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Gulf of Mexico Fishery Management Council Workshop on Interrelationships between Coral Reefs and Fisheries

May 20-22, 2013
Tampa, Florida

Final Summary Report

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NOAA CORAL REEF CONSERVATION PROGRAM

This report does not represent and should not be construed to represent any agency determination or policy.

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CHAPTER 1. INTRODUCTION

1.1 Executive Summary

A workshop on *Interrelationships between Coral Reefs and Fisheries* was held in Tampa, Florida May 20-22, 2013. The purpose was to discuss current and emerging threats, challenges, and opportunities to the management of corals and associated fisheries, both now and in the future. Coral ecosystems face both local (e.g., pollution) and global (e.g., climate change) threats. Understanding these impacts and developing potential mitigation strategies is critical to maintaining optimal fishing yields in habitats such as coral reefs. The workshop was developed by a steering committee and organized into eight themes broadly categorizing the most important challenges in the management of coral reefs, fishes, and associated fisheries. Specifically, themes discussed were: 1) management of corals and fisheries; 2) critical linkages among habitats (e.g., seagrass meadows, mangroves, and coral reefs) and fish; 3) threats to coral/fishery health; 4) deepwater coral; 5) spatial ecology; 6) fishery and ecological consequences of impacts to coral health; 7) mitigation of coral losses; and 8) future research. Presenters also made recommendations for Council action. The workshop aimed to inform important management questions such as:

1. What are the "essential" features of the interrelationship between corals and fisheries?
2. If trends in coral condition continue, should we adjust management plans for coral-associated species?
3. What adjustments can be made to our management approach (for corals and/or fish)?
4. What do we need to know, in order to answer these questions?

This workshop served as an information baseline to better understand how corals influence fish populations in general and species supporting fisheries specifically. Speakers considered possible future states for coral reef fisheries including information on the specific linkages between corals and various fish species and provided evidence that fish respond negatively to coral loss. Climate change impacts marine ecosystems through ocean warming by increased thermal stratification, reduced upwelling, sea level rise, increases in wave height and frequency, and increased risk of diseases in marine biota. Decreases in surface ocean pH due to absorption of anthropogenic CO_2 emissions can impact organisms that absorb calcium from surrounding waters, such as corals and crustaceans. Environmental threats to coral health can be episodic and widespread (e.g., bleaching), or localized and chronic (e.g., pollution). Global and local stressors may affect coral distribution, abundance and health resulting in declining fish yields from coral reef ecosystems if current rates of coral degradation continue. Local responses (e.g., reducing pollution) may partially mitigate global effects (e.g., climate change) illustrating complex linkages in these ecosystems and the need for localized responses.

The specific manner in which many of these mechanisms interact remains an ongoing topic of research; nevertheless they do exist and require consideration to optimize management because declining yields of coral associated fishes are expected if current rates of coral degradation continue.

The importance of coral as habitat was widely acknowledged. As an example, parrotfish density was more heavily influenced by habitat quality than mere larval supply, and in turn a high density of parrotfish was needed in order to maintain reef habitat quality.

The movements of some coral reef fishes illustrated how impacts in one ecosystem will have cascading impacts on the others; for example, some fish species move from reefs to seagrasses and mangroves, and others move from shallow waters to deeper, mesophotic waters and back throughout various life stages. Management efforts need to consider the role of this larger "coastal seascape" and any spatial and temporal mismatches between existing scales of ocean governance.

Given the variety of stressors on coral systems, much of the workshop focused on management options to reduce or mitigate these effects. Such actions would be an important step toward maintaining fisheries yields from species occupying these habitats. Workshop participants recommended refining the mapped areas representing coral Essential Fish Habitat in the Gulf of Mexico and considering new Habitat Areas of Particular Concern to protect deepwater corals and associated ecosystems. Knowledge of the distribution and extent of deepwater corals in the Gulf of Mexico is growing rapidly and deepwater corals provide habitat for some potential fishery species.

Many of the most relevant questions are not yet fully answered, but several workshop participants described promising methods that can be used to help fill gaps in our knowledge. Presenters recommended continued focus on the identification and protection of deepwater coral habitats, mitigation of oil spill impacts to coral systems and improving understanding of emerging threats such as lionfish and coral diseases. This workshop provided a helpful forum to: improve the basic understanding of the relationships between corals and fisheries; evaluate the various threats and other factors that impact them; examine trends, and identify and discuss potential problems, solutions, and management strategies.

The full slide presentations and abstracts from this workshop are freely available on the Gulf Council FTP site (http://ftp.gulfcouncil.org/?user=anonymous) under the "Coral\\Workshop\Presentations" folder. Audio/video recordings are archived and selections can be made available upon request to Council staff. Many of the workshop participants are contributing related chapters to a peer-reviewed, edited volume expected to be released in 2014 that will continue adding to the collective knowledge of this subject and hopefully serve as a useful reference for scientists and managers alike.

CHAPTER 2. ACKNOWLEDGMENTS

The workshop was funded by NOAA's Coral Reef Conservation Program (CRCP) through a multi-year Cooperative Conservation Agreement with the Council. The participants and agenda were developed by Council staff with primary input from the Council's Special Coral Scientific and Statistical Committee and NOAA's CRCP and additional guidance from individuals at a number of involved research universities and managing agencies. The workshop was open to the public, noticed in the Federal Register and posted on the Council's website.

CHAPTER 3. BACKGROUND AND PURPOSE

The Gulf of Mexico Fishery Management Council (Council) is responsible for the conservation and management of coral and fishery resources occurring in federal waters of the Gulf of Mexico, per the Magnuson-Stevens Fishery Conservation and Management Act. There are 142 coral taxa and 31 reef fish species in the Council's respective fishery management plans (GMFMC 2012a) including two Endangered Species Act-listed coral species (potentially soon to be seven, if proposed rules [78 FR 57835] are finalized). The population status and trends of Gulf coral species is itself of direct concern. Beyond the regulatory obligation to manage coral as its own natural resource, the Council appreciates the functional role corals provide as habitat (either directly as structure or indirectly through trophic relationships) for a number of Council-managed fish species, including many of the most commerciallysignificant species such as groupers and snappers (e.g., Szedlmayer and Lee 2004). For the most part, stock assessments and fishery management plans of reef-associated species do not account for potential changes in the ecosystem services that corals and other habitat types provide. This may be partly because the mechanisms that affect coral health are complex and not fully understood. But research from other regions of the world has shown that declines in coral health/cover (and associated ecosystem services) negatively impact the overall productivity of dependent fish populations (similar to the concept illustrated in Figure 3.1). Similar losses in the Gulf of Mexico ecosystem could lead to unanticipated impacts on managed fisheries, which in turn could necessitate additional management measures. This workshop aimed to: improve the basic understanding of the relationships between corals and fisheries and examine any trends; evaluate the various threats and other factors that impact them; and identify and discuss potential problems, solutions, and management strategies.

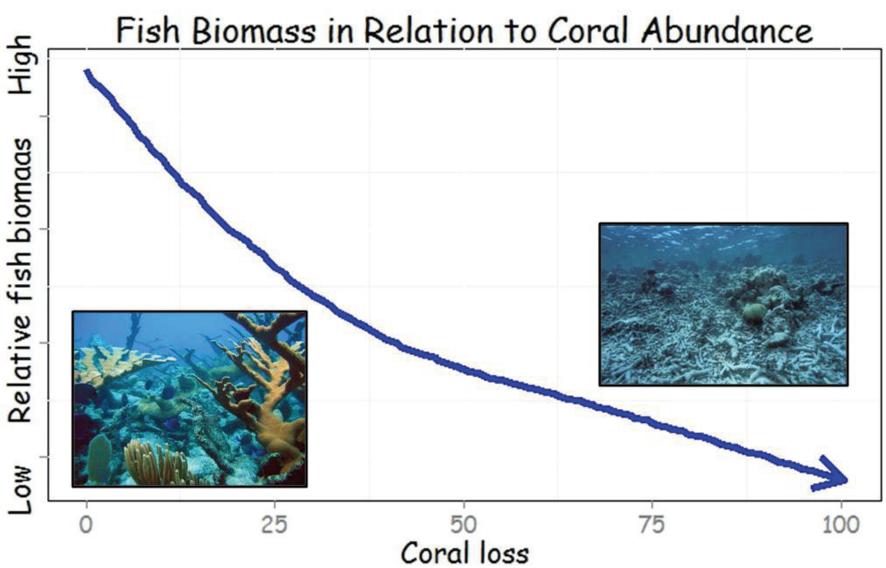

Figure 3.1. Conceptual diagram describing a decline in fish biomass in relation to coral loss on shallow Caribbean reefs (Council staff).

CHAPTER 4. MAJOR THEMES AND SELECTED PRESENTATION SUMMARIES

The three-day workshop encompassed 37 presentations and several panel discussions to assess the status of coral reefs and fisheries and find opportunities from improved management efforts to sustain this resource. Workshop presentations and panel discussions were organized into eight broad themes in order to evaluate specific aspects of corals, reef fishes, and associated fisheries:

- **Management**
- **Critical Linkages**
- **Deepwater Coral**
- **Threats**
- **Spatial Ecology**
- **Consequences**
- **Mitigation**
- **Future Research**

A list of presenters and primary affiliation is given in Appendix 3.

4.1 Management

The workshop began with an overview of existing coral related management practices in use in the Gulf of Mexico and other U.S. management regions (South Atlantic, Caribbean, and Western Pacific). Managers summarized regulatory efforts by their agencies but also spoke to the types of scientific information needed to enable improved management strategies.

Gulf of Mexico

An overview of coral habitat distribution and trends in established fisheries throughout the Gulf of Mexico was provided. In addition, the Gulf of Mexico Fishery Management Council's (Council's) current management efforts (Table 4.1.1) were detailed with definitions and locations of coral Essential Fish Habitat (EFH), habitat areas of particular concern (HAPC), sanctuaries, and reserves (Figure 4.1.1). In the eastern Gulf of Mexico, these important areas include the Florida Keys reef tract, the Dry Tortugas, the West Florida Shelf, and Pulley Ridge, which are dominated by hermatypic coral reefs, and the Florida Middlegrounds, Madison-Swanson, Steamboat Lumps, and The Edges, which are hardgrounds where stony corals represent a less conspicuous component of the benthic fauna (David and Gledhill 2010). In the north central Gulf of Mexico, natural hermatypic coral reefs are rare with little to no vertical relief (Parker et al. 1983). The Pinnacles reef tract off Mississippi and Alabama consists of hard bottom, reef-like structures near the shelf edge at depths of 60 – 100 m (Weaver et al. 2001). These structures are colonized by octocorals, black corals and sponges, rather than reef-building stony corals, but are home to over 70 fish species generally associated with Caribbean coral reefs (Weaver et al. 2001). The remainder of the inner-shelf area is composed of sand, mud, and silt

(Dufrene 2005) that has been populated in recent decades by numerous artificial structures including oil and gas platforms for energy extraction. In the western Gulf of Mexico, there are numerous natural mid-shelf and outer-shelf banks and salt domes including the East and West Flower Garden Banks, and the carbonate/drowned barrier reefs of the South Texas Banks (Bright et al. 1984, Hickerson et al. 2008, 2012; Rezak et al. 1985; 1990). A summary was given of the approximate number of coral and fish species found in the areas described above as well as the snapper and grouper fisheries that many of these areas support; however, it was noted that the absence of available baseline information for many areas continues to present challenges for effective management.

Table 4.1.1. Current management efforts and year designated as a sanctuary, habitat area of particular concern (HAPC), and reserve in the Gulf of Mexico. Notes: The Edges* is closed 4 months out of the year to all fishing compared to the other reserves which are closed year-round. The effective date is listed under each type of management effort which may differ from the corresponding reference document date.

Areas	Sanctuary	HAPC	Reserve	Reference
Alderdice Bank		2006		GMFMC 2005
Bouma Banks		2006		GMFMC 2005
Fathom 29		2006		GMFMC 2005
Florida Middle Grounds		1984		GMFMC and SAFMC 1982,GMFMC 2005
East Flower Garden	1992	2006		GMFMC 2005
West Flower Garden	1992	2006		GMFMC 2005
Geyer Bank		2006		GMFMC 2005
Jakkula Bank		2006		GMFMC 2005
McGrail Bank		2006		GMFMC 2005
MacNeil Bank		2006		GMFMC 2005
Madison-Swanson		2006	2000	GMFMC 1999, 2003, 2005, 2008
Pulley Ridge		2006		GMFMC 2005
Rankin Bright Bank		2006		GMFMC 2005
Rezak-Sidner Bank		2006		GMFMC 2005
Steamboat Lumps			2000	GMFMC 1999, 2003, 2008
Stetson	1996	2006		GMFMC 2005
Sonnier		2006		GMCMC 2005
The Edges*			2009	GMFMC 2008
Tortugas North		2006	2002	GMFMC 2001, 2005
Tortugas South		2006	2002	GMFMC 2001, 2005

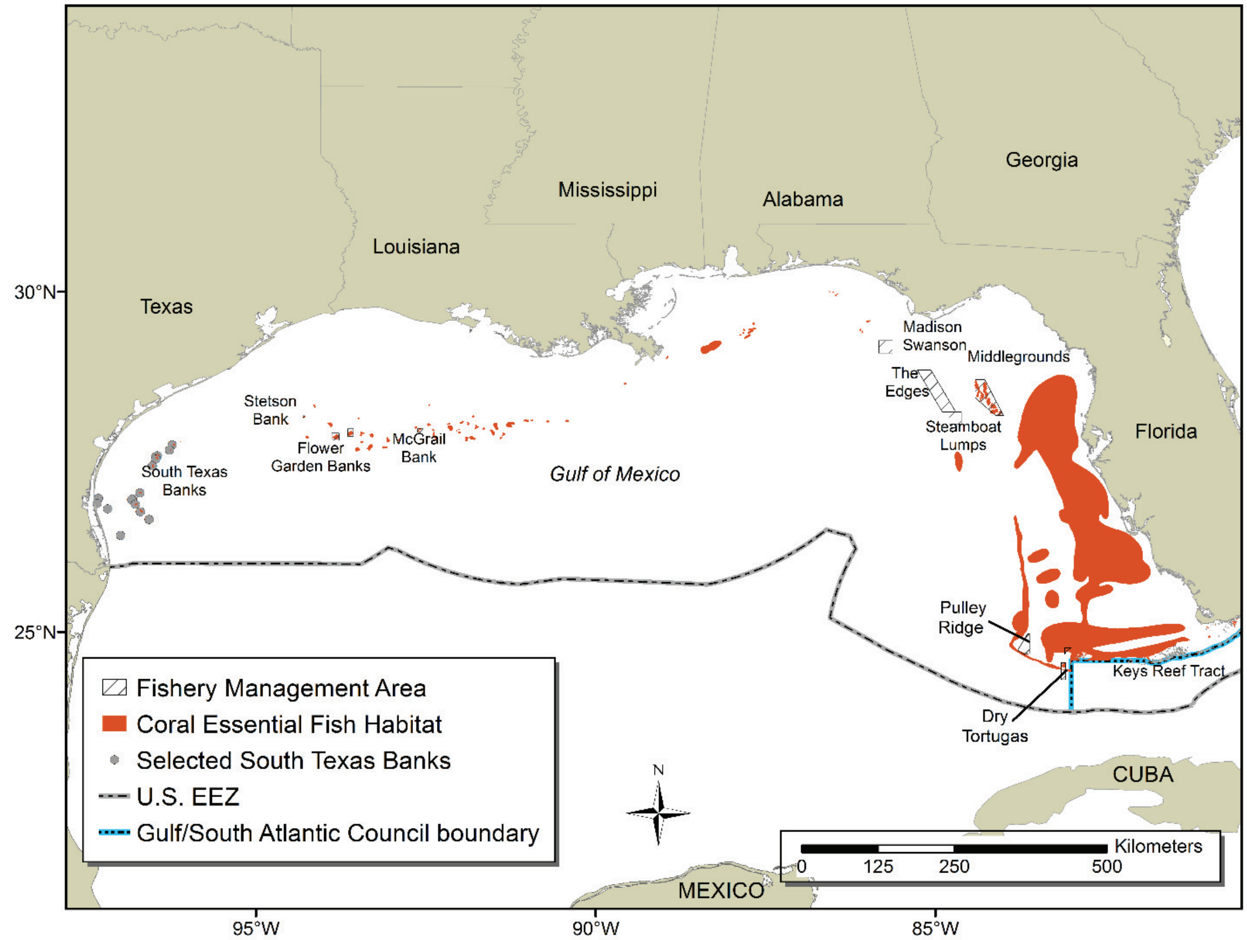

Figure 4.1.1. Map indicating the boundary of the Gulf of Mexico Fishery Management Council jurisdiction and that of the South Atlantic Council (blue line) and various areas within the Gulf Council's jurisdiction that have been designated as fishery management areas and coral essential fish habitat (EFH).

