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FINAL

Deepwater Coral Research and Monitoring Plan for the South Atlantic Region

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Background and Need to Support Management

The SAFMC manages coral, coral reefs and live/hard bottom habitat, including deepwater corals, through the South Atlantic Coral Fishery Management Plan. Mechanisms exist in the FMP as amended to further protect deepwater coral and live/hard bottom habitats. The SAFMC Habitat and Environmental Protection Advisory Panel and Coral Advisory Panel have supported proactive efforts to identify and protect deepwater coral ecosystems in the South Atlantic region. The Council has endorsed the Panels' recommendation for designation of new deepwater Coral Habitat Areas of Particular Concern under the Federal Coral FMP. New deepwater coral HAPCs will be designated through the Fishery Ecosystem Plan Comprehensive Amendment.

Scope

The **Deepwater Coral Research and Monitoring Plan for the South Atlantic Region** constitutes the regional research component of the implementation plan that will be a part of the NOAA Deep-Sea Coral and Sponge Conservation and Management Strategy. The purpose of the plan is to guide deepwater coral ecosystem research and monitoring efforts conducted by NOAA and partners through grants and contracts in the South Atlantic region. Additional components will address needs to expand partnerships, identify funding needs and implement deliverables.

In developing this plan, the South Atlantic Fishery Management Council is responding to recent amendments to the Magnuson-Stevens Act and NOAA's determination that an agency strategy is needed to effectively and efficiently address deepwater coral ecosystems issues. The primary goal of this Research and Monitoring Plan is to support conservation and management of deepwater coral ecosystems in the South Atlantic region while addressing NOAA's strategy to balance long-term uses of the marine ecosystem with maintenance of biodiversity. The Plan will also assist in meeting the new mandates of the Magnuson-Stevens Act.

This plan incorporates recommendations and needs developed through the Deep-Sea Corals Collaboration meeting held in Tampa, Florida in 2002 and the Deep Sea Corals workshop report (McDonough and Puglise 2003). This will allow the Council to build on the expertise and insight of the international deepwater coral research community. To focus the needs to the South Atlantic region, the Council has engaged regional experts to serve as the primary contributors of this Research and Monitoring Plan.

This Research and Monitoring Plan responds directly to mandates included in the 2006 reauthorization of the Magnuson-Stevens Act:

"SEC. 408. DEEP SEA CORAL RESEARCH AND TECHNOLOGY PROGRAM.
"(a) IN GENERAL.—The Secretary, in consultation with appropriate regional fishery management councils and in coordination with other federal agencies and educational institutions, shall, subject to the availability of appropriations, establish a program—
"(1) to identify existing research on, and known locations of, deep sea corals and submit such information to the appropriate Councils;
"(2) to locate and map locations of deep sea corals and submit such information to the Councils;
"(3) to monitor activity in locations where deep sea corals are known or likely to occur, based on best scientific information available, including through underwater or remote sensing technologies and submit such information to the appropriate Councils;
"(4) to conduct research, including cooperative research with fishing industry participants, on deep sea corals and related species, and on survey methods;
"(5) to develop technologies or methods designed to assist fishing industry participants in reducing interactions between fishing gear and deep sea corals; and
"(6) to prioritize program activities in areas where deep sea corals are known to occur, and in areas where scientific modeling or other methods predict deep sea corals are likely to be present.
"(b) REPORTING.—Beginning 1 year after the date of enactment of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006, the Secretary, in consultation with the Councils, shall submit biennial reports to Congress and the public on steps taken by the Secretary to identify, monitor, and protect deep sea coral areas, including summaries of the results of mapping, research, and data collection performed under the program."

The president signed the reauthorized Magnuson-Stevens Act on January 12, 2007. Therefore, the first report is due to Congress on or before January 12, 2008. It is the Council's intent to review the report at the December 2008 Council meeting. Table 1 presents a timeline for items contained in this Plan based solely on the South Atlantic Council's priorities.

For purposes of this plan, **Deepwater Coral Ecosystems (DWCE)** are defined as: Deepwater coral, coral reefs, and live/hard bottom habitat in waters extending from 200 m to the seaward boundary of the EEZ.

