseverant collaborators. One of several focal points that recur at trinational meetings in the GOM region is place-based management at the ecosystem scale. This dissertation focused on combining policy and science to promote the creation of the International Gulf of Mexico Marine Protected Area Network (IGOMMPAN).

A network of marine protected areas (MPAs) is an effective tool for implementation of ecosystem-based management on the scale of a regional sea or large marine ecosystem. An MPA network not only protects healthy habitats but also provides an ecological insurance policy in that a damaged or distressed habitat site can be repopulated or restored ecologically by nearby or oceanographically linked populations and productive, healthy habitats that are protected via place-based management. As demonstrated by the April 2010 BP Deepwater Horizon oil spill, the GOM living marine resources are fragile, yet the commercially important species and nearshore communities may be resilient to perturbations. Such a focusing event acts as a catalyst for increased governance and environmental protection. Trinational collaborators harnessed the attention to apply science to advocate for IGOMMPAN. The main objectives of IGOMMPAN are to preserve natural resiliency to adverse anthropogenic and natural disasters and phenomena, to protect ecological connectivity, and to conserve biodiversity through shared resources and management tools. With these objectives in mind, the overarching goal of IGOMMPAN, as agreed upon by MPA practitioners from the U.S., Mexico, and Cuba at the Veracruz workshop in July 2012, is to preserve biophysical connectivity through the protection of stepping-stone habitats that can be linked through standardized governance methods for sustaining human and environmental health and well-being.

Sustainable ecosystem resources require sustainable governance. Although no formal trinational governance exists in the GOM region, standard governance methods do exist despite the different legal systems of the U.S., Mexico, and Cuba. Each nation's legal framework provides regulatory mechanisms to create and manage MPAs domestically. With any formal regulatory regime, a blended governance approach is recommended throughout all phases of IGOMMPAN implementation. Top-down activities, such as agency involvement and formal diplomatic negotiations, are especially important given the scale of the large marine ecosystem and the requirement for regulatory control. Top-down implementation also ensures that Gulfwide issues are considered throughout the network even if an issue is not ripe for local management at a specific site. Bottom-up strategies are critical for an international MPA network because stakeholder support at local levels is a prerequisite for place-based management. Community-level approaches would vary throughout the region based on cultural differences, local concerns, and the presence of local, national, or international non-governmental organizations in support of IGOMMPAN. Effectiveness of existing MPAs throughout the GOM varies, and some may be considered paper parks because lack of funding prevents proper enforcement, monitoring, adaptive management, and regulatory attention. However, the importance of linking to an international network may focus more attention and resources at federal and local levels to improve conditions at individual MPAs. The collective contribution of well-managed individual MPAs to resource protection at the scale of a large marine ecosystem is critical for achieving Gulfwide conservation goals.

Internationally, several treaties apply to the GOM living marine resources and could be used to create IGOMMPAN. However, successful negotiation of a new treaty for the purpose of creating and maintaining IGOMMPAN would be the most effective governance vehicle. Trilateral treaty negotiation is a lengthy process; therefore, an IGOMMPAN treaty would likely be an inefficient approach. Existing treaties, including those without legally binding provisions, offer platforms for trilateral negotiation that would otherwise be difficult or prohibited per the U.S. embargo against Cuba. The SPAW Protocol is an ideal framework for formalizing IGOMMPAN because provisions include a specific requirement to create a network of protected areas (SPAW Protocol art. 7 1990). However, the SPAW Protocol lacks Mexico’s ratification, which is likely a consequence of CONAPESCA’s (*Comisión Nacional de Acuacultura y Pesca*; Mexico’s federal agency that regulates fisheries) concern that MPAs may excessively restrict fishing activities. Unless and until Mexico ratifies the SPAW Protocol as have the U.S. and Cuba, the most expeditious way to form IGOMMPAN using existing law is via the Cartagena Convention, which all three nations ratified. The Cartagena Convention encourages international cooperation, and Article 10 is dedicated to specially protected areas and information exchange about the areas (Cartagena Convention art. 10 1983). A trilateral agreement, in accordance with the Cartagena Convention, would be a paradigmatic instrument for international governance via place-based management in the GOM. The agreement should include language to establish a trinational commission to create and maintain IGOMMPAN.

The Trinational IGOMMPAN Commission would create and administer IGOMMPAN based on recommendations from scientists, resource managers, and MPA practitioners throughout the GOM region. Scientific forums and workshops in support of IGOMMPAN targeted protection of biodiversity hotspots and ecological connectivity. Rare, hard-substrate habitats on the GOM's continental shelf provide stepping-stone connections among the four cornerstone coral reef ecosystems: Florida Keys, Flower Garden Banks, Veracruz Reef System, and Alacranes Reef. Faunal similarities exist at the four cornerstone sites, particularly among taxa including corals, reef fishes, and mollusks, including invasive species. The concentric nature of the GOM and the major currents enable Gulfwide transportation of organisms, most notably pelagic larvae, among habitat sites throughout the continental shelf. Major currents, such as the Loop Current, connect some cornerstone sites directly, and smaller scale currents, gyres, and eddies contribute to stepping-stone connectivity of other hard-bottom sites among the four cornerstones. Demographic connectivity also occurs among motile species that exhibit small-scale movements or highly migratory behaviors.

With knowledge of connectivity mechanisms and types of hard-bottom habitats that contribute to the existing ecological network in the GOM, MPA practitioners from the U.S., Mexico, and Cuba convened in July 2012 to identify IGOMMPAN design parameters and candidate sites. To address ecosystem-level protection, participants identified and weighted 31 design parameters in several categories: biological, geophysical, threats, management, political feasibility, environmental education and outreach, and cultural features. Participants also identified 36 candidate sites, which all occur in federal waters (Fig. 5.1; Table 5.1). Most

IGOMMPAN candidate sites are existing MPAs under the broadest definition, but there are several exceptions. Exceptions include the Pinnacles, northwestern GOM Reefs and Banks, South Texas Banks, Tamaulipas Banks, and Campeche Bank Reefs. These candidate sites lack comprehensive, ecosystem-based protection and are areas that each contains several distinct habitat sites.

Regarding IGOMMPAN candidate sites that are multi-feature areas, the entire areas would not likely be protected, with the possible exception of the Pinnacles area because it is much smaller than the other such areas. These areas cover large swaths of the continental shelf, but all hard-bottom habitat features within each area may not warrant comprehensive place-based protection. The paucity of biological data for these sites increases uncertainty, which does not bode well for stakeholder support of new MPAs. The South Texas Banks were used as a case study to identify MPA sites for habitat features that lack biological data. Scientists aboard the *R/V Falkor* set out in September 2012 with the objective of mapping the South Texas Banks. Multibeam bathymetric data for 12 outer-shelf South Texas Banks were analyzed to create a dataset of geomorphic variables to be used collectively as a surrogate for biodiversity.