U.S. South Atlantic

The waters of the U.S. South Atlantic contain extensive deepwater coral habitat including what may be the world's largest contiguous distribution of deepwater coral ecosystems. Regulations to designate five areas as deepwater Coral Habitat Areas of Particular Concern (CHAPCs) were approved in 2009. Within the CHAPCs, encompassing over 23,000 square miles, bottom contact fishing gear (i.e., longlines, trawls, dredges, and pots) and other fishing activities that could threaten the health and continued existence of these communities (e.g., Figure 4.1.2) has been prohibited. The South Atlantic Fishery Management Council (SAFMC) worked cooperatively with fishermen to designate areas within the CHAPCs where traditional fisheries can continue without impacting bottom habitat. Based on recent research on deepwater corals in this region, the SAFMC is considering expansion of several existing CHAPCs, including the Oculina Bank, Stetson Miami Terrace, and Cape Lookout. The SAFMC continues to take a precautionary approach to managing deepwater coral ecosystems, while including all stakeholders.

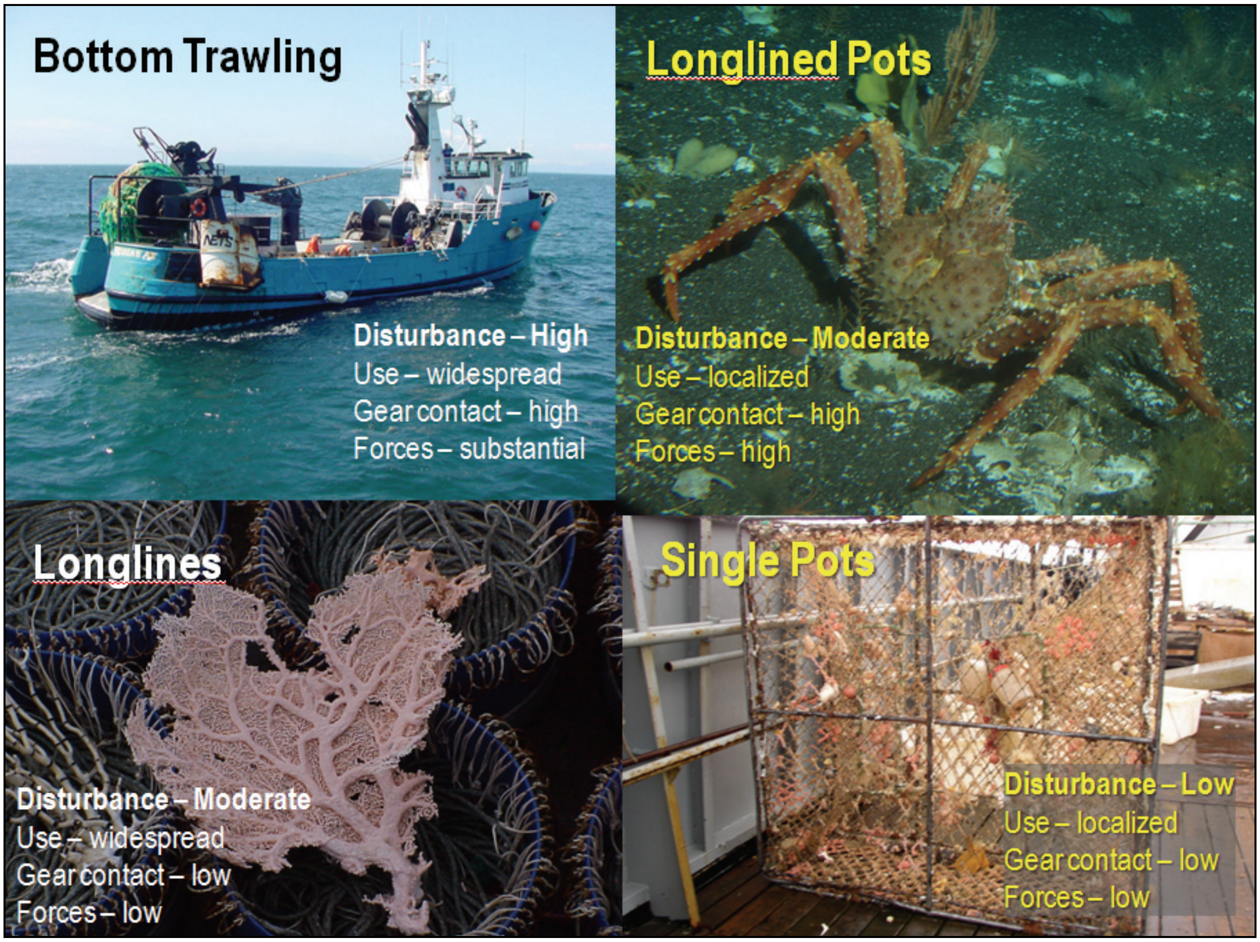

Figure 4.1.2. Examples of gear types (bottom trawling, bottom longlines, longline pots and individual pots) and their associated impacts to deepwater coral habitats in Alaska (Source: R. Stone NMFS, presented by T. Hourigan)

U.S. Western Pacific

The waters of the U.S. western Pacific are largely tropical and support extensive coral reef habitat, fishes, and associated fisheries. Given the richness of these coral systems (e.g., > 800 managed reef fish species) they have struggled with methods to identify appropriate fishery harvest levels necessary to maintain coral reefs (through linkages) while harvesting the optimum yield for managed species. The Western Pacific Fishery Management Council provided an overview of a data-poor fisheries approach used to identify appropriate catch limits (Catch-Maximum Sustainable Yield approach) and described how this approach could be extended to other regions with similar challenges such as the Gulf of Mexico.

Endangered Species Listed Corals

An on-going challenge for fisheries managers is developing appropriate protection for threatened or endangered species while to the extent practicable maintaining associated fisheries. This problem is exacerbated by continued loss of coral habitat as additional species are considered for protection under the Endangered Species Act (ESA) in both the Atlantic and Pacific. A description was provided of the evaluation process in response to the 2009 petition to list 82 coral species under the ESA. NOAA Fisheries has proposed ESA listings for 66 of these species, 59 in the Pacific and 7 in the Western Atlantic (78 FR 57835). If approved, this will mean seven additional coral species occurring in the Gulf of Mexico will be considered either Endangered or Threatened, requiring development of new species recovery plans and potentially designation of new critical habitat. In addition, the two Western Atlantic coral species (elkhorn and staghorn) already listed under the ESA are proposed to be reclassified from threatened to endangered. Developing solutions may require innovative management ideas coupled with improved mapping and habitat descriptions to identify the full distribution of affected species and identify regions/methods to minimize interactions with fishing activities, if necessary. The Gulf and South Atlantic Councils recently encountered this situation in the Florida Keys reef tract and created a large number of small gear-restricted areas to prevent lobster trap interactions with *Acropora* spp. under ESA protection (GMFMC 2012b).

4.2 Critical Linkages

This theme focused on known connections between corals and coral-dependent/reef-associated fish as well as important habitat influences and inputs (e.g., carbon and algal cover) and wider ecosystem connections.

Connectivity

A connectivity example from the Caribbean described how coral reef fishes move from reefs to seagrasses and mangroves throughout various life stages with a seasonal influence. The Caribbean coastal seascape has a characteristic structure grading from land to mangrove forests, to seagrass beds, to coral reefs, and out to the deep ocean. The physical, chemical and biological interactions resulting from this landscape are critical to the maintenance of overall biological diversity and resilience of the coast and its ability to sustain human uses such as fishing which drive coastal economies. Coral reef fishes move readily across the seascape, using seagrasses and mangroves as nurseries for juveniles, inter-connected by daily and seasonal movements related to feeding and reproduction. Studies using tagging, telemetry, and stable isotope analysis to track the timing and extent of fish movements and dispersal emphatically support the need for new spatial approaches to governance of human uses and management of marine resources according to feeding and reproduction needs. Habitat alterations in one ecosystem will have cascading impacts on the others. It was suggested that management efforts need to consider the role of this larger coastal seascape and that there are spatial and temporal mismatches between the existing scales of ocean governance and the ecological processes and systems they attempt to manage (Figure 4.2.1).

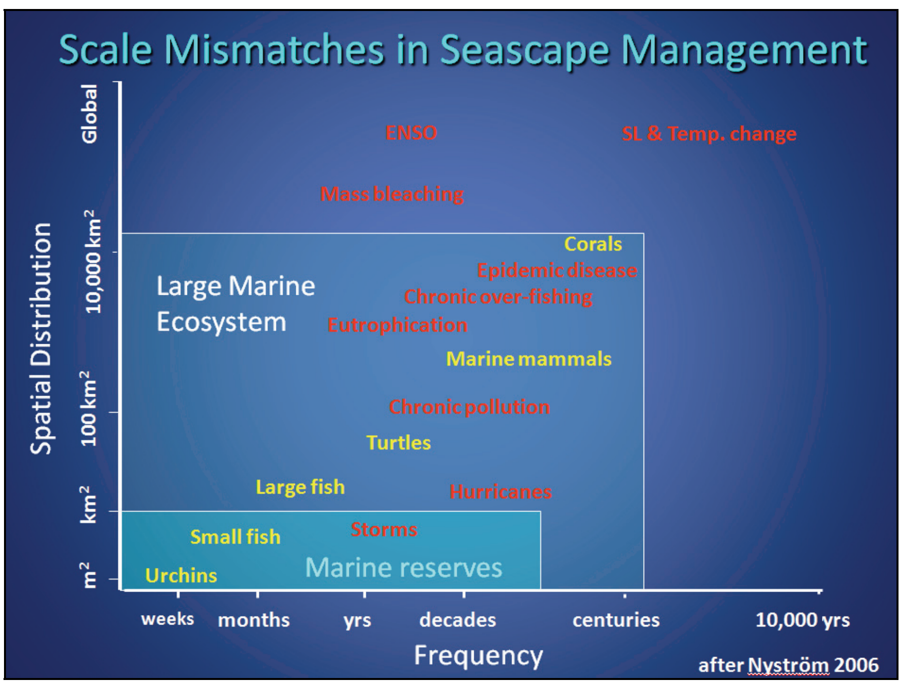

Figure 4.2.1. Spatial and temporal scale mismatches of organisms (lifespan and home range) and potential stressors (duration and spatial extent) (after Nyström 2006 in J. Ogden presentation).

A second example of connectivity was of source/sink dynamics observed in reef fish populations off Puerto Rico. Studies on these reefs demonstrated that deeper mesophotic habitats are also valuable to commercially-important reef fish harvested in shallow-water fisheries at different life stages (Figure 4.2.2). It is likely that similar connectivity patterns occur in other regions (such as Pulley Ridge and the Florida Keys) and these connections are vital for sustainable management of harvested species.

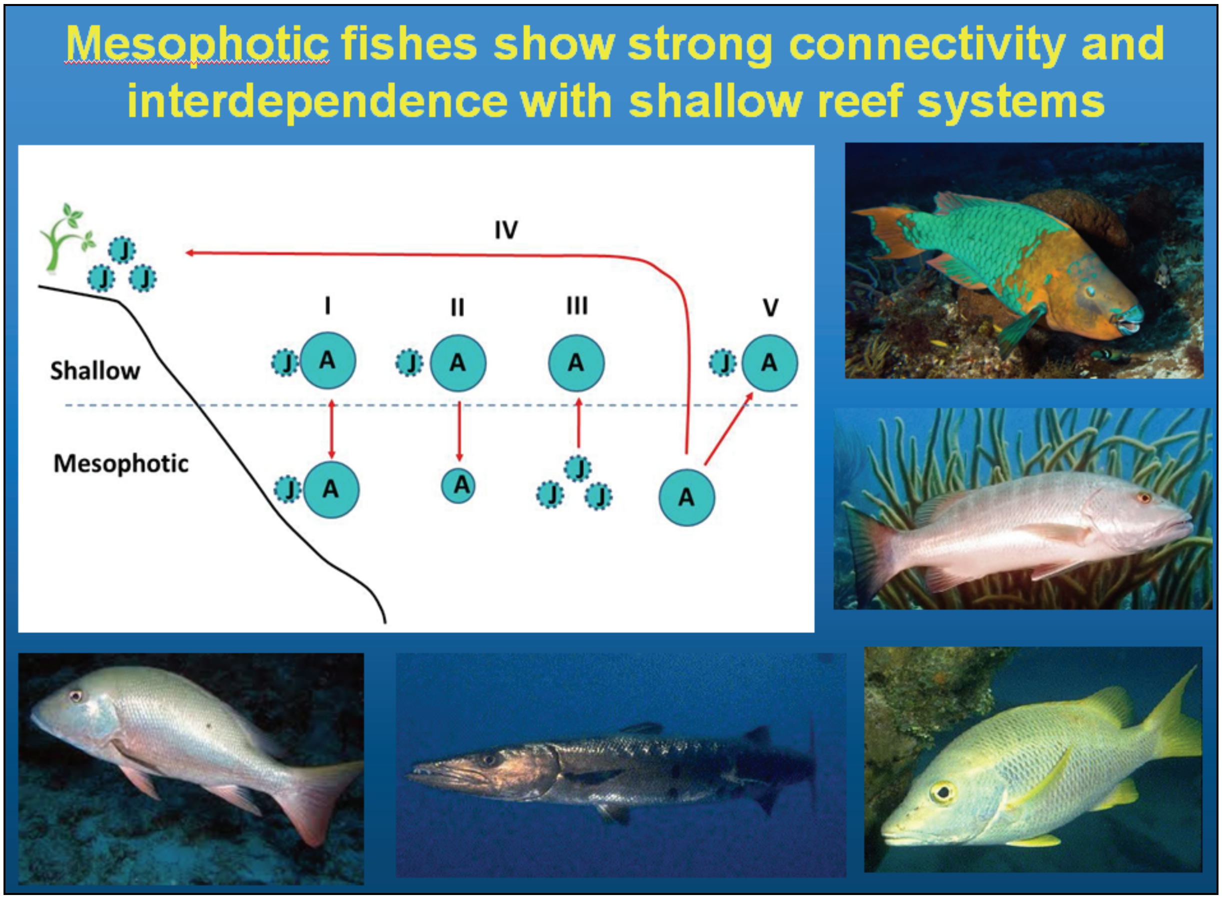

Figure 4.2.2. A depiction of the connectivity of reef fishes from shallow to deepwater reefs off Puerto Rico. A = Adult; J = Juvenile (R. Appeldoorn presentation).

Interdependence of herbivores and coral reef health

Herbivorous parrotfish were used to illustrate the dependent nature that reef herbivores have with coral reef health. Research has demonstrated that parrotfish density was more heavily influenced by habitat quality than by larval supply, and that in turn, a high density of parrotfish was needed in order to maintain reef habitat quality. This case study illustrated the importance of successfully managing herbivorous fishes that are under increasing fishing pressure as other higher trophic level species have become depleted.

Another example of interdependence and critical linkages discussed was the future of coral reef fisheries and the general status and trend of reef fisheries globally. Workshop panelists discussed specific linkages between corals and various fish species, providing evidence that fish respond negatively to coral loss, as conceptualized in Figure 3.1. One of the major threats to coral health was global climate change, and participants discussed which fish species may be most severely impacted by it.

4.3 Deepwater Coral

A great deal of research has been performed on Gulf deepwater and mesophotic corals in recent years, including information on potential deepwater coral associated fisheries. Deep (> 300 m) reef habitats in the Gulf of Mexico include complex structures formed by deepwater corals, emergent rock formations, authigenic carbonate (generated as a byproduct of microbial metabolism of methane) and artificial structures (shipwrecks, oil platforms). These hard-substrates occur throughout the Gulf and the deepwater corals that colonize them play an important role in increasing habitat complexity. The branching scleractinian (stony) coral *Lophelia pertusa* is a flagship species for deepwater corals as it is the only deepwater coral that forms complex reef structures in the Gulf of Mexico. These long-lived, fragile coral colonies provide habitat for abundant and diverse invertebrate and fish communities. The known depth distribution of *L. pertusa* in the Gulf of Mexico is fairly narrow (approximately 380 – 650 m) compared to the octocorals (soft corals, gorgonians) and antipatharians (black corals), which also increase habitat heterogeneity in deep waters (up to ~2500 m in the Gulf). Similar to shallow coral colonies, deepwater corals are also susceptible to anthropogenic disturbances as they are slow growing and long lived (some octocoral and black coral colonies can live for hundreds to thousands of years). Distribution of individual species and broader categories of corals (Figure 4.3.1) is influenced by depth, geology and environmental conditions, with at least six different types of octocoral assemblages occuring in the deep northwest Gulf and the West Florida Slope (250-2500 m). The predominant deepwater black corals *Leiopathes* spp. appear broadly distributed across both regions, but appear to be restricted to the upper slope of the Gulf of Mexico. There are more than 70 species of fishes that have been observed associated with deep-water corals in the Gulf, several of which have potential commercial value. These include barrelfish, wreckfish, and snowy grouper at the shallower sites (< 400 m) and blackbelly rosefish, roughys, and thornyheads at the deeper sites. In addition to potential finfish fisheries, the deep *L. pertusa* reefs support large numbers of golden crab, which was historically fished off the west Florida slope, but is no longer a managed fishery in the Gulf of Mexico. Two deep coral areas in particular have been well studied (Viosca Knoll and the West Florida Slope) (Figure 4.3.2) and appear to support the largest concentrations of deepwater corals, (particularly *L. pertusa*) in the Gulf of Mexico. Most deepwater areas within the Gulf of Mexico have not yet been surveyed for coral habitats, however, predictive habitat modeling can provide an important tool to help identify where such habitats may occur (Figure 4.3.3).

