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Opportunities for Trinational Governance of Ecologically Connected Habitat Sites in the Gulf of Mexico

[Shortened Title: Trinational Governance in the Gulf of Mexico]

Harriet L. Nash* and Richard J. McLaughlin

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. A combination of a compatibility analysis of existing national marine policies and ecosystem-based marine spatial planning would improve management of transboundary living marine resources based on biophysical characteristics of the large marine ecosystem. Goals of such a science-based governance approach are to enhance the understanding of connectivity elements and processes, to map distribution of habitats with high biodiversity, to minimize discontinuity among national marine policies, and to maximize coordinated international protection. The proposed outcome is the design and implementation of an international network of marine protected areas to conserve shared transboundary living marine resources of the Gulf of Mexico. Existing conditions in the Gulf of Mexico region support an enterprise to design several alternatives for an international network of marine protected areas for joint consideration by policy decision-makers from the United States, Mexico, and Cuba. The same model combining science and policy could apply to other transboundary large marine ecosystems.

Key words : transboundary ecosystem, marine protected area network, connectivity, international governance

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* Corresponding author: Harte Research Institute for Gulf of Mexico Studies, Texas A&M University - Corpus Christi, 6300 Ocean Drive, Unit 5869, Corpus Christi, Texas 78412-5869, USA. E-mail: harriet.nash@tamucc.edu, Tel. +1-361-825-2011.

1. Introduction

The Gulf of Mexico (GMx) is a semi-enclosed, international sea that comprises a large marine ecosystem (LME) bordered by three nations: the United States (U.S.), Mexico, and Cuba. As such, the GMx 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 GMx 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 oil platforms, distributed in a semicircular fashion around the GMx 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 GMx is an integral component of ecosystem conservation and management on an international scale. 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. GMx coastal communities are inherently linked to the ability of the LME to provide other goods and services as well. The habitat complex in the GMx 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 GMx. However, existing MPAs throughout the GMx 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 GMx. Also, some 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.

Over the past several years, 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 Trinational Initiative group developed, and the group met again in March 2009, October 2009, and September 2010 (Guggenheim and Chamero, 2008; Trinational Initiative, 2011). Participants from the U.S., Mexico, and Cuba agreed to encourage research and conservation of several taxa as well as strengthening and extending existing MPAs in the GMx 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 GMx 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 as well as 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.

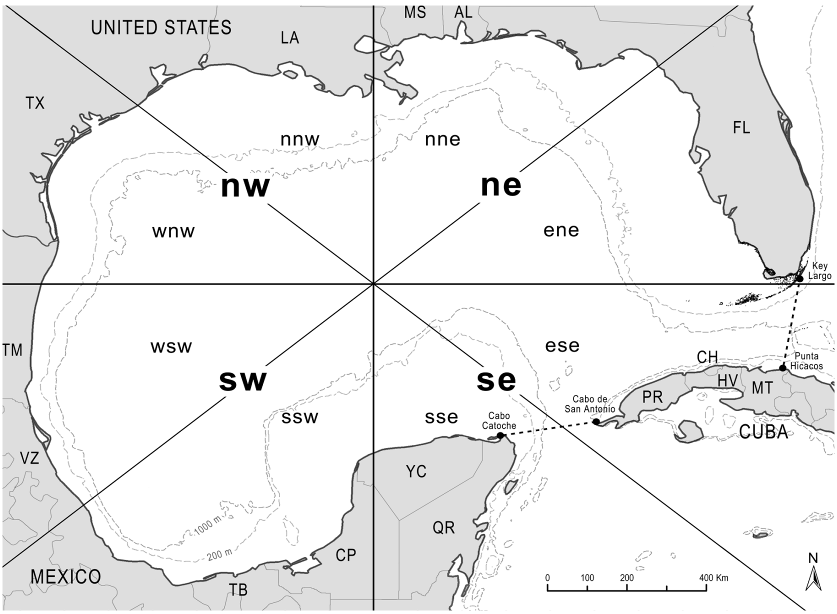
In 2009, the Global Environment Facility (GEF), partnered with the United Nations Industrial Development Organization, created the Gulf of Mexico Large Marine Ecosystem Project (GoM-LME, 2011). The project's goals are to identify hurdles, solutions, and strategies for transitioning the GMx to ecosystem-based management through collaborative efforts of the U.S., Mexico, and Cuba. Specific GEF study priorities for the GMx include hypoxia, fisheries, biodiversity, and coastal development. Originally supported by the Federal governments of the three GMx-bordering nations, the project is currently supported by the U.S.'s National Oceanic and Atmospheric Administration (NOAA) and Mexico's Secretariat of the

Environment and Natural Resources. Perhaps in the future Cuba will rejoin the project to ensure a truly regional design for sustainable ecosystem-based management in the GMx.