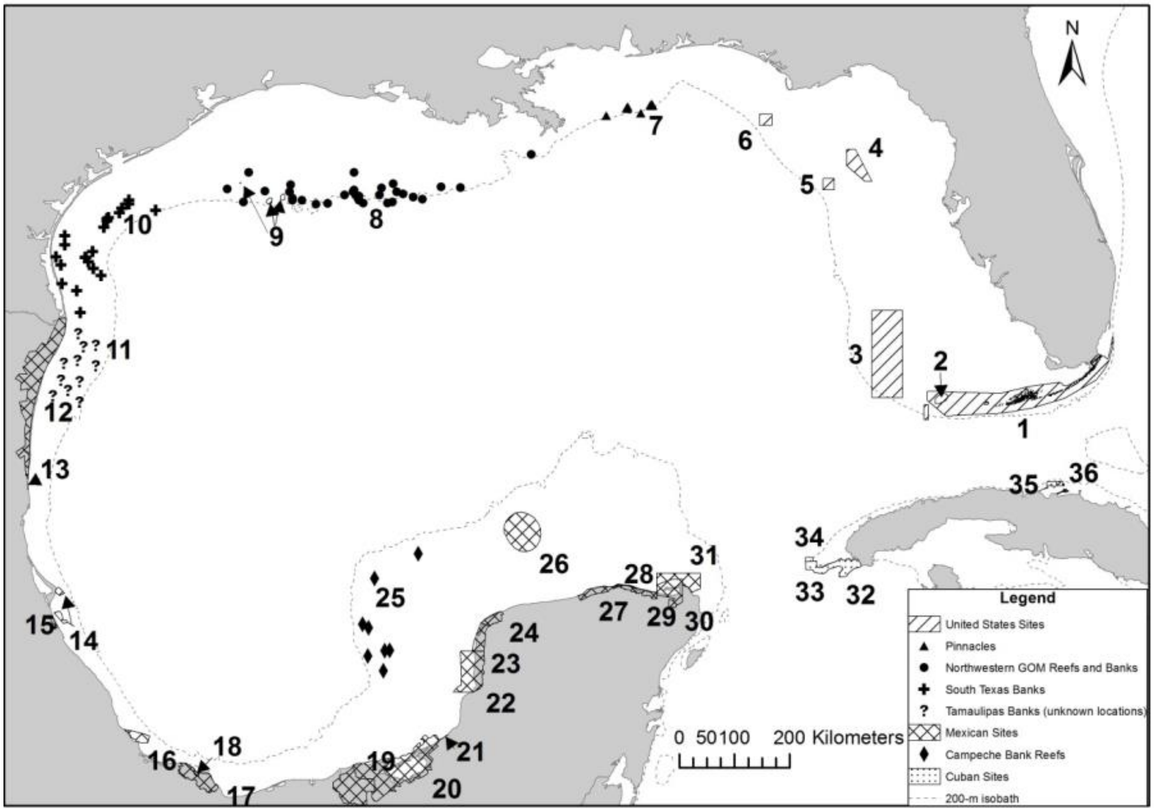

Fig. 5.10. IGOMMPAN candidate sites (duplicate of Fig. 3.2). Site key is in Table 5.1.

Table 5.1
List of IGOMMPAN candidate sites and key for Fig. 5.1.

Site Number	Site Name
1	Florida Keys National Marine Sanctuary
2	Dry Tortugas National Park
3	Pulley Ridge Habitat Area of Particular Concern
4	Florida Middle Grounds Habitat Area of Particular Concern
5	Steamboat Lumps Fishery Reserve
6	Madison-Swanson Fishery Reserve
7	Pinnacles[a]
8	Northwestern Gulf of Mexico Reefs and Banks[a]
9	Flower Garden Banks National Marine Sanctuary
10	South Texas Banks[a]
11	Tamaulipas Banks[a]
12	Área de Protección de Flora y Fauna Laguna Madre y Delta del Río Bravo
13	Santuario Playa de Rancho Nuevo
14	Sistema Arrecifal Lobos-Tuxpan
15	Manglares y Humedales de Tuxpan
16	Parque Nacional Sistema Arrecifal Veracruzano
17	Reserva de la Biosfera de los Tuxtlas
18	Manglares y Humedales de Laguna Sontecomapan
19	Reserva de la Biosfera Pantanos de Centla
20	Área de Protección de Flora y Fauna Laguna de Términos
21	La Playa Tortuguera Chenkán
22	Reserva de la Biosfera Los Petenes
23	Reserva de la Biosfera Ría Celestún
24	Reserva Ecologíca Estatal El Palmar
25	Campeche Bank Reefs[a]
26	Parque Nacional Arrecife Alacranes
27	Reserva de Dzilam
28	Santuario Playa Ría Lagartos
29	Reserva de la Biosfera Ría Lagartos
30	Área de Protección de Flora y Fauna Yum Balam
31	Reserva de la Biosfera Tiburón Ballena
32	Reserva de la Biosfera Peninsula de Guanahacabibes
33	Guanahacabibes National Park
34	San Antonio Bank
35	Ecological Reserve Mono-Galindo
36	Cayos de las Cinco Leguas Faunal Refuge

[a] These sites are each complexes of several sites. They are also the sites that do not currently have ecosystem-based protection.

Multivariate statistics were performed on six geomorphic variables, and results were interpreted to identify a biodiversity pattern among the outer-shelf banks. The study concluded with a ranking tool designed to guide prioritization of future biological expeditions and to propose MPA designations for specific sites in the area of the outer-shelf South Texas Banks. The conclusions were used to prioritize the 12 sites in high, medium, and low categories. The five high-priority sites are proposed for definite inclusion in IGOMMPAN, and the six medium-priority sites should be seriously considered for inclusion as well. Similar statistical analyses using geomorphic surrogates are suggested for the other candidate sites that are multi-site complexes. Results would refine IGOMMPAN so that each site is a discrete habitat unit contributing to preservation of biodiversity and biophysical connectivity throughout the GOM.

Research and analysis presented herein are compelling reasons to create IGOMMPAN and a path for its success. As a large marine ecosystem experiencing many chronic and episodic stressors, the GOM would benefit from an MPA network to support ecosystem-based management. The policy component encourages use of the negotiation avenue provided by the Cartagena Convention to create a Trinational IGOMMPAN Commission via trilateral agreement. Connectivity, both biophysical and of the human dimension, are demonstrated to exist throughout the GOM region. Continued trinational collaboration is imperative for the success of IGOMMPAN, and MPA practitioners from the U.S., Mexico, and Cuba have agreed to meet as regularly as possible to maintain continuity and to pursue communication and information-sharing strategies to support IGOMMPAN goals. Additional efforts, such as agency public meetings, socioeconomic analysis, and stakeholder involvement, are also vital. Once established, IGOMMPAN could link to other established MPA networks, such as the U.S. nearshore Gulf of Mexico MPA network, the Caribbean MPA Managers network, and the North

American MPA Network. Expansion of network connections would strengthen IGOMMPAN by increasing protection of natural resiliency, connectivity, and biodiversity thereby sustaining human and environmental health and well-being.