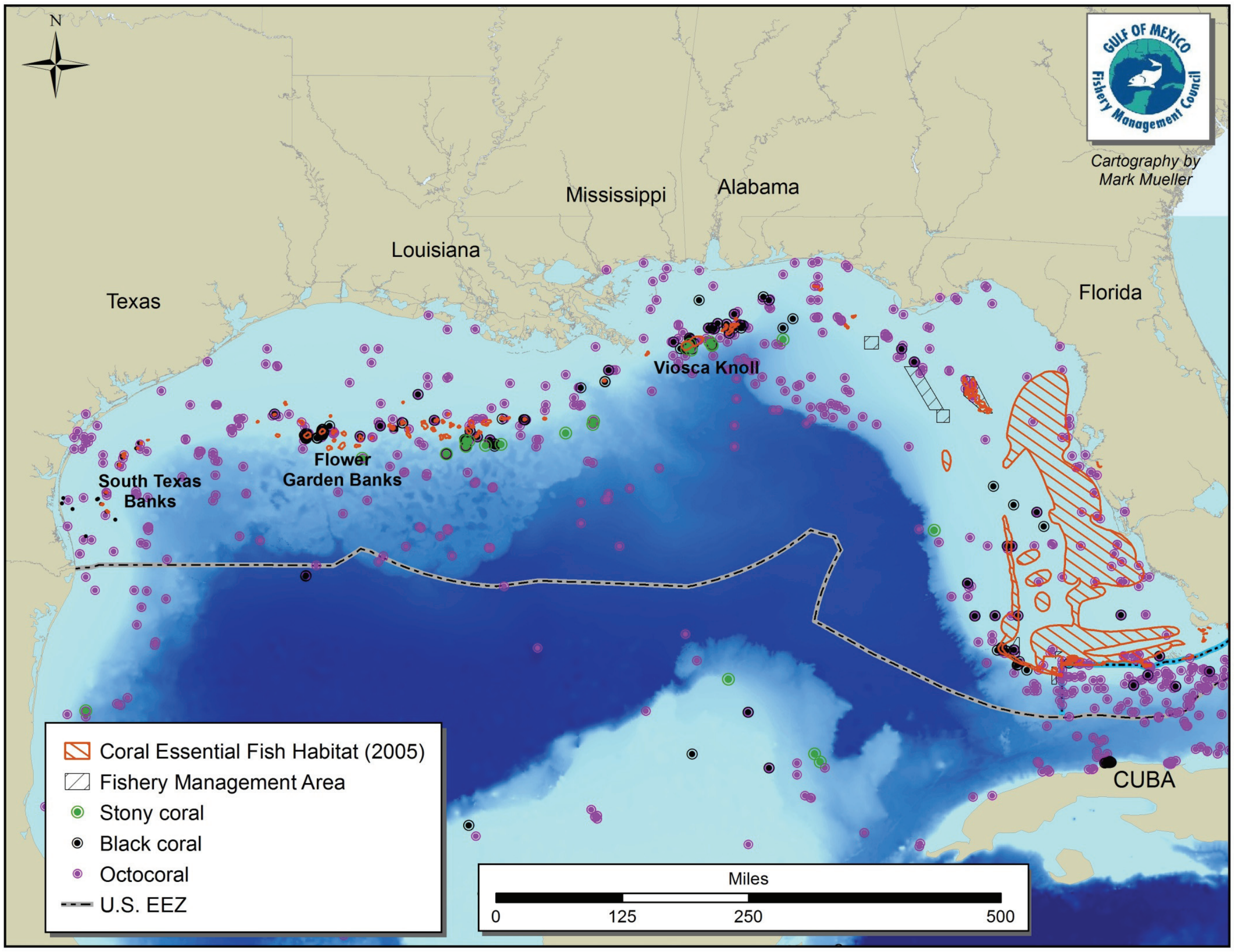

Figure 4.3.1. A preliminary deepwater coral distribution dataset compiled by Etnoyer (2011). Map by Gulf of Mexico Fishery Management Council.

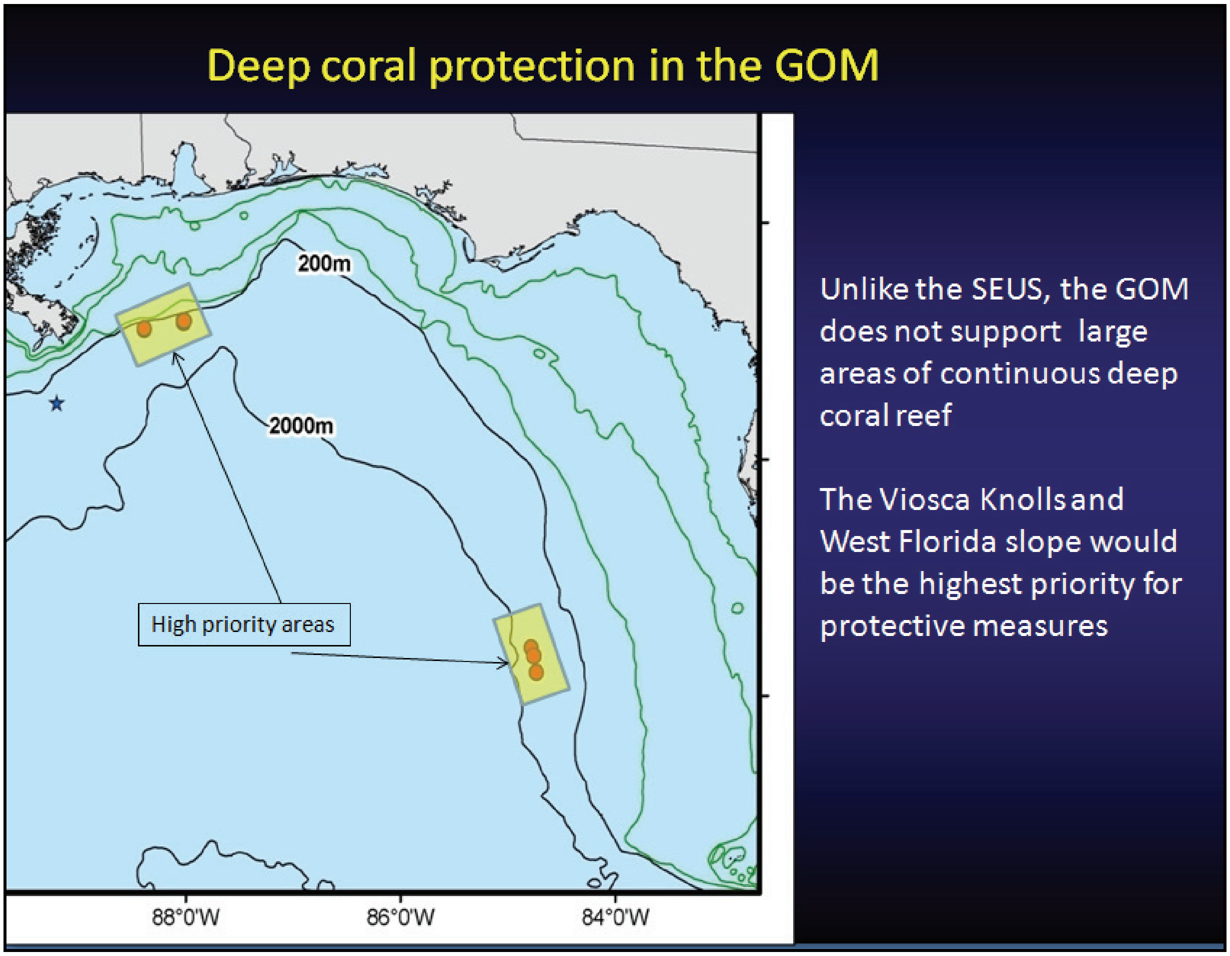

Figure 4.3.2. High priority areas for deepwater coral protective measures (e.g., HAPC) as identified by S. Brooke and S. Ross during the workshop.

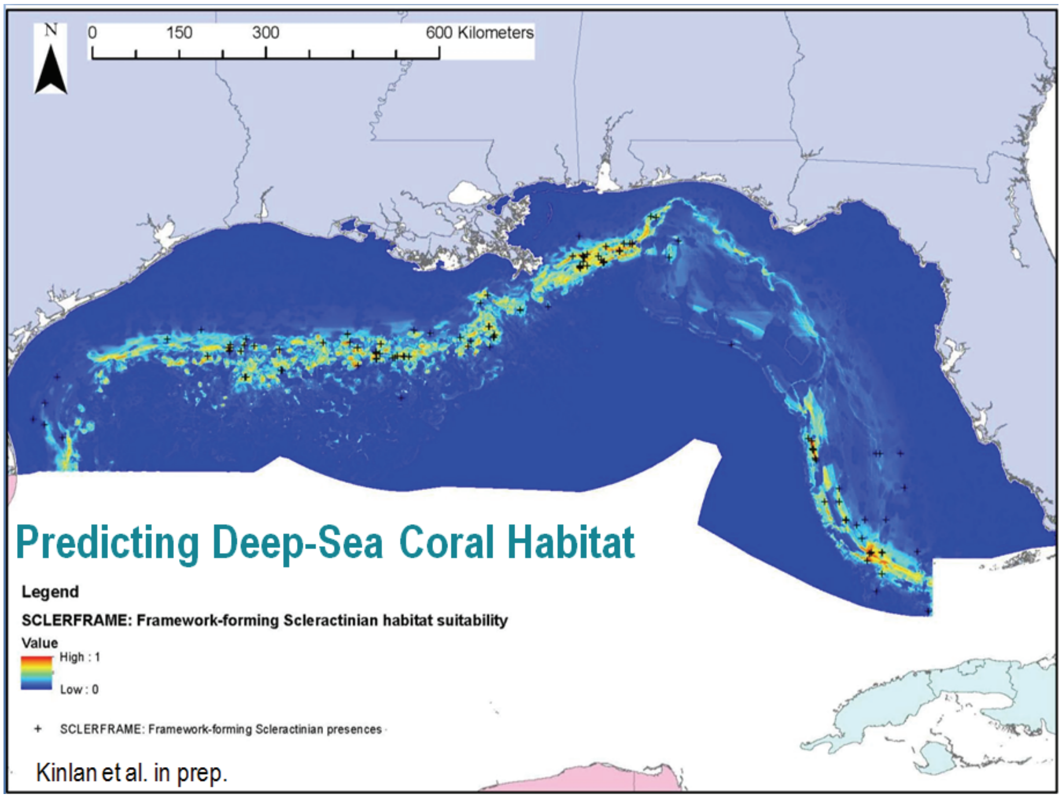

Figure 4.3.3. Preliminary results of one predictive coral habitat suitability model for the deepwater scleractinian coral and actual observed locations (T. Hourigan presentation).

4.4 Threats

Coral ecosystems face a large list of threats to their health and persistence that will impact the productivity of associated fisheries. The ESA Coral Biological Review Team conducted an extensive review of available scientific information and identified ocean warming, disease, and ocean acidification to be the most influential threats in posing extinction risks to the 82 candidate coral species (Pacific and Atlantic) between now and the year 2100 (77 FR 73226). Threats of local origin but having widespread impact included sedimentation, nutrient enrichment, and fishing, and were considered of medium importance in determining extinction risks. NOAA's Coral Reef Conservation Program has more generally identified climate change (including ocean acidification), fishing impacts, and impacts from land-based sources of pollution as primary threats (NOAA CRCP 2009).

Climate change

The broad threat of climate change was addressed by multiple presenters. Coral reefs have been increasingly impacted by bleaching in recent years. Temperature stress on corals is likely to increase in the next several decades, as a result of climate change processes. Global climate models are frequently used to assess potential impacts, but these models have a very coarse spatial resolution. "Downscaled" (localized) climate models for the Caribbean have been used to project temperature, salinity, and current vectors throughout the water column to the year 2100 and similar models for the Gulf will be available shortly. Results predicted increases in water temperatures likely to result in extensive coral bleaching across the region, albeit with large spatial variations. Examining combinations of current reef condition, restoration processes and future stress may be useful for prioritizing resources for coral reef managers.

An example of localized impacts of bleaching to coral reefs and the associated fish fauna was provided from research done around Lee Stocking Island, Bahamas in which bleaching caused a widespread die-off of lettuce coral. Within a year, the dead lettuce coral was overgrown by macroalgae and changes in the fish assemblage were observed. These patterns suggest that mass mortality of corals can negatively affect the demography and community structure of reef fishes associated with corals.

Ocean Acidification

Acidification of the oceans is increasingly recognized as a threat to marine ecosystems including coral reefs. Ocean acidification refers to the ongoing decline in oceanic pH resulting from the uptake of atmospheric carbon dioxide (CO_2). This results from increasing atmospheric carbon dioxide concentrations that are partially absorbed by seawater and converted to carbonic acid. This process has led to a 30% increase in the acidity of surface seawaters. Future predictions indicate that the oceans will continue to absorb carbon dioxide and become even more acidic. A more acidic environment could have a dramatic effect on some calcifying species such as shallow and deepwater corals.

In addition to the direct effects of bleaching and ocean acidification, stressed corals may also be more susceptibile to disease.

Coral Disease
Coral diseases have increased dramatically in frequency, type (Figure 4.4.1), and geographic distribution over the last few decades and are now affecting a wide range of species (Figure 4.4.2).

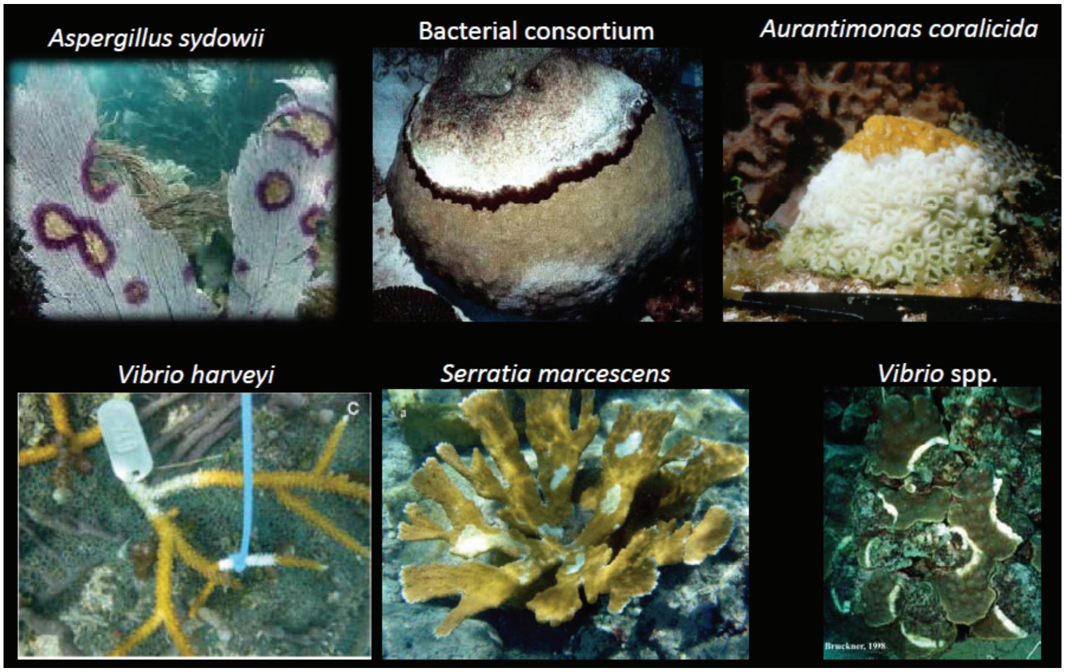

Figure 4.4.1 Photographs of known diseases affecting coral species (E. Muller presentation).

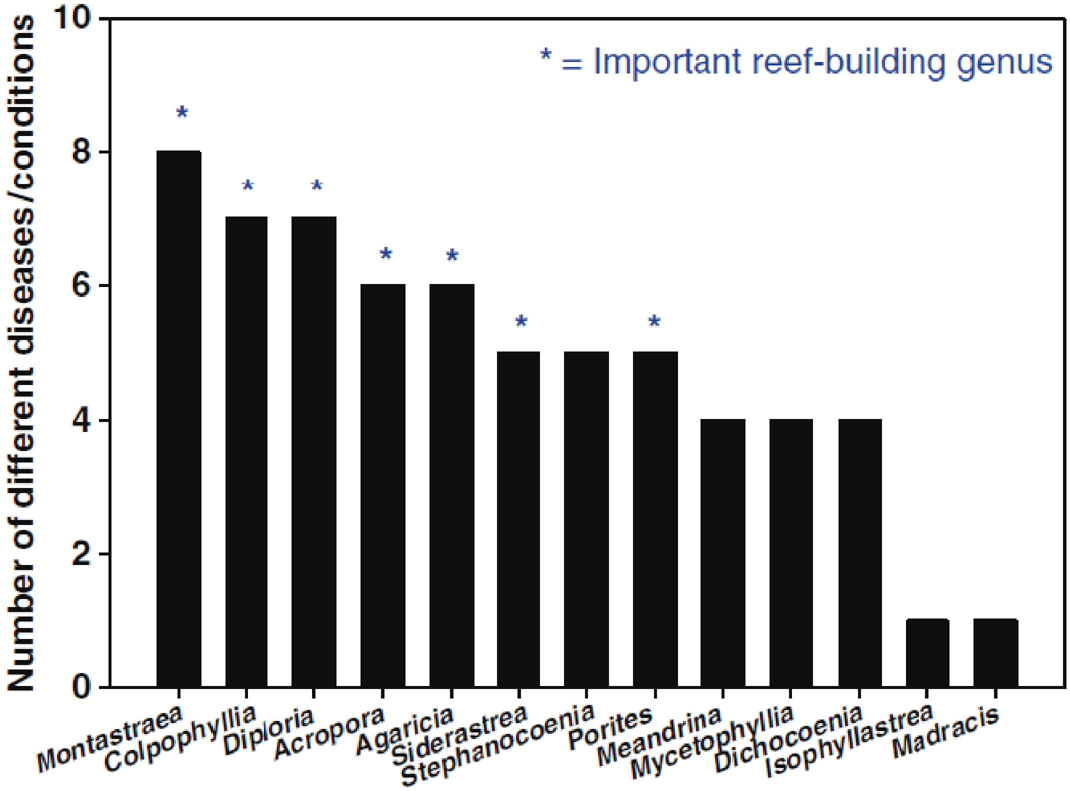

Figure 4.4.2. **Number of different diseases or conditions affecting various species of coral.** Data source: Weil and Rogers (2011).