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 the University of Veracruz—collaborated to develop an annual series of trinational student workshops regarding governance in the GMx 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 GMx, 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 University of Veracruz hosted the second annual trinational governance workshop in Veracruz, Mexico in August 2011. The second workshop theme emphasized watershed and coastal issues throughout the GMx. 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 initiative group, scientific fora, and ocean governance workshops, this paper explains the importance of unified, comprehensive protection of ecologically connected habitat sites throughout the GMx. With emphasis on habitats exhibiting biological connectivity and biodiversity, the existing ecological network can be transformed into an international network of MPAs in the GMx. A protected network in the GMx 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. This paper discusses the existing ecological nexus and the ripeness of desire among the three nations for integrated marine conservation and management policy in the GMx.

2. Biophysical setting

The region for the proposed international MPA network is the GMx, which encompasses waters of the U.S., Mexico, and Cuba. The GMx is a semi-enclosed oceanic basin that is connected to the Caribbean Sea via the Yucatan Channel and to the northwestern Atlantic Ocean by the Florida Straits. Terrestrial boundaries of the GMx 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 GMx 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 (Figure 1; Felder, Camp, and Tunnell, 2009).



Source : Adapted from Felder, Camp, and Tunnell, 2009

Figure 1. Gulf of Mexico study area

As denoted by the contour lines in Figure 1, the GMx 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 GMx has a surface area of about 1.5 million square kilometers, approximately a third of which covers the continental shelf (Tunnell, 2009). The Sigsbee Abyssal Plain is the deepest region at over 3700 m deep 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 Yucatan Peninsulas, respectively.

Regardless of shelf sediment type, the vast majority of the GMx 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 GMx 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, Bright, and McGrail, 1985). Areas with true coral reefs include the Florida Keys region off southern Florida, the Flower Garden Banks on the outer continental shelf off Texas, the Lobos-Tuxpan and Veracruz Reef Systems off the Mexican state of Veracruz, the Campeche Bank Reefs (e.g., Alacrán Reef) on the shelf west of the Yucatan Peninsula, and reefs in the region of the Guanahacabibes Peninsula and Los Colorados Archipelago off northwestern Cuba (Figure 2; Tunnell, 2007a). Coral reefs in the northwestern GMx are submerged while coral reefs in the southern and eastern GMx are typically emergent. The hard-bottom banks, such as Stetson and Southern Banks in the north-northwestern part of the GMx, exhibit a gradual transition from temperate communities nearshore to tropical communities offshore (Rezak et al. 1985). The transition for benthic communities on the GMx mid and outer shelves, as seen elsewhere as well, appears to be associated with substrate type (Rezak, Bright, and McGrail, 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 western Florida and the Yucatan Peninsula is composed of carbonate sediments while the continental shelf off eastern Mexico, Texas, and Louisiana consists of mostly terrigenous sediments (Rezak, Bright, and McGrail, 1985). The combination of sedimentation, subsurface salt movement, and rifting results in salt diapirism, which is common in some areas of the GMx. 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 GMx, 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 GMx (Rezak, Bright, and McGrail, 1985).