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Appendix. Maps of 12 outer-shelf South Texas Banks.

The following maps were created using bathymetric data collected in September 2012 on the *R/V Falkor*. They are presented in geographic order from north to south.

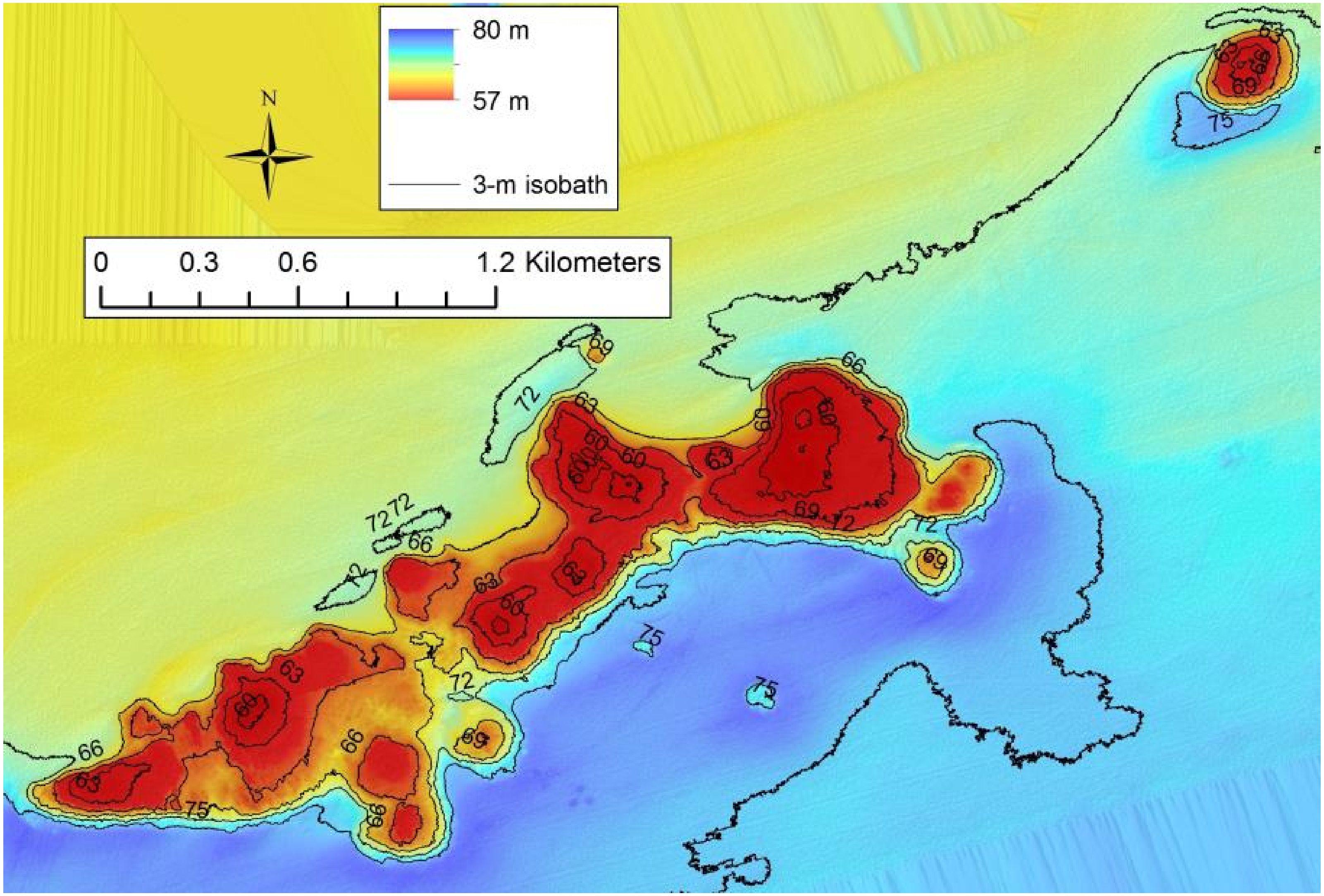

Fig. A.1. Baker Bank, mapped at 1-m resolution.

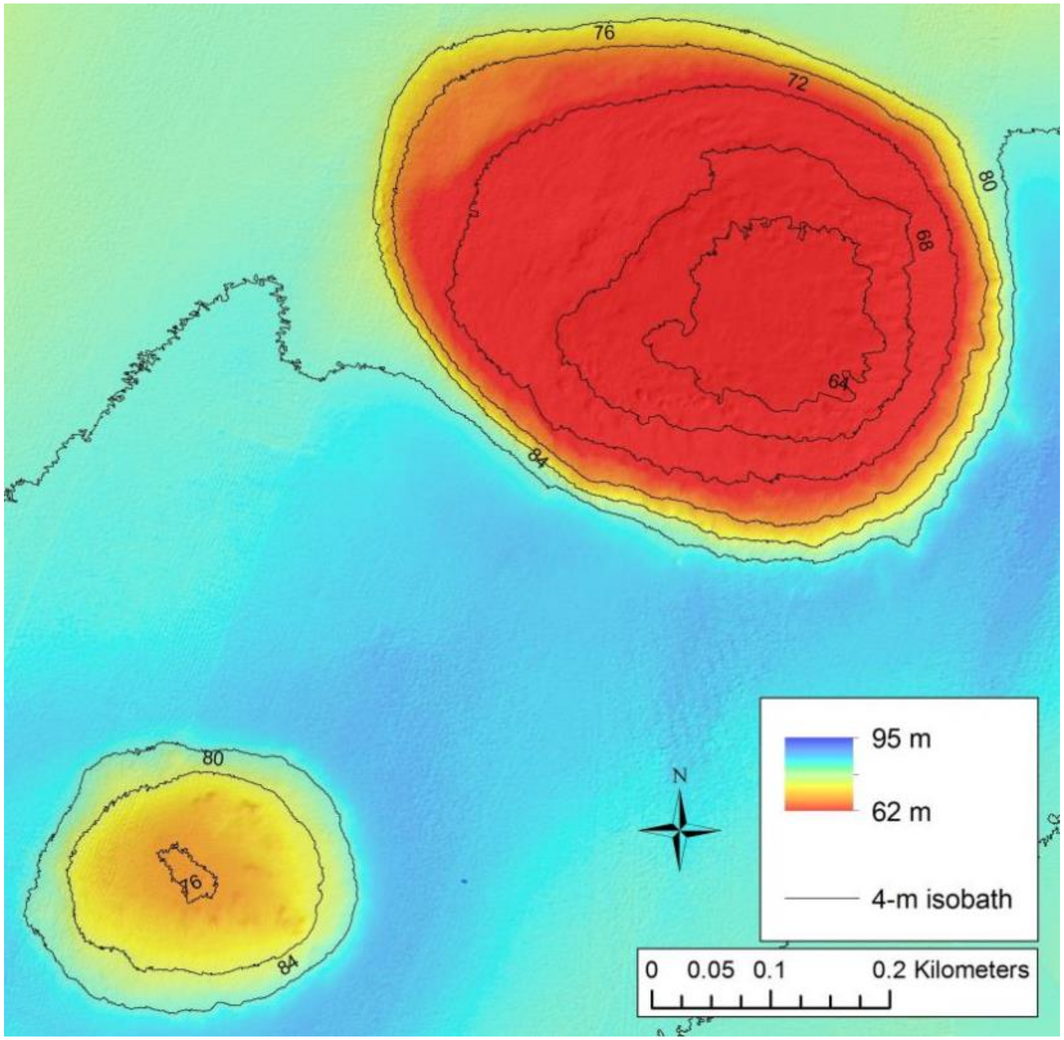

Fig. A.2. South Baker Bank, mapped at 1-m resolution.