A study was conducted to test the effects of temperature and pH on the progression rates of black band disease. Results indicated that corals infected with black band disease showed decreased rates of disease progression when exposed to low pH seawater (Figure 4.4.3). Conversely, elevated water temperatures (e.g., > 31^{0}C) increased the progression rates of black band disease. Therefore, low pH may mitigate the virulence of some coral diseases, but increased virulence under high water temperatures has the potential to supersede these effects. Experimental results demonstrate the linkages among environmental components and organisms and the potential for unpredictable or cascading effects through ecosystems.

Figure 4.4.3. **Example coral infected with black band disease** (E. Muller presentation).

Overfishing and synergistic effects on resiliency

Overfishing is another potential threat to coral reefs and associated ecosystem services. This would be particularly true if herbivorous fish that help to control macroalgae are harvested in greater numbers in the Gulf of Mexico, as they are elsewhere in the world where higher trophic level species have been depleted. In the Caribbean, over-harvesting of herbivorous fish in combination with other stressors such as nutrient pollution and losses of urchins and fast-growing corals has reduced the resilience of reefs and their ability to construct fish habitat. Reducing local impacts such as overfishing of species important to coral reef functioning may help improve coral resiliency to larger global threats such as climate change.

Invasive Species

Indo-Pacific lionfishes (*Pterois volitans* and *P. miles* [Family Scorpaenidae]) are the first non-native marine fishes to establish in the Western North Atlantic. Lionfish are long-finned reef-associated species that are widely distributed throughout the western Pacific. Lionfish were first confirmed in the United States in 1985 (Dania, Florida) and since that period have rapidly spread in distribution and increased in abundance (Figure 4.4.4). Lionfish are now considered established off the Atlantic coast of the United States, Gulf of Mexico, Bermuda Island, the Bahamas, Turks and Caicos Islands, Cuba, Jamaica, Dominican Republic, Puerto Rico, Mexico, Honduras, and Costa Rica. Lionfish are present, but not considered established in the U.S. Virgin Islands, Belize, Panama, and Colombia although their range continues to expand. In the U.S., the lionfish has rapidly increased in abundance and is now as abundant as many native grouper species in the Atlantic Ocean. There is a growing concern about effects of lionfish on coral reefs and fishes due to their ability to compete with native species for prey, rapid growth rates, and lack of natural predators in their invasive habitat.

Invasive lionfish are an increasing threat to a number of reef-associated fisheries in the U.S. Atlantic, Caribbean, and Gulf of Mexico including herbivorous reef fishes that sustain coral reef health by controlling macroalgae growth. On a positive note, grouper can disrupt lionfish foraging success, demonstrating an important ecological benefit to healthy grouper populations on coral reefs.

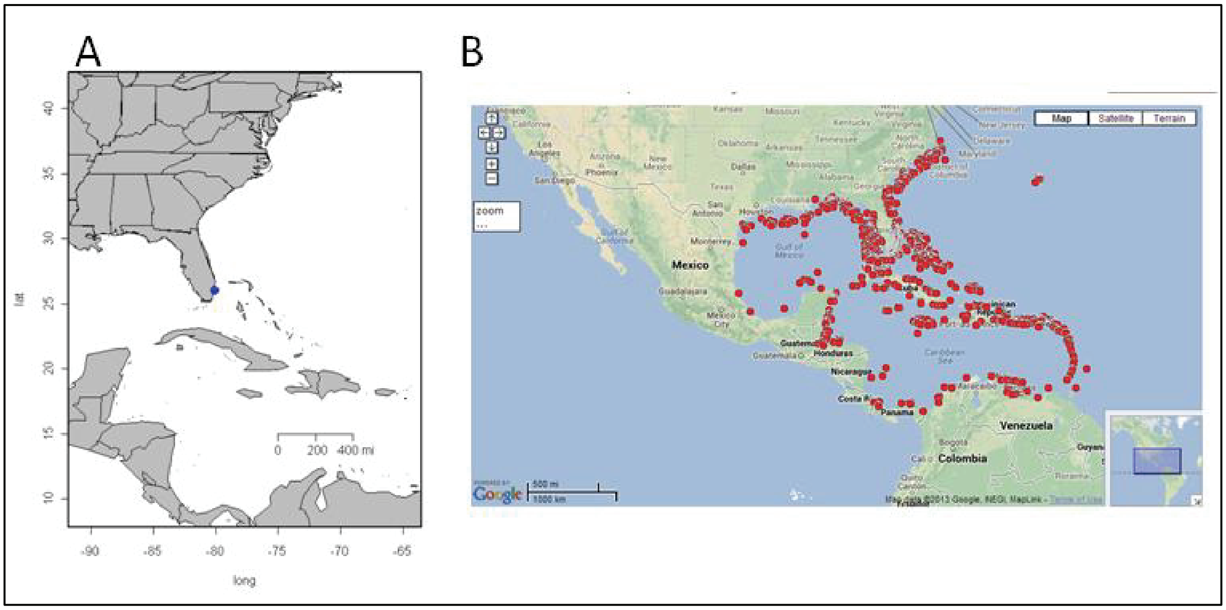

Figure 4.4.4. **A) Distribution of lionfish in 1985 (blue dot), B) compilation of lionfish sighting reports in North America from 1992 through 2011 (red dots) demonstrating the dramatic increase in number and geographic range.** Source: http://nas.er.usgs.gov/taxgroup/fish/lionfishdistribution.aspx

Deepwater Coral Threats
There is potential for negative impacts to deepwater coral. Energy industry extractive activities are a concern, as are fishing gear impacts (e.g., any potential increases in royal red shrimp trawling, reactivation of the golden crab trap fishery and/or increased 'deep drop' fishing for reef fish). Careful consideration must be given to any activities that may interact with deepwater coral in order to maintain coral health and associated fisheries productivity. Some notable potential threats were presented as shown in Figure 4.4.5.

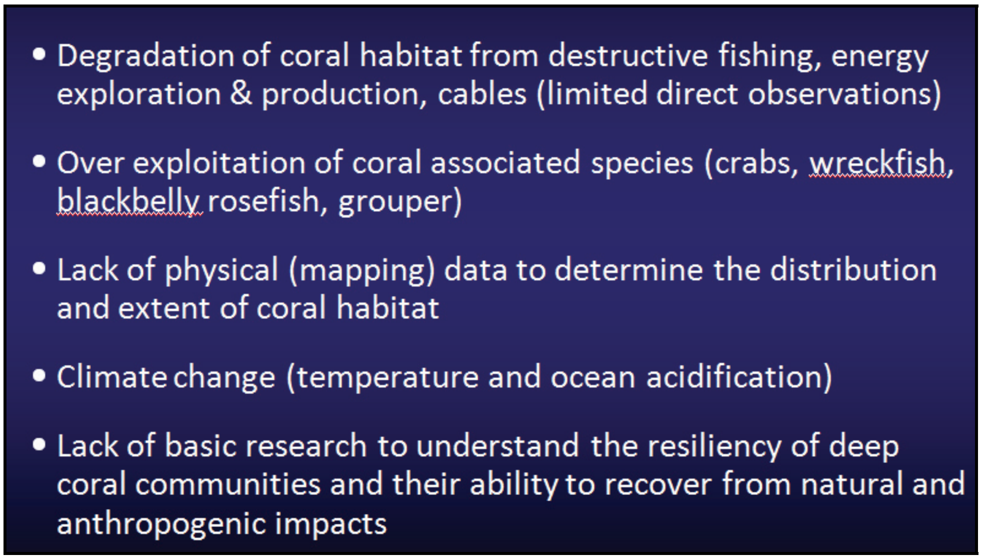

Figure 4.4.5. Potential threats to deep coral ecosystems in the Gulf of Mexico (S. Brooke and S. Ross presentation).

4.5 Spatial Ecology

In nature, organisms are distributed neither uniformly nor at random, forming instead three or four dimensional spatial patterns dependent on habitat structure and function. Spatial ecology is focused on the identification of spatial patterns and their relationships to ecological phenomena. With detailed information about, for example, a species' life-stages, dynamics, demography, movement, and behavior, ecological events can be explained through the application of spatial statistical models. In marine settings, this technique is used to answer questions about changes in distribution, abundance, or diversity (e.g., organisms such as corals) in relation to environmental conditions, disturbance events, or human activities. Spatial modeling provides a cost-efficient and practical analytical tool to fill spatial data gaps and examine macro-ecological relationships.

A spatial modeling study was described that examined changes in Caribbean reef complexity and structure associated with coral reef decline. This type of "reef flattening" can have substantial impacts on reef fish abundance and distribution with corresponding changes in fishery yields and ecosystem services (Figure 4.5.1), although in the Gulf of Mexico some coral structures are formed on geological edifices less prone to collapse.

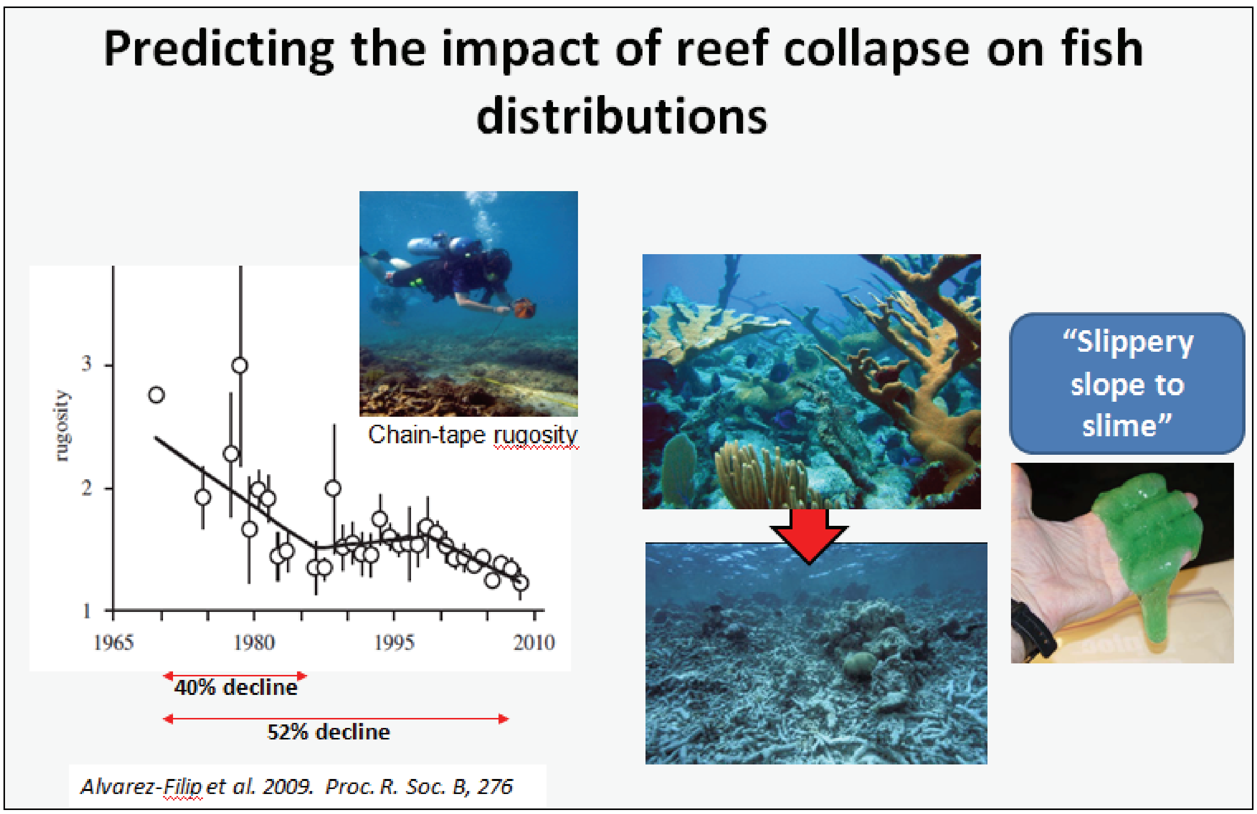

Figure 4.5.1. Reductions in coral reef complexity/structure over time. This trend can have detrimental impacts on coral reef fishes and associated fisheries (S. Pittman presentation).

Council staff are developing a spatial database focused on Gulf of Mexico corals and associated fisheries in order to provide readily-accessible baseline information for analyses and management decisions by the Council, NOAA Fisheries, and other interested users (Figure 4.5.2). Some of the datasets compiled so far have suggested potential refinements to the spatial representation of coral EFH to more accurately reflect the actual distribution of coral. For example, rocky dominant bottom sediments such as those shown in Figure 4.5.3 may provide suitable substrate for coral settlement, yet much of the current coral EFH boundary does not include these areas.

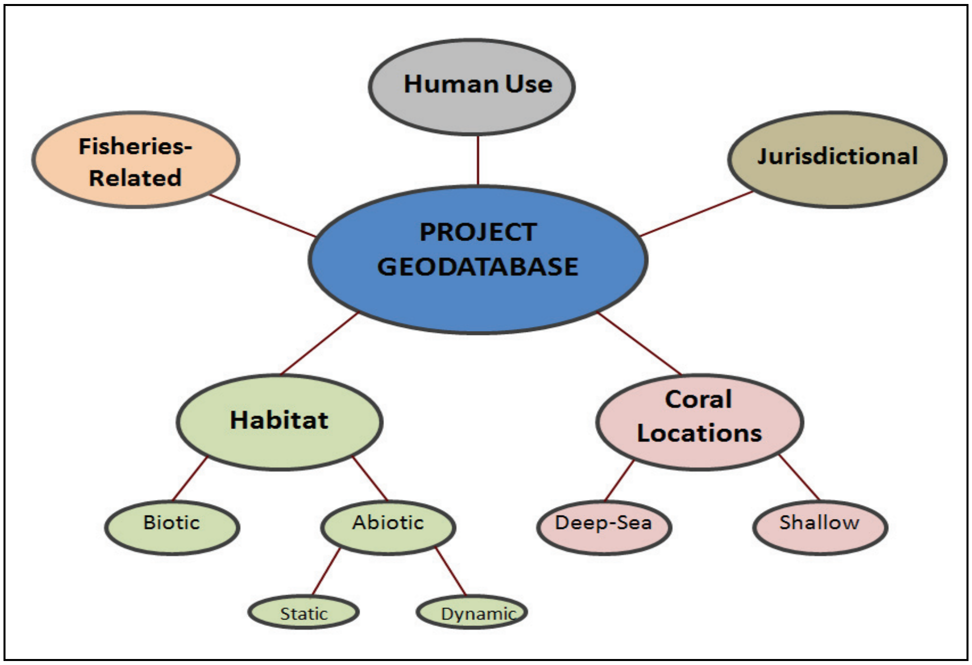

Figure 4.5.2. Schematic diagram of the spatial database in development to support improved coral and reef fish management by the Gulf of Mexico Fishery Management Council (M. Mueller & J. Froeschke presentation).