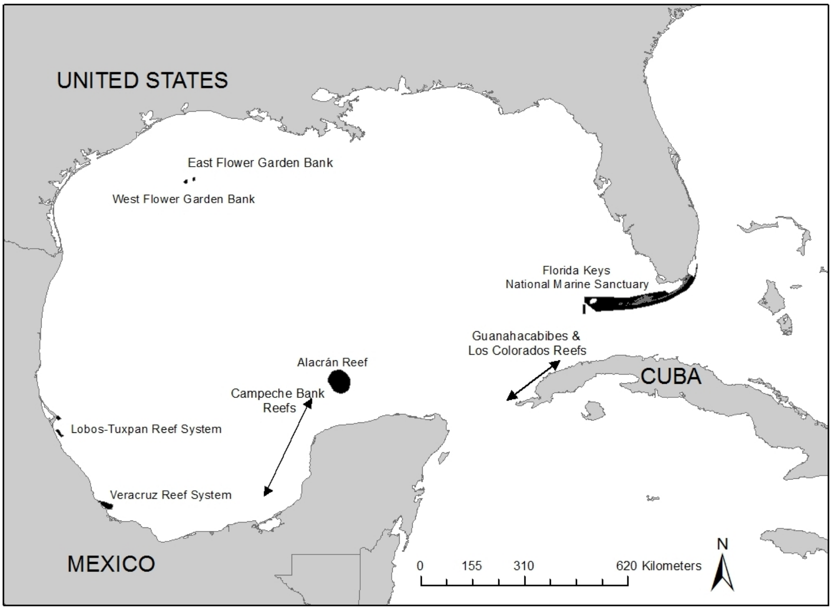


Figure 2. Gulf of Mexico areas with true coral reefs
(Note that the Campeche Bank Reefs and the Guanahacabibes & Los Colorados Reefs are shown in more detail in Figures 4 and 5, respectively.)

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, Bright, and McGrail 1985). Beyond the continental shelf in the GMx, 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 dominated 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) as well as 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 GMx. Additionally, the Yucatan Current transports planktonic organisms from the Caribbean Sea through the Yucatan Strait. Upon entry into the GMx, surface water is entrained into the Loop Current, which intrudes to variable extents into the eastern GMx and then exits via the Florida Current, which becomes the Gulf Stream. When the Loop Current extends into the northwestern GMx, 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, Nowlin, and Reid, 2005; Carrillo, Horta-Puga, and Carricart-Ganivet, 2007). Another major circulation phenomenon in the GMx 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 GMx (DiMarco, Nowlin, and Reid, 2005; Carrillo, Horta-Puga, and Carricart-Ganivet, 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 LME such as the GMx.

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, that 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 as well as some juveniles, from one habitat feature to another. Surface currents, deep currents, convergent currents, and episodic turbulence and their variable velocities and directions play 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, larval behavior, adult spawning strategies, current patterns, 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, Jones, and Thorrold, 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). 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 play 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, Doherty, and Carleton, 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 retention and dispersal according to DNA parentage analysis (Planes, Jones, and Thorrold, 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 Gulf of Mexico

Specifically in the GMx, 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 GMx and Wider Caribbean region. Several studies support connectivity in the GMx based on transport via ocean currents (Lugo-Fernandez *et al.*, 2001; Phinney *et al.*, 2001; Jordan-Dahlgren, 2002; McBride and Horodosky, 2004; Vásquez-Yeomans *et al.*, 2009; Paris *et al.*, 2008). 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 GMx (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 GMx in 1983-1984 (Phinney *et al.*, 2001). A high degree of gorgonian species similarity occurs across large distances in the southern GMx, 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 GMx (McBride and Horodosky, 2004). Currents are likely the driving mechanism for transporting bonefish larvae (*Albula* spp.) from offshore areas of the GMx 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 GMx and Wider Caribbean. 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 GMx (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 GMx and Wider Caribbean (Girard, Tucker, and Calmettes, 2009; Hueter *et al.*, 2009).

Within the GMx and Wider Caribbean 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 GMx 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 as well as 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 GMx hosts more than 15,000 species making it one of the most diverse marine ecosystems in the world (Tunnell, 2009). The GMx is a faunal transition zone, or ecotone, with high biodiversity of mesopelagic fishes (Bangma and Haedrich, 2008). GMx had the highest species richness and species abundance when comparing mesopelagic fish fauna to those of the North and South Sargasso Seas as well as the Venezuelan and Columbian Basins of the Caribbean Sea. High but variable levels of biodiversity of benthic fauna exist throughout the GMx continental shelf (Rabalais, Carney, and Escobar-Briones, 1999). However, the northern GMx generally does not have high biodiversity of deep-benthic fauna, but the Mississippi Trough has the highest deep-benthic species richness in the northern GMx (Haedrich, Devine, and Kendall, 2008). Finally, seabird diversity varies seasonally, but the southern GMx hosts close to four times as many seabird species as the northern GMx (Peake, 1999; Davis, Evans, and Wursig, 2000; Tunnell, 2007c).