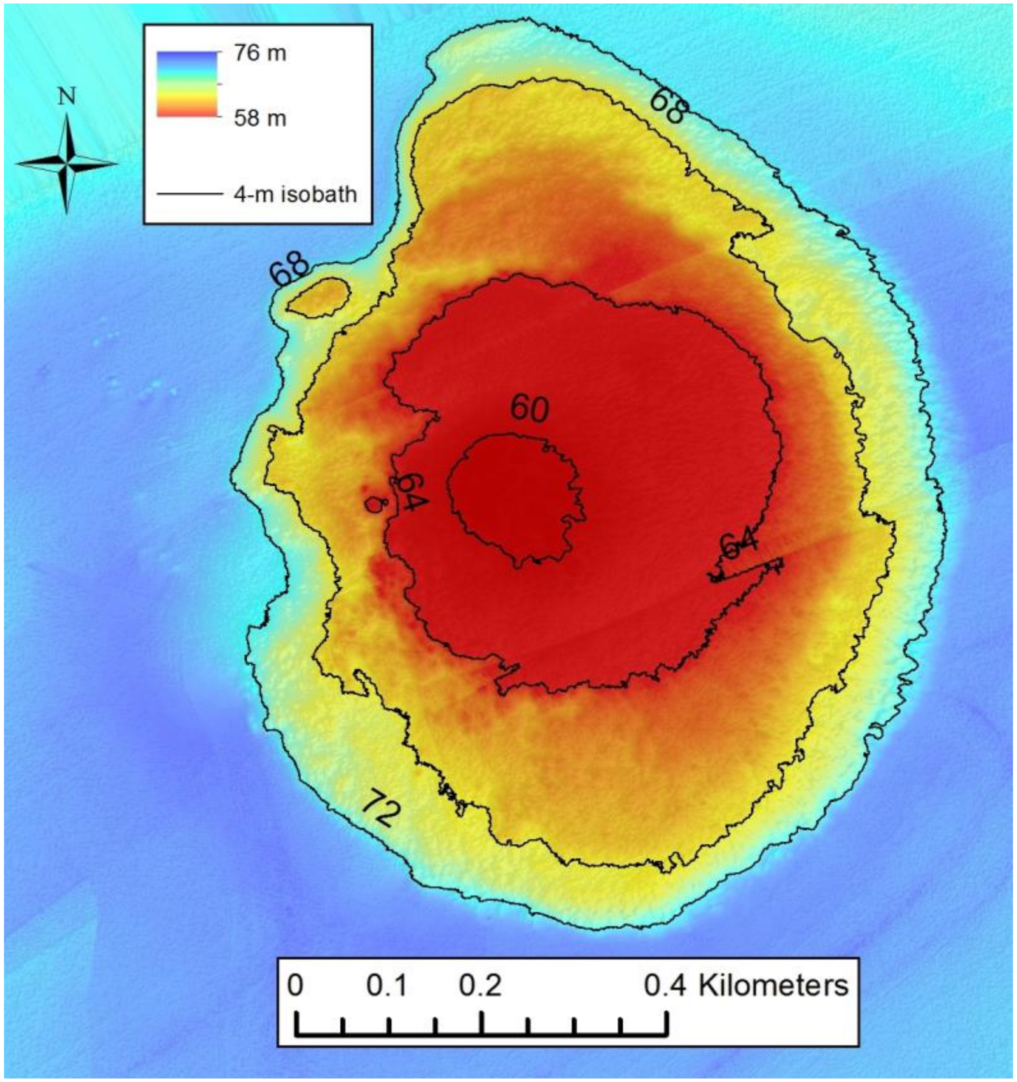

Fig. A.3. Aransas Bank, mapped at 1-m resolution.

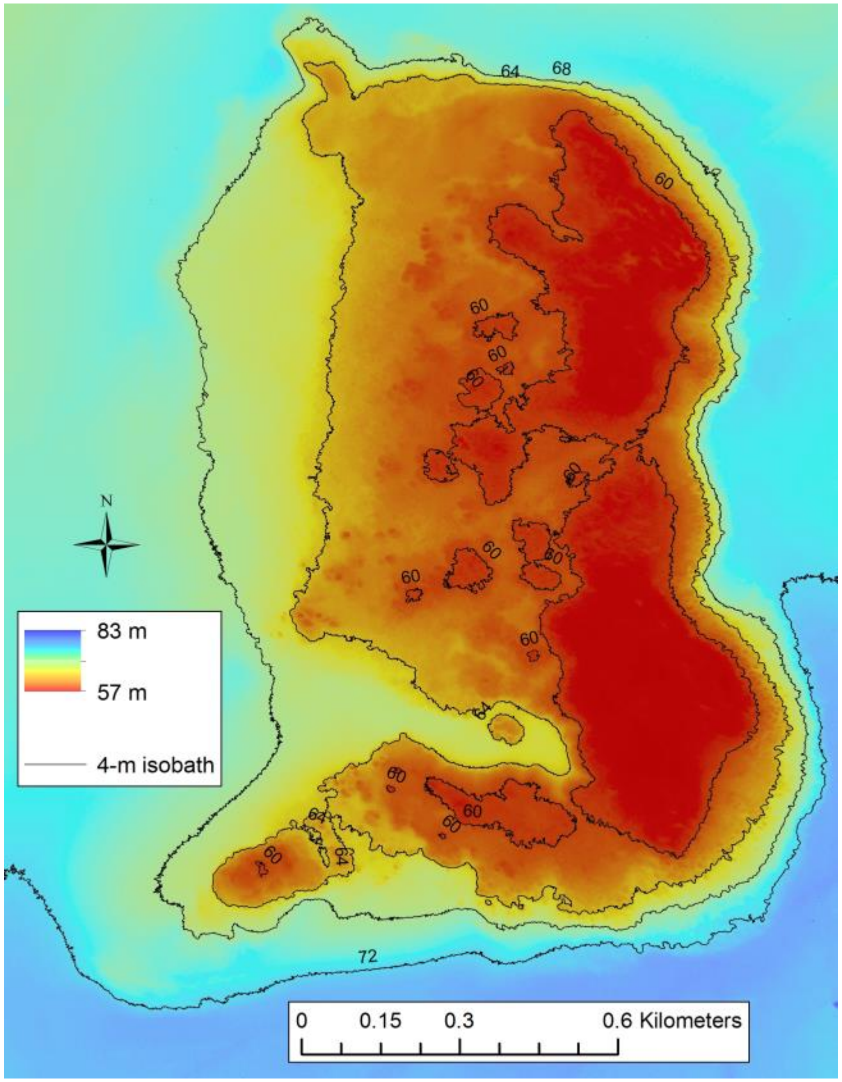

Fig. A.4. North Hospital Bank, mapped at 1-m resolution.