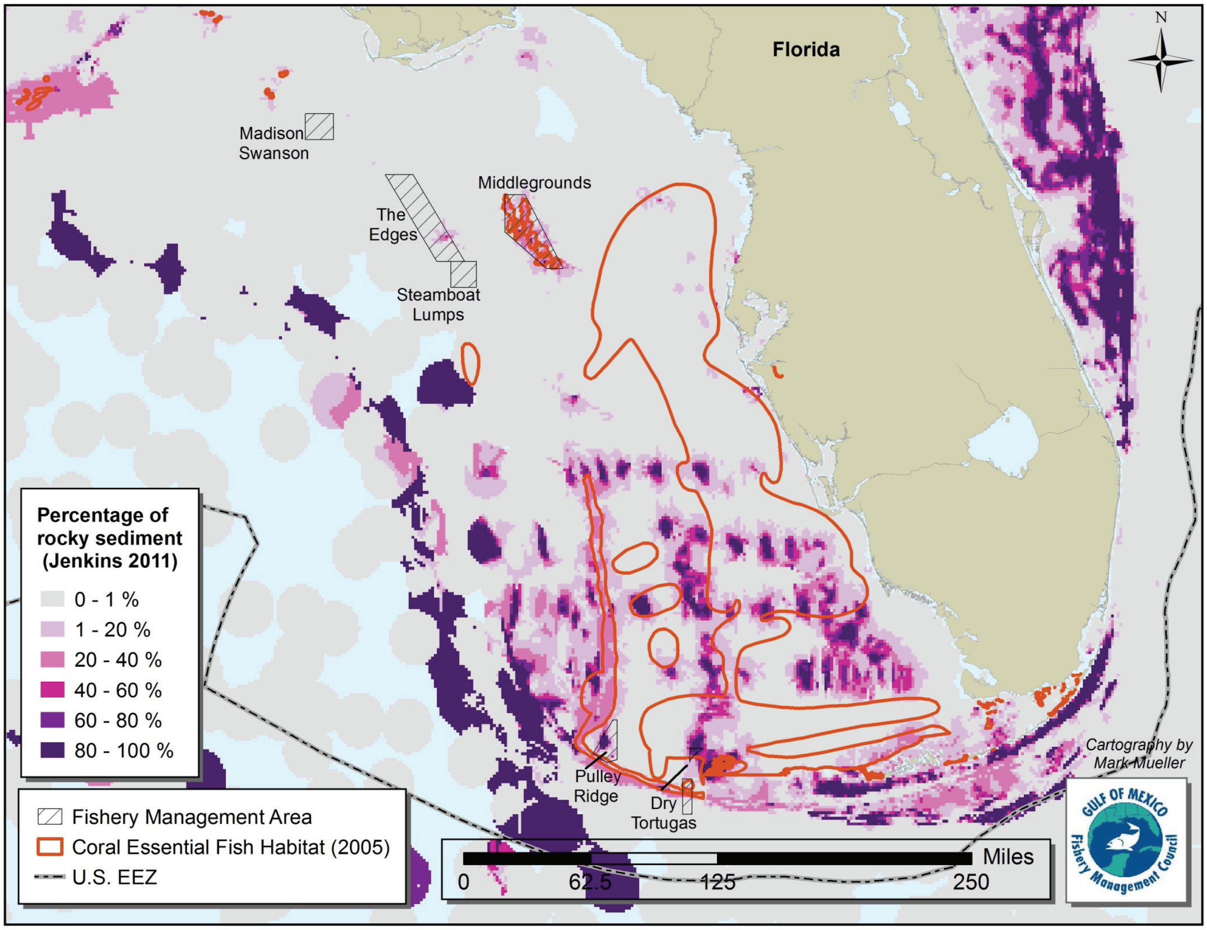

Figure 4.5.3. Map of Coral Essential Fish Habitat and rocky bottom sediments as described in Jenkins (2011) (M. Mueller & J. Froeschke presentation).

4.6 Consequences

This theme explored the short and long-term impacts of the various threats to coral health.

Deepwater Horizon Oil Spill Impacts
A major focus throughout the workshop was the 2010 Deepwater Horizon oil spill's impact on corals and fisheries. Information on detailed impacts that have been measured on reef fish community structure, recruitment, and size was presented, along with recommendations to help fill in knowledge gaps.

Known and potential oil spill impacts to coral and reef fish EFH, the restoration process, and various funding sources resulting from oil spill civil and criminal penalties were discussed. Restoration recommendations from a Marine Restoration Workshop (http://www.research.usf.edu/absolute-news/templates/gomurc-template1.aspx?articleid=333&zoneid=32) that relate to coral ecosystems and associated fishery species included:

- Supplement existing and develop new fishery-independent surveys.
- Implement more timely reef fish catch estimation in recreational fishery by funding 1-month sampling periods or shorter over a 10-year period.
- Fund only scientifically sound marine restoration projects
- Support offshore marine restoration projects to complement coastal restoration program
- Expand restoration options in view of complex nature, offshore origin and ecosystem-wide scale of disaster, e.g., include support for compensatory research and resource management actions
- Dedicate funds remaining from Natural Resource Damage Assessment (NRDA) early restoration and resolution of legal claims to support endowment for long-term Gulf-wide observing, monitoring, mapping and research program that supplements project-level monitoring required under NRDA.

Socioeconomic consequences of reef health decline
Socioeconomic consequences of declining reef health and effectiveness of resource management measures were discussed based on work conducted in the Caribbean. This study focused on understanding the relative importance of threats to coral reefs including climate change, and the implications for livelihoods. Management tool effectiveness was also evaluated and used for recommendations to improve management throughout the Caribbean. Better understanding and integrating social information and how future changes in reef condition will impact coastal communities can contribute to improved management for sustainable fisheries, fisheries-dependent livelihoods and adaptive capacity.

4.7 Mitigation

Given the variety of threats to corals, there is growing interest in developing mitigation strategies. Two potential approaches are replacing lost coral reefs with artificial reefs and culturing corals to rebuild coral reefs.

Artificial reefs
Patterns of coral occurrence on offshore oil and gas platforms in the Gulf of Mexico were discussed. Petroleum platforms serve as both sources and sinks for larval dispersal by hermatypic and ahermatypic coral (including the common invasive species orange cup coral, *Tubastraea coccinea*), with important connections to the Flower Garden Banks. It is possible that these platform coral colonies may help promote the long-term stability of coral communities in the northern Gulf of Mexico where the presence of the many oil and gas platforms (3,228 active and 777 non-producing as of March 2012 according to Bureau of Safety and Environmental Enforcement data) has contributed to an expansion in coral range. However, concern was raised because many artificial reefs are dominated by non-native corals that may be exacerbating problems with invasive species (possibly including reef associated lionfish). Given the broad distribution of these structures it is also possible for them to serve as vectors for dispersal for both native and invasive coral species.

A controlled study comparing shallow water artificial reefs and natural coral reefs found that fish species richness and abundance (all species combined) was relatively greater on the natural reefs compared to artificial reefs. The results suggested that artificial reefs with structural complexity and other abiotic and biotic features similar to those of natural reefs can best mitigate in-kind losses of reef fish populations and assemblages from natural reefs (Carr and Hixon 1997).

Coral culturing
A report was given on *Acropora* spp. coral culturing and nursery efforts by the Coral Restoration Foundation in the Florida Keys. One impetus for this work is that *Acropora* spp. provide essential habitat for prey and target species of commercially important fish, and restoring their populations will increase the overall productivity of the surrounding areas . Nursery techniques have improved to the point that substantial numbers of these fast growing corals can be propagated and successfully replanted onto suitable reef sites; the scale is limited by funding. Restoring coral reefs would require substantial effort in terms of the number of species to be cultured and the number of individuals required to grow a reef. Some workshop participants cautioned that any efforts toward replanting *Acropora* spp. may be futile if the underlying causes of coral mortality on the reef are not addressed.

4.8 Future Research Priorities

This final theme was explored through a panel discussion. Panelists provided detailed written "vision statements" as discussion prompts. For example, "what are the highest priority research needs for support of ecosystem-based management of coral ecosystems and associated fisheries?" The panel noted that outstanding research questions include:

- What is the extent and interconnectivity of coral habitats?
- What is the extent of fishing pressure on these habitats and its likely trophic and habitat effects?
- How might expected future change factor into these effects?

It was discussed that a transition to ecosystem-based management would benefit from:

- A more explicit spatial understanding of coral habitats at the scale of the whole Gulf.
- Studies that look at similar ecosystems with and without fishing – highlighting the key role of no-take reserves as a paradigm for both research and possibly resilience.
- Incorporating these results into models to explore plausible scenarios of change.

A summarized list of the panel's priority research needs is given below:

- Artificial reefs versus natural reefs—design artificial reef programs that do not promote overfishing of targeted fisheries.
- Expanded and improved habitat maps through new efforts and proactive campaign to acquire and integrate past surveys (e.g., oil and gas surveys).
- Experiments to assess integrated means of restoring and improving coral reef resilience and condition, for example, application of closed areas, manipulations to ratio of herbivores and predators, and primary restoration efforts (e.g., transplants).
- Lionfish must be addressed—no easy solution but need to attempt control of the population, possibly via removals.
- By an adaptive process, implement ecosystem-based fisheries management at required scales from local patch reefs to Large Marine Ecosystem.
- Develop the marine spatial planning tools that are required for ecosystem based fisheries management, for example, to inform area closures and develop networks of research reserves.
- Improve evaluation of fisheries-related ecosystem services
- Continue development and education/training related to ecosystem models for management strategy evaluation.
- Genomics research to define metapopulation boundaries and connectivity across and outside Gulf region (Caribbean basin); knowledge required to inform stock assessment and spatial management efforts.
- Improve assessment of fishing pressure and impacts of reductions on coral ecosystems.
- Expand research operational capabilities in region, especially for mesophotic and deep coral ecosystems, e.g., access to research vessels and *in situ* ocean technologies.

Deepwater coral future research priorities

Identification and description of deepwater coral habitat is an on-going effort (e.g., Figure 4.8.1). New discoveries include scleractinian species *Lophelia pertusa, Madrepora oculata*, *Enallopsammia profunda*, antipatharians (black corals), octocorals (gorgonians and soft corals), hydrocorals and sponges, all of which provide structure to support a diverse and abundant associated community. Observations suggest that deepwater coral reefs concentrate biota much as shallow reefs do and research has documented 55 species of fishes utilizing deep Gulf of Mexico reefs, and at least 30 of these species appear to have an obligate association with reef habitat.

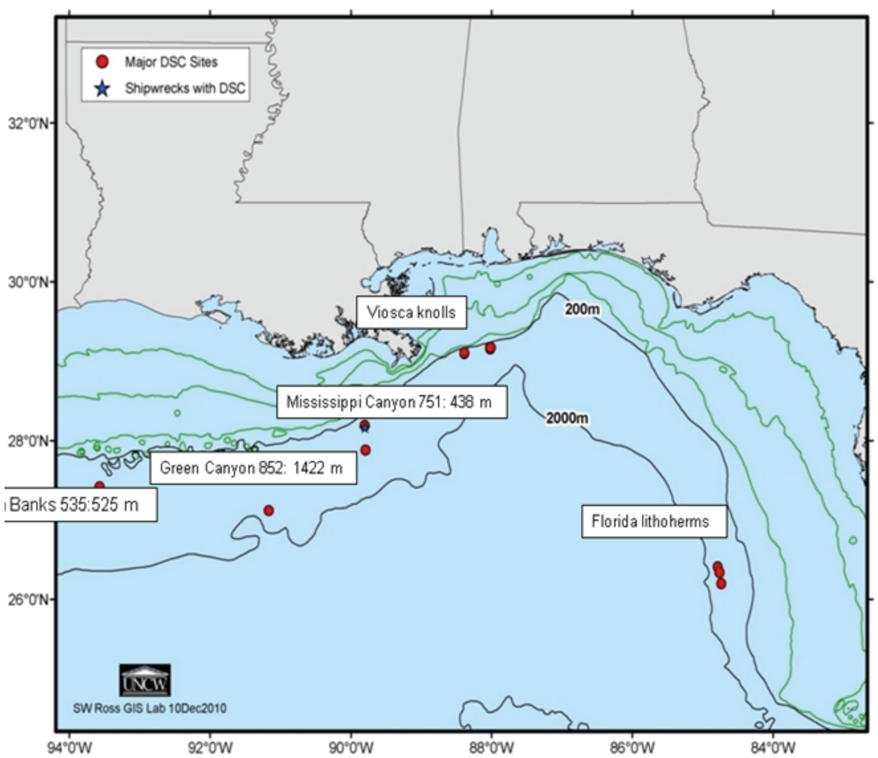

Figure 4.8.1. Recently discovered deepwater coral sites (S. Brooke and S. Ross presentation).

CHAPTER 5. CONCLUSIONS AND NEXT STEPS

Overall, more and better quality data are needed to better answer research and management questions. For example, there was general agreement that the spatial representation of coral EFH should be updated using better information that is now available, and that these types of efforts should be ongoing. Improving the spatial description of coral EFH would ensure that important coral habitats receive the benefits associated with EFH designation and would aid in prioritization of conservation and management efforts by removing areas currently designated as EFH that are actually unsuitable for corals.

There were recommendations to continue obtaining and integrating better habitat and ecological data (especially spatially-explicit data) into management decisions, specific recommendations were for:

- A comprehensive mapping initiative using multi-beam acoustics and ground truthing of fish-habitat relationships in the Gulf of Mexico as a basis to stratify *in situ* sampling and to assess the condition of reef features.
- Improved monitoring of habitat status and trends (benthic and fish community structure).
- Use of high resolution fishery-dependent catch and effort data to better understand the impacts of fisheries on fish populations.
- Development of rapid, *in situ* assessment methods for reef fishes that allow more frequent and timely stock assessments.

Workshop participants suggested that better information was needed about specific fishing impacts to coral in the Gulf of Mexico and that researchers and managers need to improve our ability to detect (and adjust for) negative coral impacts, and to better identify and quantify threats to coral persistence.

Workshop participants recommended designation of new Habitat Areas of Particular Concern with bottom contact gear restrictions to protect deepwater coral aggregations. Sites named specifically included Viosca Knoll 826 and 862/906 in the northwestern Gulf, and a portion of the west Florida Slope (Figures 4.3.2 and 4.8.1). These areas would qualify for protection under the discretionary provision of the Magnuson-Stevens Act (2006 re-authorization Sec. 408) that allows for restriction of bottom tending gear in known deepwater coral habitat.

In the context of oil spill restoration priorities, several workshop participants urged the Council and NOAA Fisheries to support an offshore focus when prioritizing restoration projects, rather than favoring coastal projects, since so much of the ecological impact occurred far offshore and because early indications suggest that many project proposals being submitted are coastal and terrestrial. There were specific recommendations that the Council:

- Continue to inform NRDA trustees and other Deepwater Horizon oil spill penalty-funded programs about the Gulf Council's preferred options to aid recovery of impacted fishery and coral resources and EFH

- Partner with the Gulf States Marine Fisheries Commission, fishermen, and scientific community to develop innovative restoration options for coral ecosystems--shallow, mesophotic and deepwater--for funding consideration by the RESTORE Act sections 1603, 1604, and 1605 programs, and other funding sources.

This workshop established a "knowledge baseline" of our collective understanding of the relationships between coral health and associated fish populations. These relationships are often complex and/or indirect, but they do exist. The same can be said for the many serious threats to the long-term health and productivity of corals and coral-associated ecosystems. Many of the most relevant questions are not yet fully answered, but several workshop participants described promising methods that can be used to help fill the missing gaps in our knowledge.

Many of the workshop participants are contributing related chapters to a peer-reviewed, edited book that will continue adding to the collective knowledge of this subject and hopefully will serve as a useful reference for scientists and managers alike.

The relationships established between Council staff, workshop participants, and other researchers and managers as a result of this workshop have already and will continue to lead to improved data sharing and collaboration. For example, several new datasets from participants have been added to the spatial baseline compilation, and two of the presenters with relevant experience were recently added to the Council's Special Coral Scientific and Statistical Committee. Such resources and expertise, and the information provided throughout this workshop, will help the Council and partners improve management of coral and fishery resources throughout the Gulf.

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APPENDIX 1: WORKSHOP FLYER

Workshop on Interrelationships between Coral Reefs and Fisheries

Hilton Westshore
May 20 - 22, 2013
Tampa, Florida

This workshop will address questions about the current & future status of fisheries that depend on healthy coral ecosystems.

Agenda Highlights

Monday May 20, 2013

- Introductions & Purpose
- Distribution & Diversity of Corals
- Coral Management
- Management Needs Panel Session
- Plenary Speaker (Peter Sale)

Tuesday May 21, 2013

- Critical Linkages
- Threats - Research Presentations & Panel
- Deep Sea Coral - Research Presentations & Panel

Wednesday May 22, 2013

- Spatial Ecology
- Consequences
- Mitigation
- Future Research Panel

Visit http://gulfcouncil.org/council_meetings/panel_committee_meetings.php **to view the full agenda.**

Presenters will include:

Peter Sale - *Assistant Director, United Nations University, Institute for Water, Environment & Health*

John Ogden - *Professor Emeritus, University of South Florida*

Mark Hixon - *Professor, University of Hawai'i*
Mark Hay - *Professor, Environmental Biology, Georgia Tech*

Tom Hourigan - *Chief Scientist, DSC Research & Tech. Program, NOAA Habitat Cons.*

Steve Ross – *Assoc. Professor, University of North Carolina Wilimington*

Jerry Ault - *Professor, Marine Biology & Fisheries, University of Miami*

Peter Mumby - *Professor, ARC Centre of Excellence Coral Reef Studies, Univ. Queensland*

Steve Murawski - *Professor, Biological Oceanography, Univ. South Florida*

Simon Pittman - *Landscape Ecologist, NOAA Biogeography Branch*

For more information contact Dr. Steve Bortone, Executive Director - steve.bortone@gulfcouncil.org, Workshop Coordinator Mark Mueller - mark.mueller@gulfcouncil.org, or call 813-348-1630.