A comprehensive biological inventory of the GMx reported thousands of species in various habitats through 2007, which is the most recent biodiversity assessment published for the GMx 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 GMx. Because there are so many high-biodiversity banks and reefs in the northwestern GMx, it is the “center of distribution and evolution” for species and community diversity in the northern GMx (Figure 3; Rezak, Bright, and McGrail,1985). In the southern GMx, 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 GMx (Moretzsohn, Sanchez Chavez, and Tunnell, 2011). Biodiversity estimates and comparisons could be used to identify which of the many hard banks and reefs on the GMx continental shelf (Table 1) would be ideal sites for increased protection based on species richness and abundance.

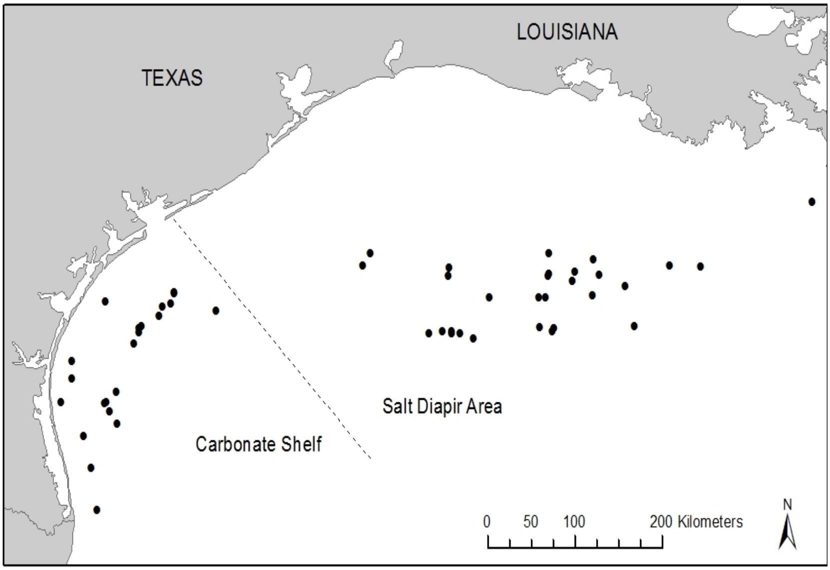


Figure 3. Selected high-biodiversity sites in the northwestern GMx

Table 1. Hard banks and reefs on GMx continental shelf in Federal waters

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 (Cuba)
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	20+	Off Texas south of Matagorda Bay

Sources : Rezak , Bright, and McGrail, 1985; Tunnell, 2007b

4. Network design

From a spatial-planning perspective, several existing hard-substrate banks and reefs on the shelf of the GMx LME would translate well into an international network of MPAs. Additional habitat sites, such as slope sites and artificial habitats, may supplement the connectivity provided by the hard banks and reefs. Some of the many intermediate delivery cold seeps on the continental slope have developed diverse communities that may offer connectivity to some of the hard-bottom habitats as well. Evidence exists of biological connectivity between hard banks and reefs and oil and gas platforms (Lugo-Fernandez *et al.*, 2001; Fenner and Banks, 2004). While including platforms with relatively short lifespans in an MPA network may not be warranted, decommissioned platforms that are toppled to the bottom in the Rigs-to-Reefs program or decommissioned platforms that are left in place without toppling might be appropriate for inclusion in an MPA network (Hoffman, 2011). Regardless, 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, as well as 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 GMx region without considering major contextual differences. When compared to the GBR setting, the GMx region has very different biophysical features, ecology, socioeconomics, and policies. For example, the GMx 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 GMx. Additionally, the Australian government strongly supported the GBR rezoning project while a network of MPAs in the GMx 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 using an MPA network.

Connectivity and biodiversity parameters in the GMx should be identified and prioritized to support several alternative designs for a trinational MPA network. A gap analysis of physical and biological data describing the GMx’s ecological network would identify areas and links in need of protection. Optimization analyses could produce alternative designs for a network of MPAs linking existing and potential new sites based on the connectivity strength of biological parameters, including species diversity. Policy decision-makers could consider the science-based MPA network designs in light of the regional marine policies and governance structures to choose the most politically effective and efficient approach for trinational implementation.