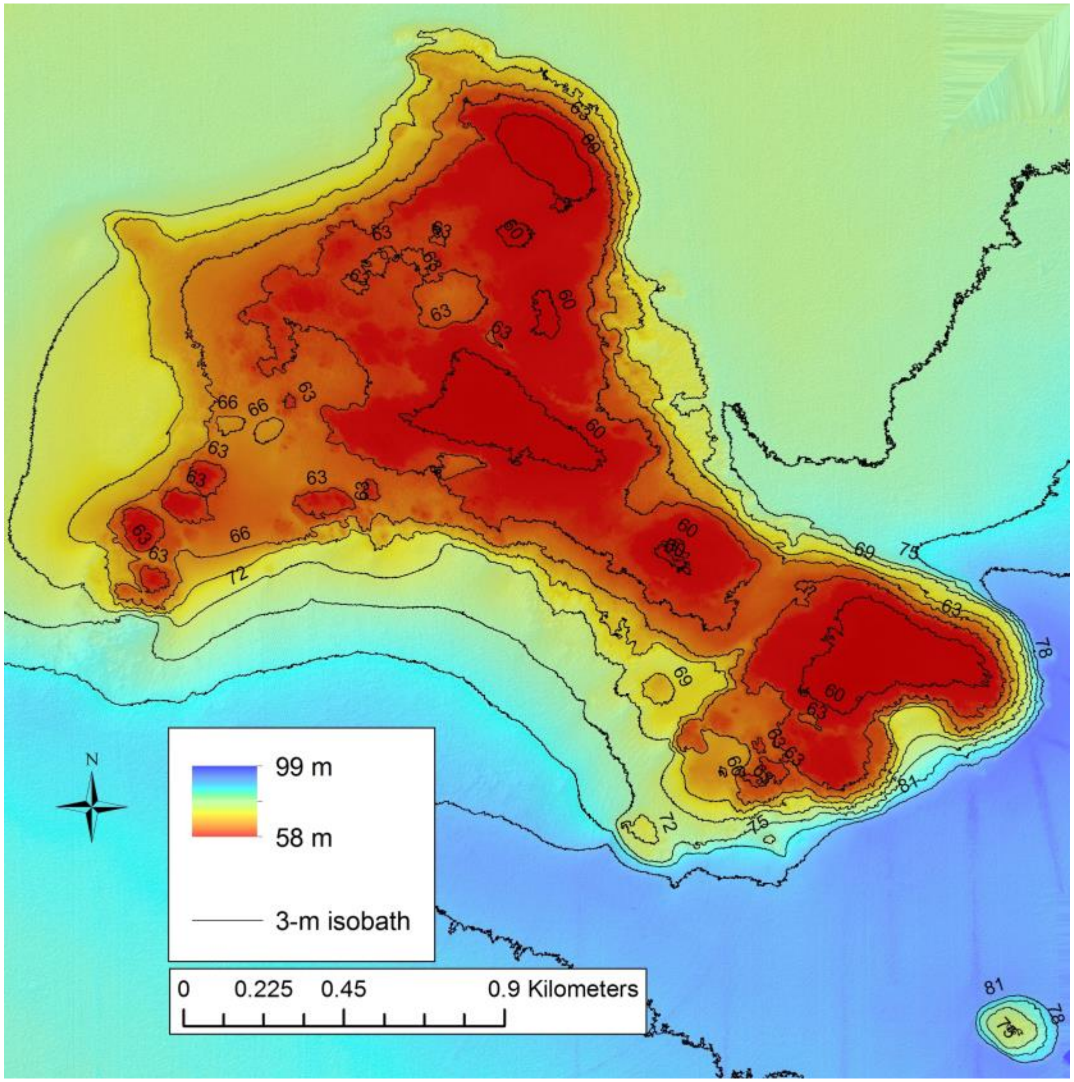

Fig. A.5. Hospital Bank, mapped at 1-m resolution.