Organized by the Gulf of Mexico Fishery Management Council

Funding provided by:

NOAA CORAL REEF CONSERVATION PROGRAM

APPENDIX 2: FINAL AGENDA

Day 1	#mins	Speaker(s) / Affiliation / Title	Presentation Title	General Topic
Monday, May 20				
1:00 PM	5	***INTRODUCTIONS (Mueller)***		
	15	Steve Bortone, GMFMC Exec. Dir	*The Importance of Being Coral: (from a Fisheries Perspective)*	Purpose
	15	C. Simmons/A. Collins/R. Ruzicka/, GMFMC/FWRI--Deputy ED/Coral Manager/Asst. Res. Sci.	*Distribution and Diversity of Coral Reefs and Associated Fisheries in the Gulf of Mexico*	Distribution
	15	GP Schmahl, Flower Garden Banks NMS--Superintendent	*Coral reefs and coral communities of the northwestern Gulf of Mexico*	Management
	15	Jerry Ault, U. Miami RSMAS--Professor	*Stock assessment in Data Poor Situations: Length-Based Approaches for Coral Reef Fisheries*	Management
	12	Jennifer Moore, NMFS PRD SERO--ESA Coral Coordinator	*Proposed ESA Listing Determinations for 82 Coral Species*	Management
	12	Graciela Garcia-Moliner, Carib. FMC--Habitat & Fishery Mgmt. Plan Specialist	*Management of reef fisheries in the Caribbean*	Management
	12	[Sandra Brooke for Anna Martin, SAFMC]	*Council perspectives on implementation of coral protected areas*	Management
BREAK 3:00 PM	*15*			
	12	Marlowe Sabater, Western Pacific FMC--Marine Ecosystem Scientist	*Application of the Catch-MSY Approach in Specifying Annual Catch Limits for Coral Reef Fishes in the Western Pacific Region*	Management
	15	Tom Hourigan, NMFS OHC--Chief Scientist DSC Research & Technology	*Fisheries Impacts and Deep-Sea Coral Ecosystems: International & National Context*	Management
	35	***DISCUSSION PANEL--Management Needs (Bortone, Ruzicka, Schmahl, Ault, Moliner, Ross, Moore, Hourigan, Sabater). MODERATOR--Carrie Simmons***		Management
4:30 PM	45	Peter Sale, United Nations Univ. INWEH--Asst. Director	*Tipping, sliding, or doing just fine – the possible futures for coral reef fisheries*	Plenary

Day 2	#mins	Speaker(s) / Affiliation / Title	Presentation Title	Topic
Tuesday, May 21				
8:30 AM	25	Peter Mumby, U. Queensland, ARC Centre Professor	*Managing sustainable Caribbean fisheries during climate change*	Critical Linkages
	15	John Ogden, Univ. South Florida--Professor Emeritus	*Interaction of Ecosystems in the coastal seascape: implications for science, management and conservation*	Critical Linkages
	15	Mark Hay, Georgia Tech--Teasley Professor of Environ. Biology	*Fishing, reef herbivores, and the cascading effects that undermine reef resilience*	Critical Linkages
	15	Richard Appeldoorn, U. Puerto Rico--Puerto Rico	*Habitat shifts and ontogenetic migrations of herbivorous reef fishes: from mangroves to the mesophotic*	Critical Linkages
	15	Andrew David, NMFS SEFSC--Research Fishery Biologist	*Northeast Gulf of Mexico Reserve Program: Monitoring changes in reef fish populations*	Critical Linkages
BREAK 10:15 AM	*15*			
	30	Mark Hixon, U. Hawai'i--Professor	*1) Effects of Coral Bleaching on Reef Fishes in the Bahamas + 2) Update: Invasion of Atlantic Coral Reefs by Pacific Lionfish*	Threats
	15	Barbara Muhling, U. Miami/NMFS SEFSC--Associate Scientist	*Management and conservation of coral reefs and marine resources in the Caribbean Sea under future climate change scenarios*	Threats / Management
	12	Erinn Muller, Mote Marine Lab--Postdoctoral Fellow	*Effects of ocean acidification and climate change on coral reef health and disease*	Threats
	12	Virginia Garrison, USGS--Research Ecologist	*Pollution and coral reefs*	Threats
	12	Kim Ritchie, Mote Marine Lab--Senior Scientist	*Toxicity of Deepwater Horizon oil and dispersant on Caribbean coral larvae*	Threats
LUNCH	*60*			

Day 2	#mins	Speaker(s) / Affiliation / Title	Presentation Title	Topic
Tuesday, May 21				
	45	***DISCUSSION PANEL--Threats & Responses (Mumby, Hixon, Muhling, Ritchie, Murawski). MODERATOR: Walt Jaap***		Threats
	25	[Tom Hourigan for P. Etnoyer & A. Quattrini]	*Forests in the deep: Octocoral and black coral habitats in the Gulf of Mexico*	Deep Sea Coral
	15	John Reed, FAU-Harbor Branch--Research Scientist/Professor	*Exploring shelf frontiers: vulnerable deep and mesophotic coral/sponge ecosystems*	Deep Sea / Mesophotic
BREAK 2:45 PM	*15*			
	15	Steve Ross, UNCW--Research Associate Professor	*Deep Reefs and Fishes in the Gulf of Mexico: Habitat Usage and Potential Fisheries*	Deep Sea Coral
	15	Sandra Brooke, Florida State Univ.--Associate Research Faculty	*Distribution of deep coral reefs in the Gulf of Mexico and priorities for conservation*	Deep Sea Coral
	12	Robert Cowen, U. Miami RSMAS--Professor	*Understanding Coral Ecosystem Connectivity in the Gulf of Mexico--Pulley Ridge to the Florida Keys*	Mesophotic / Shallow
	30	***DISCUSSION PANEL--Deep Sea / Mesophotic Coral Research & Management Needs (Hourigan, Ross, Brooke, Reed, Martin, Cowen). MODERATOR: Steve Ross***		Deep Sea & Mesophotic / Management

Day 3	#mins	Speaker(s)/Affiliation/Title	Presentation Title	Topic
Wednesday, May 22				
8:30 AM	20	Simon Pittman, U. Virgin Islands / NOAA--Landscape Ecologist	*Spatial predictive mapping: More than just a pretty picture*	Spatial Ecology
	20	David Naar, Univ. South Florida--Associate Professor	*How do you Disseminate a Decade of High-Res Multibeam Data? For example…The Florida West Shelf*	Spatial Ecology
	20	Mark Mueller & John Froeschke, GMFMC--GIS Analyst & Fishery Biologist-Statistician	*Progressing from data to information: incorporating GIS into spatial analysis & management of Gulf coral and fisheries resources*	Spatial Ecology / Management
BREAK 10:00 AM	*15*			
	20	Steve Murawski, Univ. South Florida--Professor	*Impacts of Deepwater Horizon on Gulf of Mexico Reef Fishes: What we know and what we need to know*	Consequences
	20	Andrew Shepard, GoM Univ. Research Collaborative--Director	*Disaster recovery: how do we restore marine EFH?*	Consequences
	20	Rachel Turner, FORCE Project, Univ. West Indies--Research Associate	*Reef management in a changing environment: livelihood responses and governance challenges*	Consequences
	10	***BOOK Information/Timeline (Bortone)***		
LUNCH	60			
	12	Mark Hixon, U. Hawai'i--Professor	*Fish Colonization of Coral vs Artificial Reefs*	Critical Linkages / Mitigation
	25	Paul Sammarco, Louisiana Universities Marine Consortium--Professo	*1) Coral community development on offshore platforms in the GoM: What we now know 2) A new, aggressive, invasive coral in the GoM: Shoot or Don't Shoot?*	Critical Linkages / Mitigation
	10	Virginia Garrison, USGS--Research Ecologist	*Transplanting storm-produced coral fragments for reef rehabilitation*	Mitigation
	20	Ken Nedimyer, Coral Restoration Foundation--President	*Enhancing Essential Fish Habitat through Acropora Coral Restoration*	Mitigation
	20	***DISCUSSION PANEL--Mitigation (Hixon, Sammarco, Garrison, Nedimyer). MODERATOR: Steve Bortone***		Mitigation
BREAK 2:15 PM	*15*			
	45	***DISCUSSION PANEL--Future Research Needs & Directions (Sale, Bortone, Shepard, Murawski, Ogden, Hixon, Hourigan). MODERATOR: Andy Shepard***		Future Research
	10	***WRAPUP (Mueller, Bortone)***		

APPENDIX 3: LIST OF PRESENTERS

Name (Last, First)	Title	Affiliation (primary)
Appeldoorn, Richard	Professor	U. Puerto Rico, Dept. Marine Sciences
Ault, Jerry	Professor	U. Miami, Rosentiel School of Marine & Atmospheric Science
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APPENDIX 4: SUBMITTED ABSTRACTS

The Importance of Being Coral (from a Fisheries Perspective)

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An obligation of the Councils, as established by the Magnuson Act, is to provide guidance for fisheries management and the management of associated living organisms such as corals. Many fisheries had been undergoing overfishing and were overfished, but long-term management strategies have begun the process of rebuilding these overfished fisheries to sustainable levels. Simultaneously, however, there has been a long-term decline in coral health worldwide. Many fisheries are associated with corals owing to habitat that coral structure provides and/or because of the integral foundations for trophic relationships that corals provide in the ecosystem. As corals continue to decline, it may behoove fisheries managers to adjust projected yields for those fisheries that are inextricably linked to the trophic network provided by corals. While modern fisheries management looks forward to implement ecosystem-based management, understanding the interrelationship between fisheries and corals is an essential initial step toward ecosystem-based management in those regions that have corals as part of the base of the food chain. Moreover, failure to recognize and account for the potential impacts that declining habitat fitness has in our current management strategy may make single species management strategies, currently in place, obsolete. The purpose of this workshop is to examine trends among corals and associated fisheries and identify potential problems if current management strategies continue. More importantly, the workshop serves as a platform to begin establishing ecosystem-based management in fisheries science.

Distribution and Diversity of Coral Habitat and Associated Fisheries in the Gulf of Mexico

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Carrie Simmons presented an overview of coral habitat distribution and trends in established fisheries throughout the Gulf of Mexico (Gulf). She defined the Gulf of Mexico Fishery Management Council's (Council's) current management efforts (Table 4.1.1) and provided definitions and locations of coral Essential Fish Habitat (EFH), habitat areas of particular concern (HAPC), sanctuaries, and reserves (Figure 4.1.1). In the eastern Gulf, these important areas included the Florida Keys reef tract, the Dry Tortugas, the west Florida Shelf, Pulley Ridge, Florida Middlegrounds, Madison-Swanson, Steamboat Lumps, and The Edges. In the north central Gulf natural reefs are rare with little to no vertical relief. Instead, this inner-shelf area is composed of sand, mud, and silt that has been more recently populated by numerous artificial structures including oil and gas platforms for energy extraction. In the western Gulf there are the numerous natural mid-shelf and outer-shelf banks and salt domes including the East and West Flower Garden Banks, and the carbonate/drowned barrier reefs off the South Texas Banks. This presentation summarized what was known about the approximate number of coral and fish species found in the areas described above as well as the snapper and grouper fisheries that many of these areas support. This presentation discussed historical research that provided qualitative

information, but also noted the absence of available baseline information for many areas which continues to present challenges for effective management.

Proposed ESA Listing Determinations for 82 Coral Species

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NOAA Fisheries completed comprehensive status reviews under the Endangered Species Act (ESA) of 82 reef-building coral species in response to a petition submitted by the Center for Biological Diversity (CBD) to list the species as either threatened or endangered. In December 2012, NOAA Fisheries determined, based on the best scientific and commercial data available and efforts being made to protect the species, that 12 of the petitioned coral species warrant listing as endangered (five wider-Caribbean and seven Indo-Pacific), 54 coral species warrant listing as threatened (two wider-Caribbean and 52 Indo-Pacific), and 16 coral species (all Indo-Pacific) do not warrant listing as threatened or endangered under the ESA. Additionally, NOAA Fisheries determined, based on the best scientific and commercial information available and efforts undertaken to protect the species, two Caribbean coral species currently listed warrant reclassification from threatened to endangered. In the Gulf of Mexico *Acropora palmata* (FGBNMS only known location), *Montastraea annularis*, *M. faveolata*, *M. franksi*, and *Mycetophyllia ferox* are proposed as endangered, and *Agaricia lamarki* and *Dichocoenia stokesi* are proposed as threatened. NOAA Fisheries conducted an extended public comment period and received extensive comments on the proposed rule. NOAA Fisheries must make a final determination on the listing within one year of the proposal.

SAFMC Perspectives on Implementation of CHAPCs

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The South Atlantic Fishery Management Council (SAFMC) is one of 8 United States Regional Fishery Management Councils charged with conservation and management of fisheries in their respective region's Exclusive Economic Zones. The SAFMC and the National Marine Fisheries Service have implemented measures to protect what may be the world's largest contiguous distribution of deepwater coral ecosystems. Regulations to designate five areas as deepwater Coral Habitat Areas of Particular Concern (CHAPCs) went into effect in mid-2009. Within the CHAPCs, encompassing over 23,000 square miles (> 60,000 sq. km), bottom-damaging fishing gear (i.e., longlines, trawls, dredges, pots) and other fishing activities that could threaten the health and continued existence of these communities is prohibited. The SAFMC worked cooperatively with fishermen to designate areas within the CHAPCs where traditional fisheries can continue without impacting bottom habitat. More recently, based on research deepwater coral scientists have brought forward, the Council is considering expansion of several existing CHAPCs, including the Oculina Bank, Stetson Miami Terrace, and Cape Lookout. Through this developing amendment (Amendment 8 to the Coral Fishery Management Plan), the SAFMC continues to take a precautionary approach to managing deepwater coral ecosystems, while including all stakeholders.

Application of the Catch-MSY Approach in Specifying Annual Catch Limits for Coral Reef Fishes in the Western Pacific Region

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The Reauthorization of the Magnuson-Stevens Act in 2006 had significantly changed the way Regional Fishery Management Councils deal with managing the US fisheries through implementation of annual catch limits (ACLs). Stock and output control-based approaches like ACLs pose problems for fisheries that are multi-gear, multi-species and spatially diverse by nature. The National Standard 1 Guidelines of the National Marine Fisheries Service is reliant on the existence of Maximum Sustainable Yield (MSY) for stock managed under ACLs. This provides very little guidance for reef fishes that has very few stock assessments in which the overfishing limit, a critical component of the ACL process, is based upon. Biological reference points that determine stock status are lacking for most of the species. Managing stocks that are data deficient proved to be a big challenge. The initial round of catch limit specification was based solely on catch data. This resulted in an overly restrictive limit that is not reflective of the stock abundance. The Council initiated a review of the model based approaches for data-poor stocks and chose the catch-MSY approach by Martell and Froese (2012). This model was augmented to include biomass estimates available from a statistically structured survey conducted by the Pacific Island Fisheries Science Center. This effort improved the scientific information available for the ACL specification process thereby moving the coral reef fish stocks from the tier that utilize only catch information to tier 3 that has MSY estimates based on model-based approaches.

Fisheries Impacts and Deep-Sea Coral Ecosystems: International & National Context

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Corals form complex habitats that host rich and diverse communities in deeper waters around the world. While the contribution of intact deep-sea coral habitats to fishery production is generally unknown, interactions with bottom-contact fishing gears, especially bottom trawls, have been responsible for widespread and serious damage. Discoveries that brought to light the extent and importance of deep-sea coral habitats resulted in trawl closures by several countries beginning in the late 1990s. Multilateral efforts to address impacts of deep-sea fisheries in areas beyond national jurisdiction culminated in a 2006 United Nations General Assembly Resolution (61/105) calling upon states and Regional Fishery Management Organizations and Arrangements to protect vulnerable marine ecosystems, specifically identifying “cold-water corals.” In the U.S., the National Oceanic and Atmospheric Administration (NOAA) in partnership with Regional Fishery Management Councils has taken steps to protect deepwater coral habitats from fishing impacts in most regions, mostly through authorities to protect essential fish habitat. In 2010, NOAA’s *Strategic Plan for Deep-Sea Coral and Sponge Ecosystems* laid out a series of steps to further reduce adverse impacts of fishing on these ecosystems, building on best international and domestic practices: 1) Protect identified areas of high density deep-sea corals or sponges; 2) Take a precautionary approach to “freeze the footprint” of the most damaging fishing activities – those conducted with mobile bottom-tending gears; and 3) Evaluate additional protection measures on a regional basis, with special emphasis on identifying and reducing bycatch of deep-sea corals and sponges. NOAA’s conservation efforts are supported by the Deep Sea Coral

Research and Technology Program, designed to provide the science necessary to support conservation action.