5. Marine policy and law in the Gulf of Mexico

Most waters in the GMx 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 GMx, thus excluding the Western and Eastern Gaps as well as 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 GMx region favor such a demarcated analysis as well.

5.1 Existing marine protected areas in the Gulf of Mexico

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 seven 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 GMx, which eliminates inclusion of State and local MPAs in the U.S. considering the jurisdictional boundaries within U.S. waters.

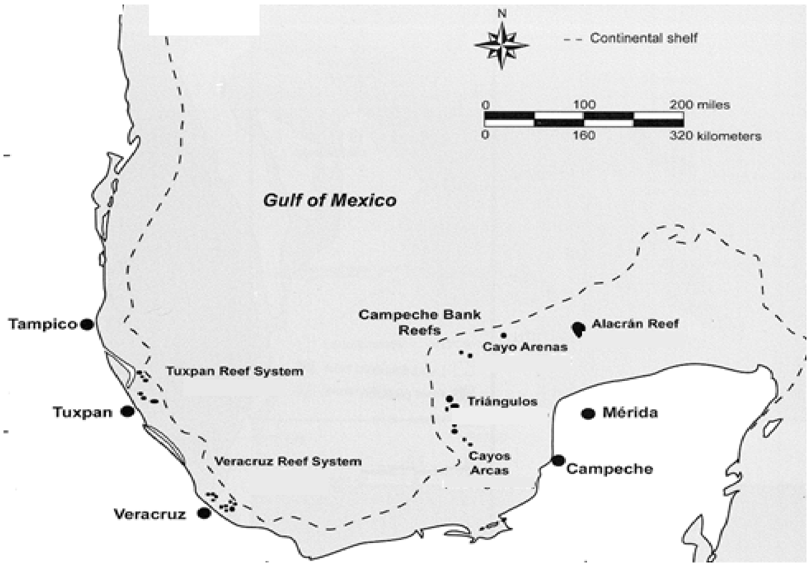
5.1.1 United States

Of all the GMx 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. GMx, and there are 295 MPAs in the U.S. waters of the GMx, which includes small State and local MPAs (NOAA, 2011). Most areal coverage is Federally 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 GMx has a no-take restriction; therefore, almost all GMx MPAs in U.S. waters are designated as multi-use (NOAA, 2011). Domestically, the Rookery Bay National Estuarine Research Reserve is developing a communication framework for existing coastal 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 the international offshore network proposed here, 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 in Federal waters. However, despite the legislative fragmentation, the 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. In Federal waters, NMSP manages two GMx 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 GMx 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 policy platform for developing a Gulf-wide 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 GMx, CONANP protects the Tuxpan and Veracruz reef systems, and in the eastern portion of the southern GMx, 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 GMx. Coral reefs in the southern GMx (Figure 4), whether existing or prospective Mexican MPAs, are likely candidates for inclusion in an international network.

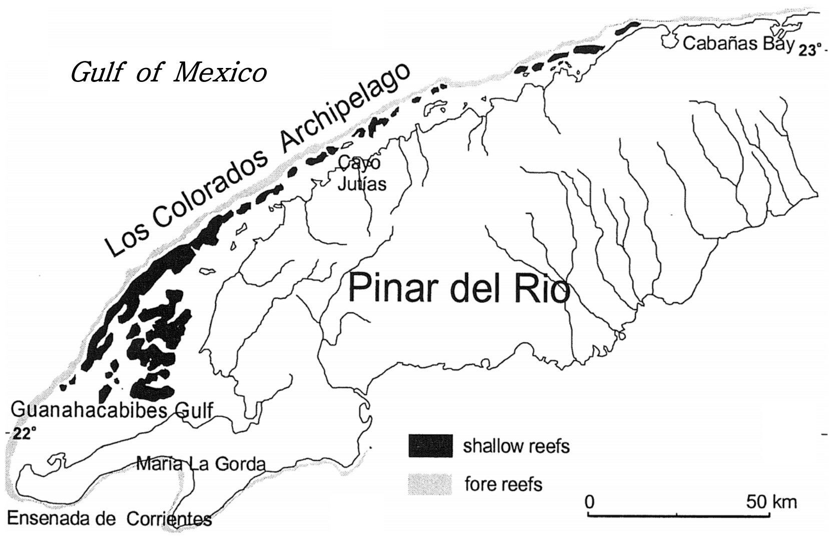


Source : Adapted from Tunnell 2007b

Figure 4. Coral reefs in the southern GMx

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 seven IUCN categories describing protected areas. Although Cuba has a much higher percentage of its Federal waters designated as MPAs than either the U.S. or Mexico, very few resources are 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 GMx. In addition to the fore reefs that fringe the entire northwestern coast of Cuba, the Los Colorados Archipelago contains many shallow reefs within and to the north of the Guanahacabibes Gulf, which extends west to northern tip of Cabo de San Antonio (Figure 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 (see Figure 1) 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).