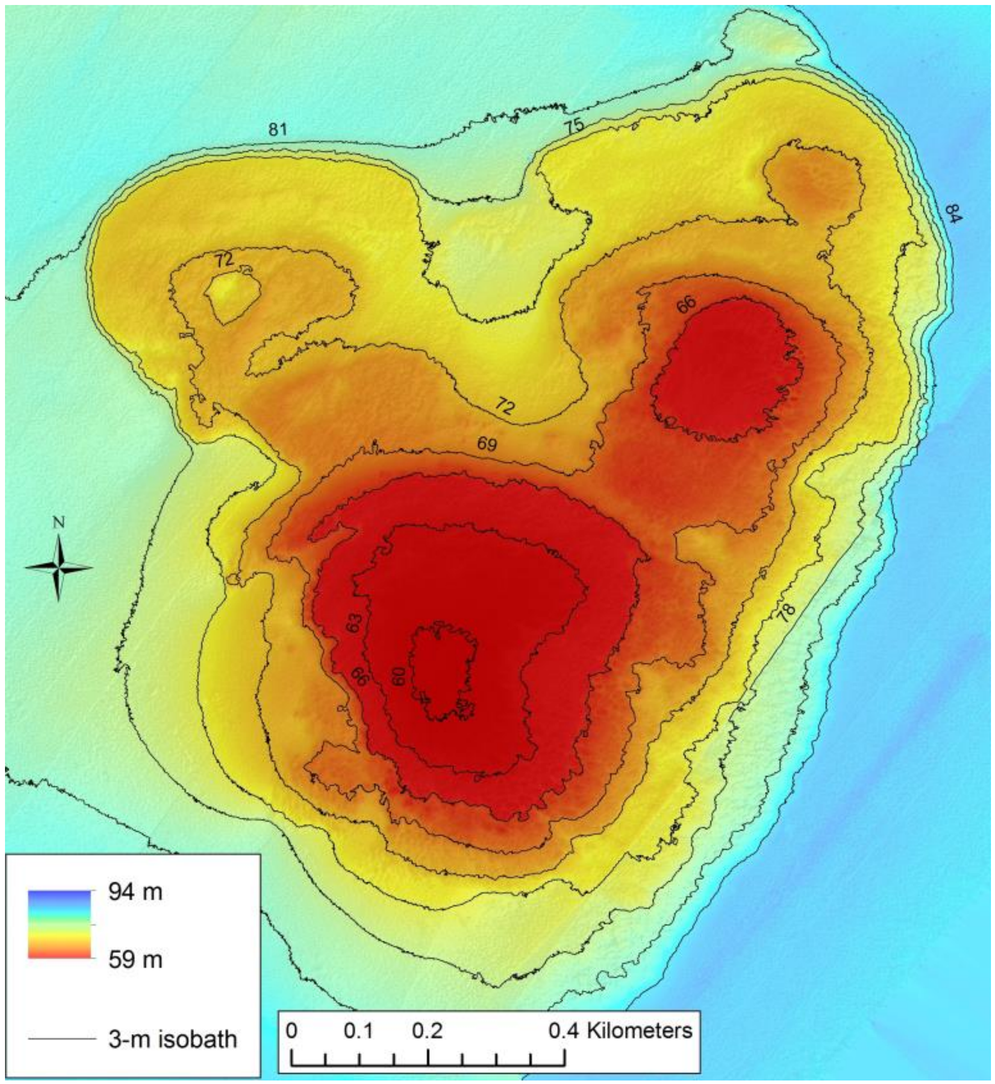

Fig. A.6. Southern Bank, mapped at 1-m resolution.

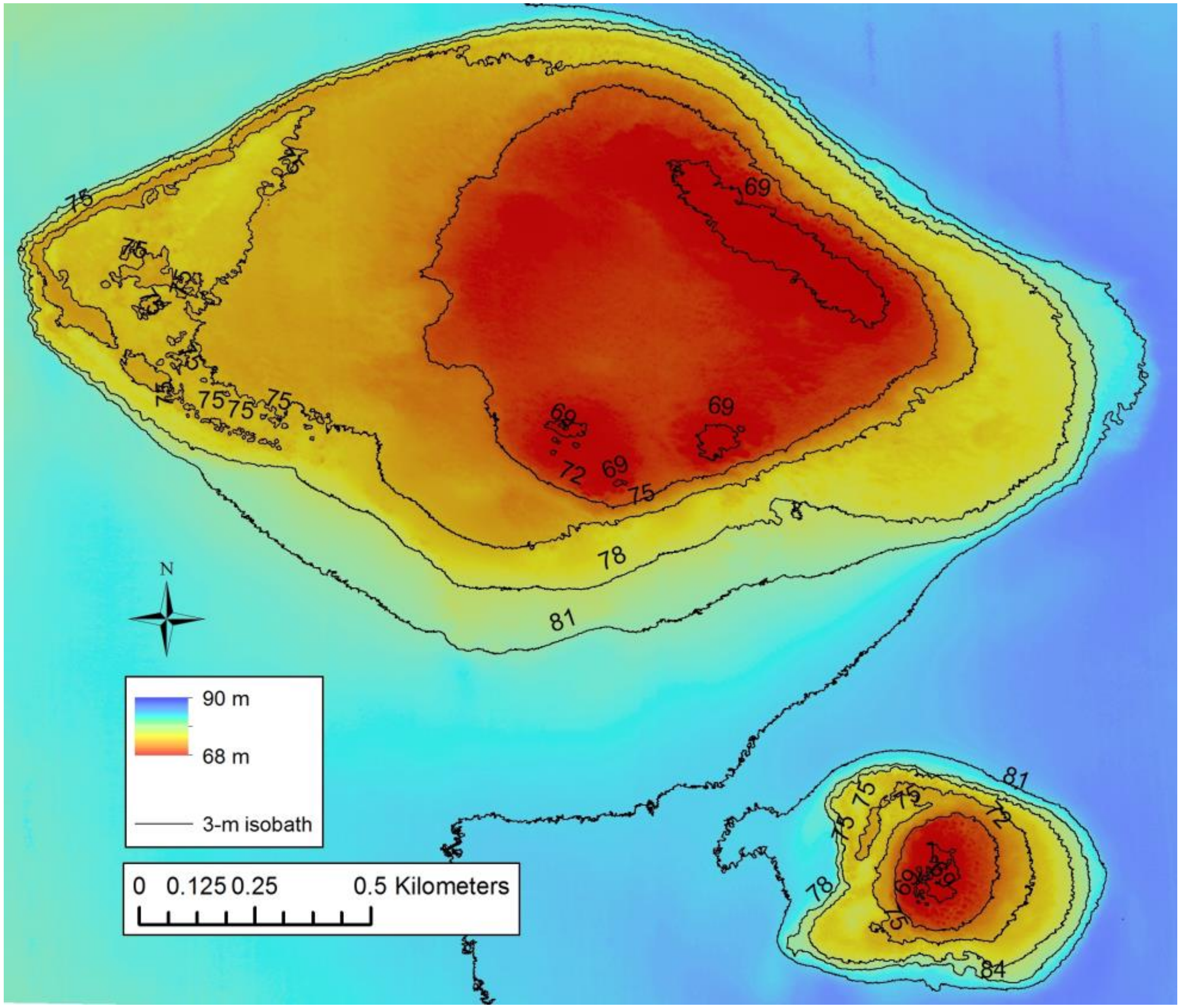

Fig. A.7. Dream Bank, mapped at 1-m resolution.