Tipping, Sliding, or Doing Just Fine –The Possible Futures for Coral Reef Fisheries
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The global environmental crisis is much bigger than climate change, and coral reefs will be just one of many casualties as we change our planet into something we have never known before. While we cannot know the future in detail, it is clear that corals are being hit hard by climate change, ocean acidification and the sundry local insults to which we subject them. As the corals decline, coral reefs are losing fundamental features that made them coral reefs, and coral-rich habitats are unlikely to still be a common feature of them within a few decades. In coral reef regions throughout the world, fisheries based on reef-associated species have been a mainstay for local food security and for the commercial market, but it is far from clear how these fisheries will be changed. There are three possibilities: sudden collapse as reefs degrade to the point where they can no longer sustain fishery species, continuation of the currently too common trend of declining yields, perhaps hastened as habitat degrades, and continuation, or even improvement, as the reefs morph into a different type of ecosystem, but one that still sustains production of fishery species

Managing Sustainable Caribbean Fisheries During Climate Change
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Recent studies are suggesting that many Caribbean coral reefs are only just able to grow and maintain their overall carbonate structure. Over the last few decades, the loss of urchins and fast-growing corals, together with nutrification and over-harvesting of herbivorous fish, have all worked in concert to reduce the resilience of reefs and their ability to construct fish habitat. Models of both the ecological and geological processes acting on reefs suggest that a positive carbonate budget (i.e. active net reef growth) is possible this century but only if local pressures are alleviated and concerted action is taken to reduce greenhouse gas emissions. Failure to do so will likely result in a long-term decline in the complexity of coral reef habitats. New models, not yet published, suggest that a loss of reef complexity could at least halve the productivity of coral reef fisheries. Thus, it is in fishers interests (in particular) to maintain high quality reef habitat, which includes careful management of parrotfish fisheries. Efforts are underway to identify the best way to manage such fisheries where a full moratorium is not possible.

Interaction of Ecosystems in the Coastal Seascape: Implications for Science, Management and Conservation
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The Caribbean coastal seascape has a characteristic structure grading from land to mangrove forests, to seagrass beds, to coral reefs and to the deep ocean beyond. The physical, chemical and biological interactions resulting from this juxtaposition are critical to the maintenance of overall biological diversity, resilience of the coast and its ability to sustain the human uses which drive coastal economies. Coral reef fishes are a case in point, as they move readily across the seascape, using seagrasses and mangroves as nurseries for juveniles and inter-connecting them with daily and seasonal movements related to feeding and reproduction. Studies of tagging, telemetry, and stable isotope analysis, tracking the timing and extent of fish movements and dispersal, emphatically support the need for new spatial approaches to governance of human uses and management of marine resources.

Habitat Shifts and Ontogenetic Migrations of Herbivorous Reef Fishes: From Mangroves to Mesophotic

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Many coral reef fishes have strong habitat relationships. An important aspect to this is the interdependence of coral reefs with associated habitats (e.g., mangroves, seagrass) and cross-shelf locations (e.g., inner and outer reefs). Connectivity across spatial scales is important for maintaining ecosystem function, including resilience and production. Herbivory is an ecological function important for maintaining reef health and fishery productivity. Examination of the distribution of key herbivores (7 parrotfishes and 3 surgeonfishes) by lifestage and habitat type across the shelf off La Parguera, Puerto Rico shows that herbiory occurs within a spatial context mediated by the ontogenetic movements of individual species. While species have different habitat requirements and patterns of ontogenetic migration, most show a consistent movement from inshore nursery areas (mangroves, seagrass, backreef or shallow reef) to forereef habitats that are progressively deeper and further offshore. There is an exponential decline in herbivore density with depth, presumably reflecting the attenuation of light available for photosynthesis. Within mesophotic coral ecosystems, there is a marked shift from benthic herbivory to planktivory with depth. Thus, the role of macroherbivores declines with depth, dropping out at about 60 m. For some species, particularly the very large but now rare rainbow parrotfish, ontogenetic migration runs the full depth spectrum from near shore mangroves to mesophotic depths, with the later potentially acting as a refuge from exploitation. Maintaining shallow nursery habitats is thus linked to maintaining or rebuilding adult herbivore populations. Understanding ontogenetic variations in habitat type and location is important for management, being critical for defining essential fish habitat over broad spatial and multispecies scales, with obvious applications to designing marine protected areas and maintaining coral reef health.

Northeast Gulf of Mexico Reserve Program: Monitoring Changes in Reef Fish Populations

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Three Marine Protected Areas (MPAs) are designated in the Gulf of Mexico for the protection of spawning aggregations of gag (*Mycteroperca microlepis*). These areas are Madison-Swanson and Steamboat Lumps (est 2000) and The Edges (est 2009). These MPAs lie on the continental shelf edge south of Panama City and east of Tampa, FL in waters between 60 and 125 m deep. The total area of the three MPAs is ~1500 sq km. All fishing is prohibited between 01 Nov and 30 Apr in Madison Swanson (MS) and Steamboat Lumps (SL) and between 01 Jan and 30 Apr in The Edges (TE). Surface trolling is allowed in MS and SL the remainder of the year and all fishing is allowed in TE outside of the closed period. The National Marine Fisheries Service has surveyed these three MPAs and adjacent open-to-fishing control areas on an annual basis during

the winter spawning season for gag. The survey is a stratified random design, stratified by habitat type (determined by multibeam bathymetry and backscatter maps) using stationary camera arrays consisting of four orthogonally spaced video cameras. All fishes are identified to the lowest taxonomic level possible and lengths are estimated (originally by paired lasers, later with stereo cameras). In addition to gag, other economically valuable reef fish (scamp, red grouper, red and vermilion snapper) are evaluated. While fish abundance has varied over time, both inside and outside the MPAs, results indicate consistently higher abundance inside the MPAs compared to the adjacent control areas as well as the eastern Gulf of Mexico as a whole. Additionally fish inside the MPAs are larger than those outside.

Effects of *Agaricia* Coral Bleaching and Death on the Demography of *Stegastes* Damselfish in the Bahamas

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Prior to 1998 near Lee Stocking Island, Bahamas, the largely planktivorous bicolor damselfish (*Stegastes partitus*) was especially abundant on living lettuce coral (*Agaricia tenuifolia*), which it used for shelter. During the 1998 mass coral bleaching event, following a year of detailed demographic monitoring of the damselfish, nearly all the lettuce coral in this region died. Within a year, the dead lettuce coral was overgrown by macroalgae and more aggressive damselfish species (*S. planifrons* etc.) displaced bicolor damselfish from this habitat. Subsequently, storms removed much of the dead coral, thereby reducing habitat for all damselfish species. Associated with declining habitat was a steady a decline in the regional population of bicolor damselfish due to both increased mortality and decreased larval settlement. These patterns suggest that mass mortality of corals can negatively affect the demography and community structure of damselfishes and likely other species associated with corals.

Management and Conservation of Coral Reefs and Marine Resources in the Caribbean Sea under Future Climate Change Scenarios

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Coral reefs in the Caribbean Sea have been increasingly impacted by bleaching in recent years. Temperature stress on corals is likely to increase in the next several decades, as a result of climate change processes. Global climate models are frequently used to try and assess potential future impacts, but these models have a very coarse spatial resolution. They may therefore be less helpful for regional predictions.

To address this, we downscaled global climate models to a regional scale for the Gulf of Mexico and Caribbean Sea, using dynamical downscaling. This resulted in projections of temperature, salinity and current vectors throughout the water column through to the year 2100. When applied to the Caribbean Sea, predicted increases in water temperatures were shown to be highly likely to result in extensive coral bleaching across the region, but with significant spatial heterogeneity. Examining combinations of current reef condition, restoration processes and future stress may be useful for prioritizing resources for coral reef managers. This was demonstrated by comparing current and future threats to reefs in the EEZs of four Caribbean jurisdictions with different socioeconomic profiles: the Cayman Islands, Colombia, Jamaica and Panama.

Effects of Ocean Acidification and Climate Change on Coral Reef Health and Disease

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Climate change and ocean acidification are two of the most detrimental stressors effecting contemporary coral reefs. Oceanic warming and anomalously high water temperatures that cause coral bleaching events have resulted in significant declines in coral cover on reefs worldwide. Bleaching, which is a general stress response of corals, is often associated with reduced immune function and an increase in susceptibility of corals to disease infection. Therefore, disease outbreaks often coincide with mass coral bleaching events causing an even further decline in coral cover. Ocean acidification, or the lowering of oceanic pH from atmospheric carbon dioxide, may also cause stress on corals and increase the susceptibility of corals to disease. However, reduced pH likely also affects the coral-disease pathogens. A preliminary study was conducted to test the effects of temperature and pH on the progression rates of black band disease. Our results indicated that black band disease had reduced progression rates when infected corals were exposed to low (7.6) pH water. High water temperature (31^{o}C) increased the progression rates of the disease. Therefore, low pH may mitigate the virulence of some coral diseases, but increased virulence under high water temperatures has the potential to supersede these effects.

Pollution and Coral Reefs

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Both natural and anthropogenic pollutants have been shown to adversely impact coral reefs and organisms. Pollutants can enter coral reef systems via the land, atmosphere, and ocean. For example, sediment from careless land disturbance, nutrient influx from sewage and use of fertilizer, persistent organic contaminants (e.g., pesticides), and endocrine disrupting compounds such as those found in some personal care products are present in the reef environment as a result of human activities. Adverse effects on reefs include: direct mortality of organisms; shifts in competitive interactions; alteration of animal-algal symbioses; interference with reproduction, settlement, metamorphosis, growth, and immune function; alteration of microbial communities (e.g., of the coral holobiont); and interference with biocommunication at the cellular to organismal level.

Toxicity of Deepwater Horizon Source Oil and the Chemical Dispersant, Corexit® 9500, to Coral Larvae

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Acute catastrophic events can cause significant damage to marine environments in a short time period and may have devastating long-term impacts. In April 2010 the BP-operated Deepwater Horizon (DWH) offshore oil rig exploded, releasing an estimated 760 million liters of crude oil into the Gulf of Mexico. This study examines the potential effects of oil spill exposure on coral larvae of the Florida Keys. Larvae of the brooding coral, *Porites astreoides*, and the broadcast spawning coral, *Montastraea faveolata*, were exposed to multiple concentrations of BP Horizon source oil (crude, weathered and WAF), oil in combination with the dispersant Corexit® 9500

(CEWAF), and dispersant alone, and analyzed for behavior, settlement, and survival. Settlement and survival of *P. astreoides* and *M. faveolata* larvae decreased with increasing concentrations of WAF, CEWAF and Corexit® 9500, however the degree of the response varied by species and solution. *P. astreoides* larvae experienced decreased settlement and survival following exposure to 0.62 ppm source oil, while *M. faveolata* larvae were negatively impacted by 0.65, 1.34 and 1.5 ppm, suggesting that *P. astreoides* larvae may be more tolerant to WAF exposure than *M. faveolata* larvae. Exposure to medium and high concentrations of CEWAF (4.28/18.56 and 30.99/35.76 ppm) and dispersant Corexit® 9500 (50 and 100 ppm), significantly decreased larval settlement and survival for both species. Furthermore, exposure to Corexit® 9500 resulted in settlement failure and complete larval mortality after exposure to 50 and 100 ppm for *M. faveolata* and 100 ppm for *P. astreoides*. These results indicate that exposure of coral larvae to oil spill related contaminants, particularly the dispersant Corexit® 9500, has the potential to negatively impact coral settlement and survival, thereby affecting the resilience and recovery of coral reefs following exposure to oil and dispersants.

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Forests in the Deep: Octocoral and Black Coral Habitats in the Gulf of Mexico

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The reef-forming scleractinian coral *Lophelia pertusa* is a flagship species for deep-sea corals in the Gulf of Mexico because *Lophelia* reefs provide important habitat and are fragile and long-lived. However, *Lophelia* has a fairly narrow depth distribution compared to octocorals (soft corals, gorgonians) and antipatharians (black corals), which increase habitat heterogeneity in deep waters (to ~2500 m in the Gulf). These coral colonies are also susceptible to anthropogenic disturbances as they are slow growing and long lived, in some cases up to 1600 years old. Here, we use phylogenetic and data mining techniques to show that octocoral assemblages are influenced by depth and by geography, with at least six different assemblage types in the deep northwest Gulf and the West Florida slope (250-2500 m). In contrast, the predominant deep-sea black corals *Leiopathes* spp. appear broadly distributed across both regions, but appears to be restricted to the upper slope of the Gulf. Fishes observed associated with black coral and octocoral aggregations include barrelfish, alfonisno, snowy grouper, blackbelly rosefish, roughys, and thornyheads. We recommend the Gulf of Mexico Fishery Management Council consider designating Habitat Areas of Particular Concern (HAPCs) or deep-sea coral zones in waters 200-2000 m depth that span the two biogeographic regions and embrace the full diversity of deep-sea coral habitat types. Both mobile and fixed gears used in demersal fisheries have potential to damage deep-water coral colonies and these should be evaluated in the development of a network of protections.

Deepwater Coral Reefs and Mesophotic Reefs off Florida- Interrelationships of Habitat and Fisheries

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Recently, the South Atlantic Fishery Management Council (SAFMC) established eight deepwater Marine Protected Areas (MPAs) and the Deepwater Coral Habitat Areas of Particular Concern (CHAPC) along the outer continental shelf off the southeastern U.S. This presentation highlights several research cruises to document and characterize the benthic habitat, benthic biota, and fish populations of these protected areas within the jurisdiction of the SAFMC. This monitoring program for the MPAs will ensure the Council remains well informed of changes within reef fish populations and coral habitats associated with these MPAs. The first report was from a cruise on the NOAA Ship *Nancy Foster* in 2011 to Pourtalès Terrace off the Florida Keys which was funded in part by NOAA Deep Sea Coral Research and Technology Program (DSCRTP) and NOAA Office of Ocean Exploration and Research (OER) to explore and sample deep-sea coral and sponge ecosystems (DSCEs) within the newly designated CHAPC and the 'East Hump's MPA. Fish populations and reef habitat were compared inside and outside of the MPA and CHAPC. During this study the southernmost deepwater *Lophelia* coral reef known in the continental U.S. was discovered off the Florida Keys. A second report summarized a cruise on the NOAA Ship *Pisces* to shelf edge MPA sites off eastern Florida in 2011 and included newly discovered and mapped deepwater *Oculina* coral habitat outside of the *Oculina* HAPC. These new finding were presented to the South Atlantic Fishery Management Council for possible inclusion to the OHAPC boundaries to protect the coral habitat from bottom trawls, longline and pots. These reefs are well known for spawning grounds for gag and scamp grouper.

Deep Reefs and Fishes in the Gulf of Mexico: Habitat Usage and Potential Fisheries

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Deep (> 300 m) reef habitats in the Gulf of Mexico include complex structures formed by deep-sea corals (DSC), emergent rock formations, authigenic carbonate rocks and artificial structures (shipwrecks, oil platforms). Such structures are common in the Gulf and DSC play an important role in habitat complexity. Two areas in particular have been well studied (Viosca Knoll and West Florida slope) and appear to support the largest concentrations of DSC in the Gulf as well as extensive hardgrounds. Until recently these sites were poorly known, but several multiyear, interdisciplinary investigations during the last 10 years have greatly improved our understanding of these important ecosystems. The deep reefs concentrate biota much as shallow reefs do. We have documented 55 species of fishes utilizing deep Gulf reefs, and at least 30 of these appear to have an obligate association with reef habitat, again similar to shallow reef ecosystems. The community structure of Gulf of Mexico deep reef fishes appears to differ from that off the southeastern US, with Gulf reefs hosting a number of fishes not generally seen on deep reefs elsewhere. Although a few commercially important fishes occur on these reefs (snowy grouper, wreckfish), there do not seem to be major commercial fisheries currently targeting these resources. A number of potentially exploitable species (blackbelly rosefish, conger eel,

barrelfish, alphonsinos, roughies) are common on these reefs, but important data on their biology and ecology are lacking. The recreational "deep-drop" fishery appears to operate at a low fishing effort in the Gulf, but this popular activity is increasing in many places and could have some impact on deep-reef fishes in the future. By-catch of deep reef fishes and impacts to deep reef habitats from other fisheries (royal red shrimp trawling, golden crab trapping) are unknown. We recommend protection measures, such as Habitat Areas of Particular Concern, for the largest deep reef habitats (in particular Viosca Knoll 826, Viosca Knoll 862/906, and a portion of the West Florida Slope) and collection of vital missing data (by-catch, key species life histories, habitat mapping) in order to ensure the integrity of these vulnerable ecosystems.

Distribution of Deep Coral Reefs in the Gulf of Mexico and Priorities for Conservation

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The primary reef-building deep-coral species in the Gulf of Mexico is *Lophelia pertusa*, but structure is also provided by other scleractinians (e.g. *Madrepora oculata*, *Enallopsammia profunda*), antipatharians (black corals), octocorals (gorgonians and soft corals), hydrocorals and sponges. These corals and sponges provide structure to support a diverse and abundant associated community, which includes several potential fishery species. There are two primary regions of deep water coral development in the US Gulf of Mexico. The most well studied deep reefs are off the coast of Mississippi within oil and gas lease blocks Viosca Knoll 826 and Viosca Knoll 862/906. More recent and possibly more extensive discoveries have been made off the west Florida slope during a series of research cruises from 2008-2012. This presentation provides a general description of both regions, including bathymetric maps, coral distribution and coral-associated benthic communities. Although these reefs appear to be undamaged, there is potential for future impacts from expansion of the energy industry (into the eastern Gulf of Mexico) and fishing (eg increases in royal red shrimp trawling, reactivation of the golden crab trap fishery and increased interest in deep dropping for large reef fish). Suggested high priority conservation areas include the Viosca Knoll sites, and the abundant coral mounds on the west Florida slope. These areas would qualify for protection under the discretionary provision of the Magnuson-Stevens Act (2006 re-authorization Sec. 408) that allows for restriction of bottom tending gear in known deep coral habitat.