Source : Adapted from Alcolado et al., 2003

Figure 5. Cuban reefs in the GMx

5.2 Toward an integrated international governance in the Gulf of Mexico

Transboundary species utilize habitats with disregard to political boundaries. Therefore, disconnected national marine policies and various anthropogenic pressures throughout the GMx 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 or utilize the same resource. Therefore, objectives of effective trinational governance of living marine resources in the GMx are: (1) to understand the key elements that maintain biological connectivity and biodiversity as mentioned in sections 3.1 and 3.2, respectively; and, (2) agree on international policies and governance mechanisms to seamlessly protect and conserve the LME 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 GMx. 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 GMx region, the three nations each have governance mechanisms in place that could support an MPA network as discussed in section 5.1.

Additionally, the GMx 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 1982 is the EEZ. The EEZ grants exclusive authority to the coastal nation over all marine resources out to 200 nautical miles. 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 245 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 1982 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 GMx (Alexander, 1999).

Important differences among the three GMx-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, Goldschmidt, and Schwartz, 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 GMx 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 conservation tool for international marine policy in the GMx 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

GMx. 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 as well as 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 GMx 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. Connectivity in other transboundary large marine ecosystems

Identifying important high-biodiversity habitats and biological connectivity coupled with a compatibility analysis of existing national marine policies could serve as the foundation for valuable ecosystem-based marine spatial planning tools in other transboundary LMEs. Creating MPAs in semi-enclosed seas and LMEs that are experiencing intense natural and anthropogenic stresses is an important method of supporting and advancing the long-term sustainable use and conservation of these valuable ocean areas. Moreover, the growing body of scientific literature suggests that transboundary MPAs can serve as a catalyst to broader political reconciliation beyond the environmental sphere (Sandwith *et al.*, 2001; Ali, 2007).

A number of transnational initiatives have been developed in marine areas to protect the environment and improve communication and partnerships among scientists and managers. Existing MPAs in the Red Sea between Israel and Jordan and among Mediterranean Sea nations at the Bonifacio Strait have been in place since the 1990s (Crosby *et al.*, 2002; Chevalier, 2007). Newer initiatives between the Philippines and Indonesia in the Coral Triangle and among South Korea, North Korea, and China in the Yellow Sea are moving rapidly forward (Nam, 2007; UNDP, 2011). Active collaboration between the Chinese and Korean governments on the initiative to restore the environmental health of the Yellow Sea continues despite a bitter maritime boundary dispute between North and South Korea that recently erupted into military conflict (Crook, 2011). Despite the political instability in the region, development of a framework for transboundary environmental cooperation likely would help resolve longstanding tensions between the two nations (Nam, 2007).

Identifying and resolving priority transboundary problems are of prime importance to all of these programs. However, prior to developing strategies to sustainably manage resources in these areas, it is essential that physical and biological connectivity be identified. The kind of ecosystem-based marine spatial planning tool that this article advocates for application in the GMx, i.e., a transboundary MPA network, would be equally well suited for use in other marine areas such as those described above.

7. Conclusions and policy implications

Based on identifiable physical and biological features and phenomena, the GMx 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. 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 GMx. 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, as well as 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 GMx. 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 GMx 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 GMx 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 GMx 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 GMx. With the heightened incentive for collaboration among the three GMx-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 GMx LME.

The ecological principles discussed here provide a solid foundation for designing an international network of MPAs in the GMx or in other transboundary LMEs. Next steps in this research include spatial designs and policy analyses for creation of a transboundary MPA network. Successful implementation, however, would require socioeconomic research to address the region'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 GMx while creating a cooperative environment among nations with historically disparate political and policy objectives.

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