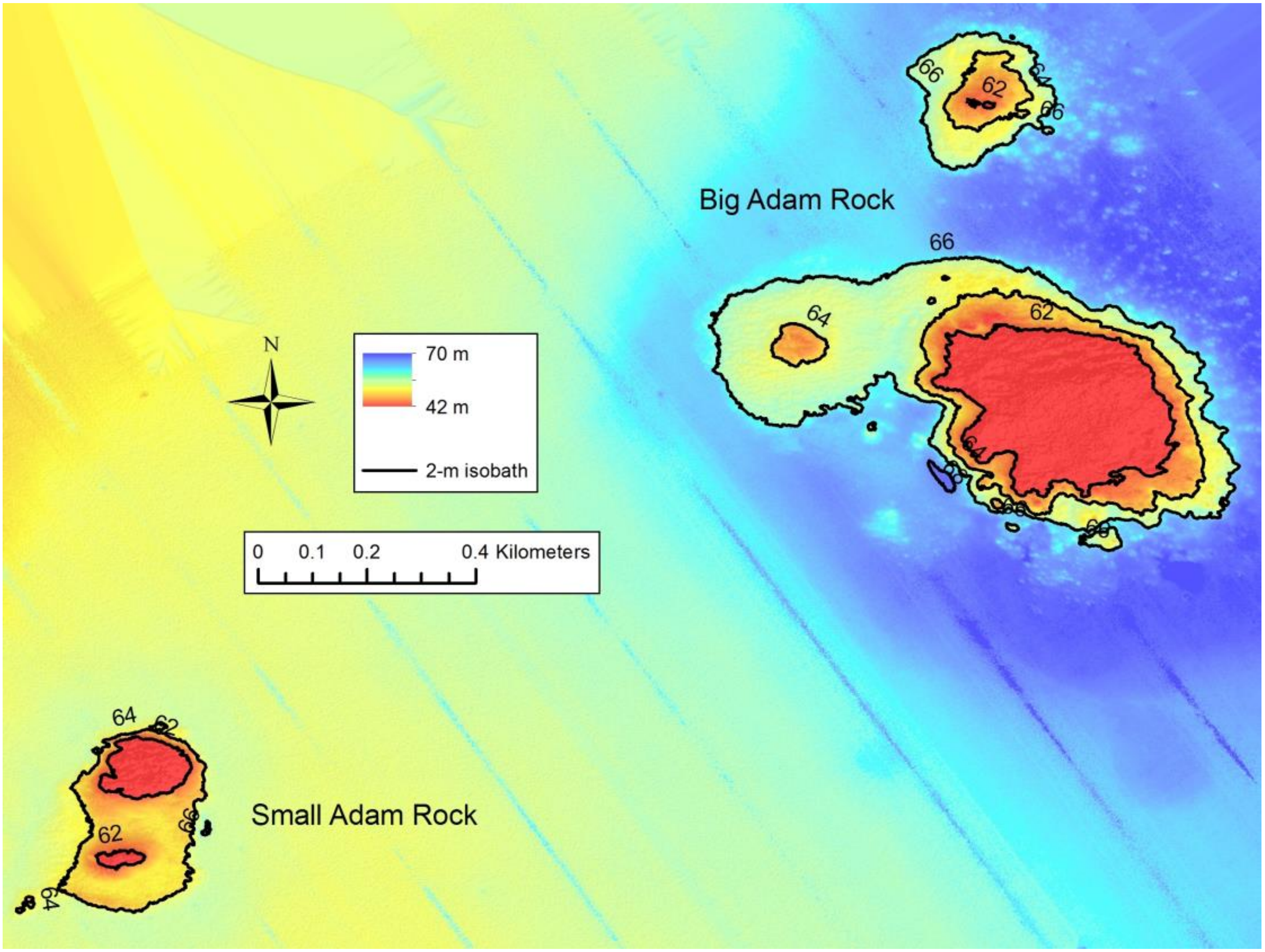

Fig. A.8. Big Adam Rock and Small Adam Rock, mapped at 1-m resolution.

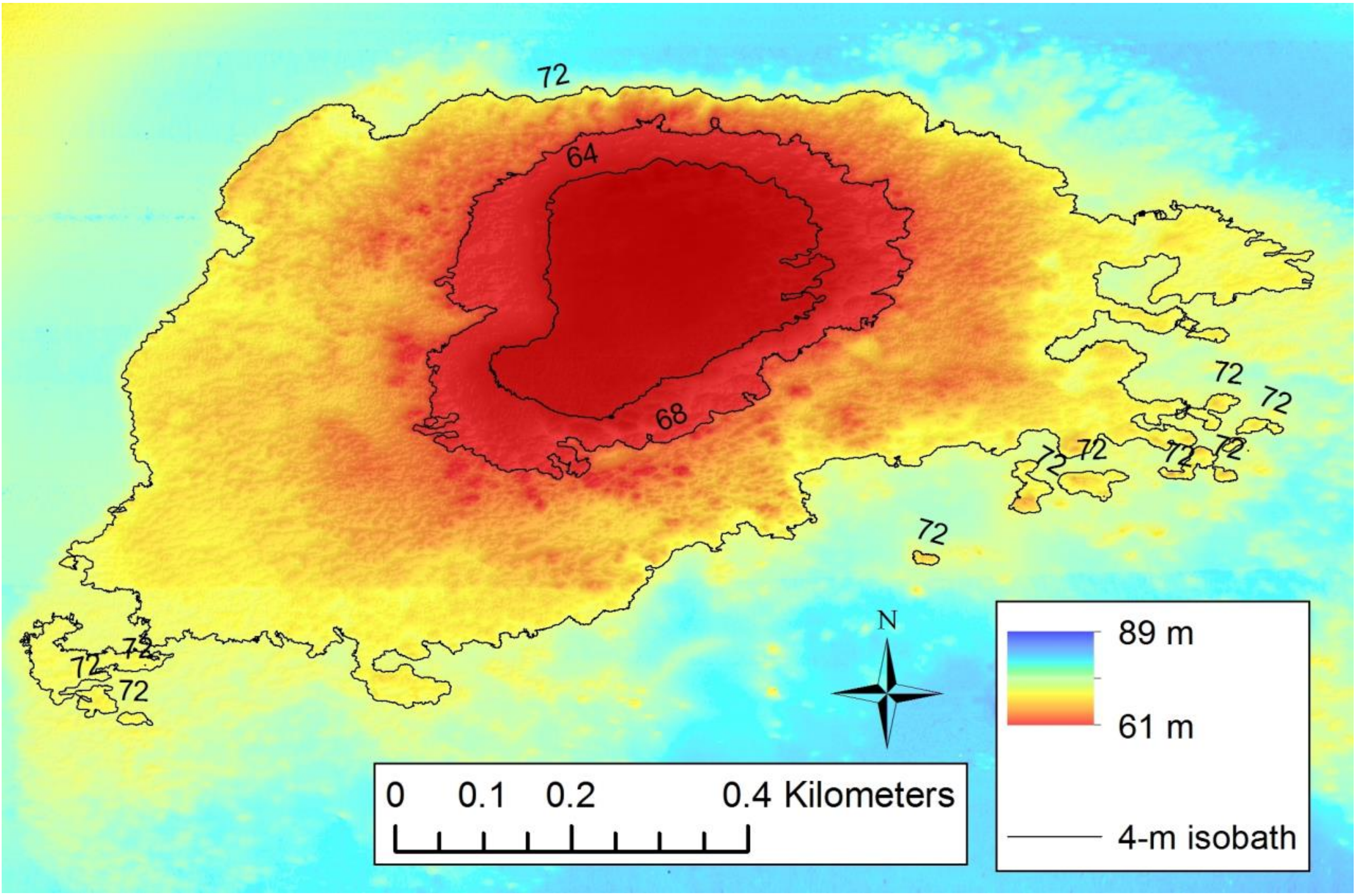

Fig. A.9. Blackfish Ridge, mapped at 1-m resolution.