Spatial Predictive Mapping: More than Just a Pretty Picture

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Spatial predictive modeling provides a cost-efficient and practical analytical tool to fill spatial data gaps and examine macro-ecological relationships. This presentation offers a multi-scale seascape ecology approach to model and map species distributions and assemblage metrics. Examples are provided to demonstrate the application to map coral reef associated species and identify ecological drivers of distribution patterns.

Progressing from Data to Information: Incorporating GIS Into Spatial Analysis & Management of Gulf Coral and Fisheries Resources

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The Gulf of Mexico Fishery Management Council, charged with sustainably managing Gulf coral and fishery resources in federal waters, is utilizing Geographic Information Systems to help create a baseline of spatial information. We are identifying and compiling widely-scattered datasets on coral locations (shallow, mesophotic and deep sea), associated fisheries, habitat (including oceanographic variables, bathymetry, benthos, bottom sediments, artificial structures, etc.) and relevant human-use and jurisdictional layers. This baseline compilation and GIS-based analysis methods are already being used to help address important management questions and better inform stock assessment science. We will be implementing an interactive map viewer and data portal to help disseminate the compiled information to managers, coral and fisheries scientists, and the fishing public. These spatially-explicit data and tools will serve to improve scientific understanding of coral/fishery interrelationships and inform decision making.

Disaster Recovery: Restoration of Coral Ecosystems and Essential Fish Habitat from Deepwater Horizon Oil Spill

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The Deepwater Horizon oil spill in 2010 was the largest in U.S. history and unprecedented in its extent and complexity of pollutants and potential impacts, and posed threats to shallow, mesophotic and deep sea coral ecosystems. Penalties for primary and compensatory ecosystem restoration via settlements and litigation will likely exceed $20 billion and are also an unprecedented opportunity to support ecosystem-based management of Gulf fisheries and coral ecosystems. This paper and presentation describes the restoration science programs, their expected amounts and objectives, and recommends actions they may take to support EBFM for coral ecosystems, for example, improved fisheries independent and recreational landings data to inform reef fish stock assessments, support for a long term observing and monitoring program, and actions to ensure restoration projects and programs are coordinated, developed and implemented with stakeholders, and science-based.

Reef Management in a Changing Environment: Livelihood Responses and Governance Challenges

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The ecological state of Caribbean reefs has deteriorated in recent decades, and faces an uncertain future with global climate change, threatening the viability of economically and socially important fisheries that depend on them. The Future of Reefs in a Changing Environment (FORCE) project aims to contribute to an improved understanding of how future changes could impact Caribbean coastal communities, and to recommend appropriate management responses

suited to regional and local contexts. Semi-structured interviews (n=500) were conducted with commercial and recreational fishers in 12 communities across four Caribbean countries (Barbados, Honduras, St Kitts and Nevis, and Belize) to identify perceptions of change in reef-related resources, responses to these changes, and anticipated responses to future changes. In each study country, interviews were also conducted with policy makers and reef managers to explore the efficacy of current management tools, future management needs, and the influence of governance arrangements on reef management. Preliminary results will be presented, highlighting common challenges to effective reef governance in the context of declining reef health.

Fish Colonization of Coral vs. Artificial Reefs

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Methods used to evaluate the performance of an artificial reef will vary according to the purpose for which the reef was built. To determine how well artificial reefs mitigate losses due to human activities on natural reefs, the performance of artificial reefs should be evaluated using contemporaneous comparisons with relatively undisturbed natural reefs. Unfortunately, comparisons between artificial and natural reefs are typically confounded by differences in reef size, age, and isolation. We compared colonization and subsequent assemblage structure of reef fishes on coral and artificial (concrete block) reefs in which reef size, age, and isolation were standardized. Species richness and fish abundance (all species combined) were greater on reefs of natural rather than artificial structure, but substantial differences in species composition were not detected. Our results suggest that artificial reefs with structural complexity and other abiotic and biotic features similar to those of natural reefs will best mitigate in-kind losses of reef fish populations and assemblages from natural reefs. Because of the open nature of most reef fish populations, estimating the contribution of artificial reefs in attracting versus producing reef fishes will require a regional assessment of rates of demographic processes on both artificial and nearby natural reefs.

Reprinted from: Carr, M. H., and M. A. Hixon. 1997. Artificial reefs: the importance of comparisons with natural reefs. Fisheries 22:28-33.

Coral Community Development on Offshore Platforms in the Gulf of Mexico: What We Now Know

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It is known that demersal and reef-associated fish require three-dimensional structure for hard-bottom habitat, and that such promotes fish community development. Corals are known to provide such structure. Oil/gas platforms in the N. Gulf of Mexico (GOM) now number approximately 3,200 and provide hard substratum for marine fauna and flora, including corals, where little existed in shallow water prior to the 1940s. The introduction of this hard substratum has facilitated the biogeographic expansion of Caribbean reef fauna there. Our research team surveyed scleractinian corals, hermatypic and ahermatypic, on 48 platforms around the Flower Garden Banks (FGB) and across the continental shelf, from Corpus Christi, Texas to Mobile,

Alabama, USA. We also assessed the coral populations on the platforms and on the FGB for genetic affinities to ≤ 37 m depth using AFLPs. The western limit for hermatypes was near the shelf edge off Corpus Christi. The highest hermatypic densities occurred at the shelf edge, ~175-225 km from shore in the central region of the GOM. Mobile served as the eastern limit for some hermatypic corals. Ahermatypes (*i.e., Tubastraea coccinea, Oculina diffusa*, *Phyllangia americana)* were absent inshore and in the north-central GOM region. Species richness of hermatypic corals peaked near the FGB. Genetic analyses revealed high self-recognition and site fidelity on the platforms and on the FGB in *Madracis decactis,* particularly in the eastern GOM, indicating that individual populations exhibited a certain level of "uniqueness" when compared to others. In addition, platform populations exhibited a strong genetic affinity to the FGB, indicating that the FGB are most likely the larval source for many of the coral populations on the platforms. There was little or no genetic affinity of coral populations across the mouth of the Mississippi River. In *T. coccinea* (invasive species), cross-recognition between populations was higher between platforms within a transect, but again absent across the river mouth. The Mississippi is a strong geographic barrier to east-west dispersal. Brooders were found to be highly effective at colonizing patchy habitats at this meso-scale – more than broadcasters (*Diploria strigosa* and *Montastraea cavernosa).* Broadcaster recruits were found rarely, indicating less effective dispersal capabilities. Oil/gas platforms have facilitated the development of coral communities across the northern GOM which appear to have in turn provided habitat for demersal and reef-associated fish.

A New, Aggressive, Invasive Coral in the Gulf of Mexico: Shoot or Don't Shoot?

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The relationship between demersal or reef-associated fish community development and hard-bottom habitat quality is well known. Coral are known to supply the type of complex hard-bottom required for recruitment of such fish. The Gulf of Mexico experienced an invasion by the ahermatypic Indo-Pacific coral *Tubastraea coccinea* in the 1940s, and it has now spread from the Florida Keys to Brazil, particularly on artificial reefs, reaching abundances of hundreds of thousands of colonies per site. A congener - *Tubastraea micranthus* - recently invaded the Gulf of Mexico. Originally, this species occurred on one of 81 platforms surveyed, occurring SW of the Mississippi River. Here, we surveyed 14 oil/gas platforms for both invasive species in that area *via* ROV, to depths of 134 m. It was found on 9. Average *T. micranthus'* densities reached 15 colonies/m^2; *T. coccinea* mean densities peaked at 20X this – or >300/m^2. Both species' densities peaked at 28.4^o lat., -90^o long. Based on percent-cover data, Platform GI-93C was probably the site of original colonization for *T. micranthus.* Percent-cover of *T. coccinea* was commonly 25%-45%, indicating that population equilibrium for this species had probably been reached in the region. Percent cover and density were highly correlated (r = 0.928) for *T. micranthus,* but less so for *T. coccinea* (0.487). Most *T. micranthus* colonies were small, indicating that these populations are in an explosive expansion phase. Colony density did not correlate strongly with colony size, indicating that environmental conditions conducive to promoting growth (habitat quality for this species) varied between sites. Depth distributions varied between sites for both species as well, with *T. micranthus* being distributed to depths of at least 138 m. This suggests that control or eradication measures for this species may prove challenging. It also suggests that Mississippi River discharge was influencing depth distribution. Due to its geographic expansion rates, it is possible that *T. micranthus* could spread throughout the Gulf of Mexico and other tropical western Atlantic sites, like *T. coccinea,* becoming a major invasive. If government chooses to attempt to control or eradicate T. micranthus, we suggest that it do so swiftly, before such is no longer possible. Since the natural morphology of *T. micranthus* is erect and branching, if it expands throughout the tropical and sub-tropical western Atlantic, we hypothesize that it could contribute to habitat quality and may promote demersal and reef-associated reef development, particularly on artificial reefs.

Survival of Transplanted Fragments of Acropora and Porites Over 12 Years

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In response to dramatic losses of reef-building corals and ongoing lack of recovery, a small-scale coral transplant project was initiated in the Caribbean (U.S. Virgin Islands) in 1999 and was followed for 12 years. The primary objectives were to (1) identify a source of coral colonies for transplantation that would not result in damage to reefs, (2) test the feasibility of transplanting storm-generated coral fragments, and (3) develop a simple, inexpensive method for transplanting fragments that could be conducted by the local community. The ultimate goal was to enhance abundance of threatened reef-building species on local reefs. Storm-produced coral fragments of two threatened reef-building species [*Acropora palmata* and *A. cervicornis* (*Acroporidae*)] and another fast-growing species [*Porites porites* (*Poritidae*)] were collected from environments hostile to coral fragment survival and transplanted to degraded reefs. Inert nylon cable ties were used to attach transplanted coral fragments to dead coral substrate. Survival of 75 reference colonies and 60 transplants was assessed over 12 years. Only 9% of colonies were alive after 12 years: no *A. cervicornis*; 3% of *A. palmata* transplants and 18% of reference colonies; and 13% of P. porites transplants and 7% of reference colonies. Mortality rates for all species were high and were similar for transplant and reference colonies. Physical dislodgement resulted in the loss of 56% of colonies, whereas 35% died in place. Only *A. palmata* showed a difference between transplant and reference colony survival and that was in the first year only. Location was a factor in survival only for *A. palmata* reference colonies and after year 10. Even though the tested methods and concepts were proven effective in the field over the 12-year study, they do not present a solution. No coral conservation strategy will be effective until underlying intrinsic and/or extrinsic factors driving high mortality rates are understood and mitigated or eliminated.

Enhancing Essential Fish Habitat through Acropora Coral Restoration

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Acroporid corals provide essential habitat for prey and target species of commercially important fish, and restoring them will increase overall productivity of the areas around them. Nursery techniques have improved to the point where substantial numbers of these fast growing corals can be produced and successfully replanted onto suitable reef sites, and the scale is limited by funding.

FUTURE RESEARCH PANEL

Each panelist provided a vision statement and discussion questions, and the moderator compiled a list of future research needs, below.

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Whereas there is clear evidence that coral-reef fishes benefit from living corals as a source of both shelter and, directly (e.g., benthivores) or indirectly (e.g., piscivores), food, whereas overwhelming evidence that shallow reef-building corals are in severe decline worldwide, whereas there is evidence that relatively intact reef ecosystems are relatively resilient to ocean warming and acidification, as well as other human-caused stressors, and whereas humans value coral reefs and their fishes, be it resolved that fisheries managers in the broader Caribbean region should take immediate action to conserve remaining reefs and their fish fauna by:

(1) **conserving reef herbivores**, especially parrotfishes (via either fishing restrictions or marine reserves), which are known to help prevent seaweeds from displacing corals,
(2) **conserving native piscivores** (via either fishing restrictions or marine reserves), which are known to help to stabilize fish population dynamics, and
(3) **targeted removals of invasive lionfish** (via either derbies or directed fisheries), an alien predator known to severely reduce recruitment of a broad variety of native reef fishes, including extirpations.

Research supporting these efforts would:

a) explore the boundaries of marine metapopulations to bring the spatial scale of management in line with ecological dynamics; and
b) explore novel means of enhancing corals and their fish fauna, while simultaneously decreasing the density of invasive lionfish.

Question: How do we most effectively and immediately implement these efforts?

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Professor Emeritus, Integrative Biology

Driven by the resources needs of relentlessly growing human populations, the coastal seascape of the Wider Caribbean has been in severe decline for at least the past 50 years. The physical, chemical and biological inter-dependencies between coral reefs, seagrasses and mangroves provide a compelling argument for **ecosystem-based management at the spatial scales of the ecosystem processes that maintain these systems**. The slowly developing National Ocean Policy has broadly outlined a series of steps in which **marine planning** and coordinated, integrated science, management and conservation in defined eco-regions have the best chance of arresting the decline and restoring and sustaining the ecosystem services upon which our social and economic welfare depend.

Question 1: What progress has Florida made in developing an ocean policy?
Question 2: What is marine spatial planning and why is it so controversial?

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Vision for future research and directions: 1. Determine the specific factor or attribute of coral reefs that are associated with **species specific, limiting (bottleneck) features on their life history**. This would allow prediction of likely future stock assessment trends and also provide direction for management activities or actions to relieve the bottleneck in the future. 2. **Trophic models** of coral communities that includes associated fisheries (predators, prey), so "what if" scenarios of future conditions can be projected. 3. **Socio-economic valuation of the coral/fisheries relationship** should be clearly defined by region.
Q1: If Corals and coral reefs continue to degrade, what should fisheries managers be doing to adjust their management strategies of reef fish associated species in the future?

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What are the *highest priority research needs for support of ecosystem-based management of coral ecosystems and associated fisheries?*
We need to understand how fisheries impact the resilience of coral ecosystems. The concept of ecosystem resilience in large part grew out of concerns over impacts climate change, specifically coral bleaching, on coral reefs. It is, however more broadly applicable and has also arisen here in the Gulf of Mexico during the Natural Resource Damage Assessment of the Deepwater Horizon oil spill.
While there are a large number of functional research problems that can help answer these questions, some basic questions are:

- What is the extent and **interconnectivity** of coral habitats
- What is the **extent of fishing pressure** on these habitats and its likely trophic and habitat effects
- How might expected future change be expected to factor into these effects

For the foreseeable future, **ecosystem-based management** in the Gulf of Mexico will rely on approximations and "rules of thumb," but will benefit from:

- A more explicit **spatial understanding of coral habitats** at the scale of the whole Gulf
- Studies that look at **similar ecosystems with and without fishing** – highlighting the key **role of no-take reserves** as a paradigm for both research and resilience
- Incorporating these results into **models to explore plausible scenarios of change**

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Tropical coastlines support over 2.5 billion people in communities from tiny hamlets to megacities, primarily in developing countries. Many of these communities are directly dependent on adjacent coastal seas for much of their food and for their livelihoods. Globally, tropical coastal seas are largely degraded due to a wide range of direct and indirect anthropogenic stressors including overfishing, pollution, and inappropriate coastal development. Our projections show that climate change and population growth will worsen stresses, and that coastal

fisheries will be substantially degraded as a consequence; these trends exacerbate the challenge to achieve sustainability.

Current methods for improving coastal marine management are inadequate to stem the general decline and a new, more effective approach is sorely needed. The primary impediments to success are not technological, but rooted in **failure to build buy-in by communities and their leadership, to confront perverse subsidies that entrench failed approaches, to build effective governance and to stamp out corruption**. In addition there is a complacent acceptance of the status quo by the 'international development community', and a general inability to work holistically. Research is needed to **better understand the degree to which coral reefs are *essential* fish habitat for each target fishery species** and to find ways to provide for their needs in the absence of flourishing reefs, but this will not solve these more pressing causes of failure.

Question: Are well-designed networks of MPAs an effective solution to achieve sustainability for reef-associated tropical coastal fisheries, and what gaps in knowledge of how to design them remain?

Panel's list of priority research needs:

- Artificial reefs versus natural reefs—is it attraction or production? Design AR programs that do not promote overfishing by targeted fisheries
- Expanded and improved habitat maps through new efforts and proactive campaign to acquire and integrate past surveys (e.g., oil and gas seabed surveys); may require new IT approaches
- Experiments to assess integrated means of restoring and improving coral reef resilience and condition, for example, application of closed areas, manipulations to balance of herbivores and predators, and primary restoration efforts (e.g., transplants)
- Lionfish must be addressed—no easy solution but need to attempt control via removals
- Evolve Ecosystem-based Fisheries Management at required scales from local patch reefs to Large Marine Ecosystem
- Develop marine spatial planning tools required for EBFM, for example, to inform areal closures and developing network of research reserves
- Improve valuation of fisheries-related ecosystem services
- Continue development and education/training related to ecosystem models for management strategy evaluation
- Genomics research to define coral and coral-associated fish metapopulation boundaries and connectivity across and outside Gulf region (Caribbean basin); knowledge required to inform stock assessment and spatial management efforts
- Improve assessment of fishing pressure and impacts of reductions on coral ecosystems (including fisheries)
- Expand research operational capabilities in region, especially for mesophotic and deep coral ecosystems, e.g., access to research vessels and in situ ocean technologies.