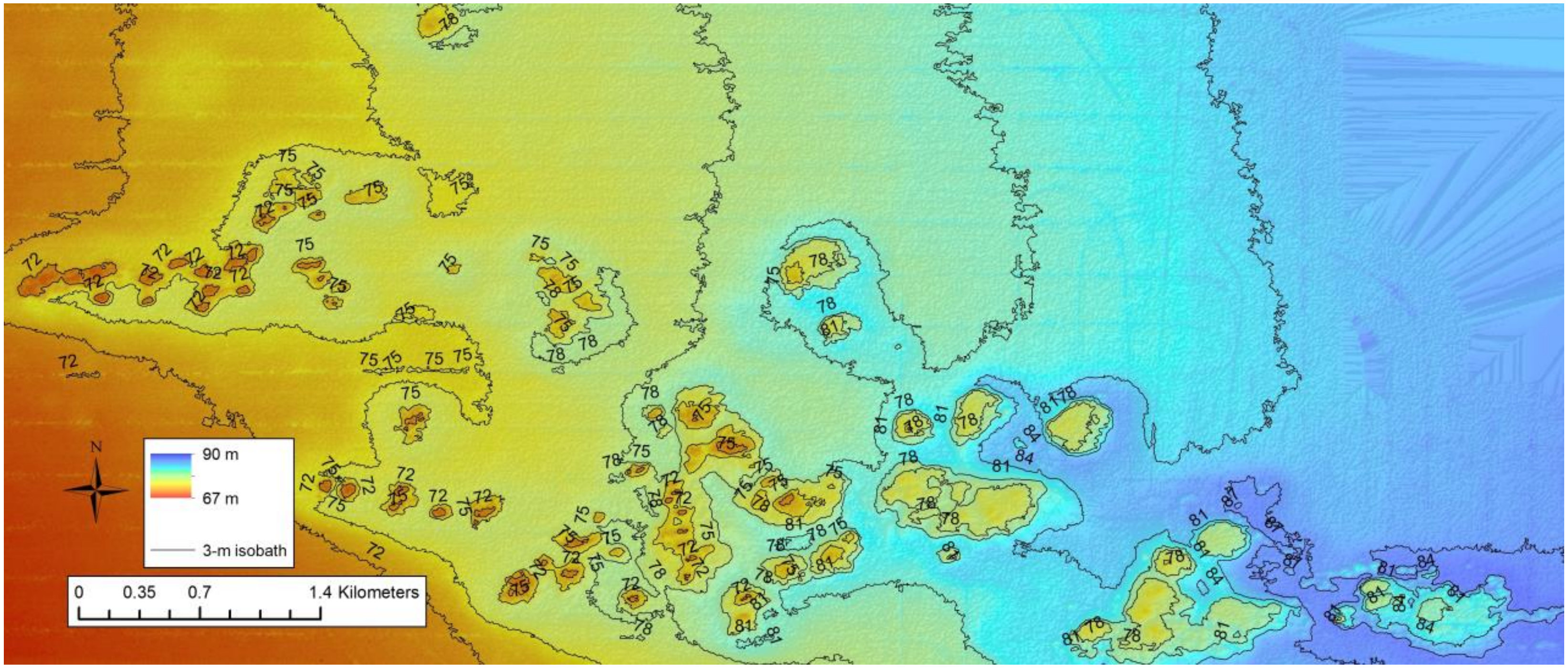

Fig. A.10. Mysterious Banks, mapped at 10-m resolution. Note that the complex is more expansive and includes features that were not completely mapped.

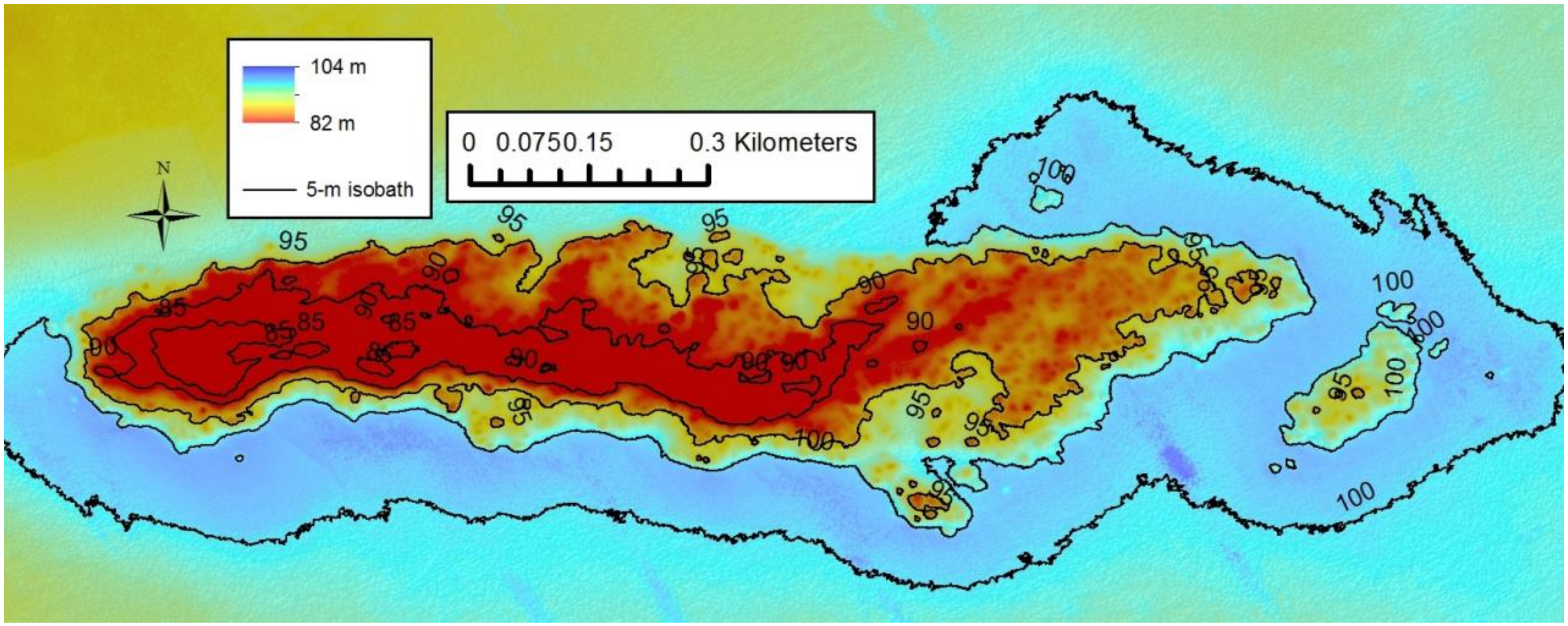

Fig. A.11. Unnamed Bank, mapped at 1-m resolution.

Biographic statement

Harriet Nash was born and raised in Dallas, Texas. She earned a B.S. in Biology from Georgetown University in 1995. After a brief career conducting cancer research, she went to graduate school in 1999 to change her career to focus on marine biology. She earned a master's degree in Coastal Environmental Management from Duke University in 2001. She has worked in the fields of environmental policy and marine biology in non-profit, private, and public sectors, including over eight years of regulatory experience as an aquatic biologist for the U.S. Nuclear Regulatory Commission. Harriet returned to her home state in 2010 to pursue a Ph.D. in Coastal and Marine System Science at Texas A&M University - Corpus Christi where she studied marine policy and law under Dr. Richard McLaughlin.