Goal

To protect deepwater corals by:

A. Refining existing (proposed) and designating new deepwater Coral HAPCs.
B. Increasing our understanding of DWCEs' ecological role and function in the South Atlantic region to guide future management actions.

Phase I: Map and describe known and expected deepwater coral ecosystems in the South Atlantic region.

Phase II: Determine the ecological role of deepwater coral ecosystems in the South Atlantic region, especially the role of deepwater coral habitats as Essential Fish Habitat, and expand the understanding of structure-forming species' biology and ecology.

PHASE I: MAP AND DESCRIBE KNOWN AND EXPECTED DEEPWATER CORAL ECOSYSTEMS IN THE SOUTH ATLANTIC REGION

Justification/Background

Deepwater coral ecosystems (DWCEs) are herein defined as deepwater coral, coral reefs, and live/hard bottom habitat in waters extending from 200 m to the seaward boundary of the EEZ. Azooxanthellate cnidarians include branching stony corals (Scleractinia), gorgonians and soft corals (Octocorallia), black corals (Antipatharia) and lace corals (Stylasteridae). These DWCEs therefore include the constructional habitats generated chiefly by colonial scleractinians as well as the non-constructional "gardens" dominated chiefly by other anthozoans and sponges. DWCEs are common within the Exclusive Economic Zone (EEZ) off the southeastern U.S. and include a variety of high-relief, hard-bottom habitats at numerous sites from the Blake Plateau off North Carolina, southward through the Straits of Florida to the eastern Gulf of Mexico. Despite a series of exploratory expeditions during the last decade, only a few DWCEs in this region have been mapped in any detail, observed directly or have had their benthic and fish assemblages examined. The limited number of direct observations via submersible or Remotely Operated Vehicle (ROV) indicate that they provide hard substrates and habitat for a relatively unknown but biologically rich and diverse community of associated fishes and invertebrates, including commercial species such as wreckfish (*Polyprion americanus*), Warsaw grouper (*Epinephelus nigritus*), deepwater snappers and golden crab (*Chaceon fenneri*).

Two potential threats—fossil fuel development and bottom fishing—create a time-sensitive need to map and characterize these habitats. A moratorium on oil/gas exploration in Florida waters has long prevented impact from fossil fuel extraction; however, recent U.S. legislation directed at expanding energy production in the Gulf of Mexico, coupled with exploration by Cuba in waters adjacent to the Florida Keys, has expanded this threat. Liquefied natural gas re-gassification facilities and several proposed natural gas pipelines and offshore facilities could also directly impact local DWCEs. With respect to fishing, DWCEs worldwide have been seriously impacted by bottom trawls (Fosså et al. 2002, Freiwald et al. 2004). In Florida waters, unprotected portions of the Oculina Bank off the central east coast (75-100 m depth) have been severely affected both by overfishing and bottom trawling (Koenig et al. 2000, 2005; Reed et al. 2005b, Reed et al. in review).

Increasing our understanding of the distribution and composition of these assemblages; the physical, trophic and biochemical interactions of their components; and the environmental forcing factors that control distribution and composition across regional to local scales will enable effective ecosystem management. Such information will also provide the requisite baseline for examining ecosystem response to potential stressors and for investigating all aspects of component organism biology, including population dynamics, physiology, genetics and biopharmacology.

<u>Objective 1: Map the distribution of DWCEs in the Southeastern U.S. EEZ.</u>

1A. Determine the extent of known DWCEs in the South Atlantic region.

DWCEs occur along the southeastern coast of the United States from North Carolina to the southwestern Gulf of Mexico. Areas where DWCEs have been identified include: 1) North Carolina *Lophelia* mounds—three mound systems represent the northernmost DWCEs in the South Atlantic Bight; 2) Stetson Reefs—hundreds of pinnacles up to 152 m tall at depths of 640 to 900 m on the eastern Blake Plateau off South Carolina; 3) Savannah Lithoherms—numerous lithoherms at depths of 490 to 550 m with up to 60 m vertical relief; 4) East Florida *Lophelia* Reefs—hundreds of 15-152m tall coral bioherms and lithoherms at depths of 600 to 870 m along the shelf margin from southern Georgia to the Straits of Florida; 5-6) Miami and Pourtalès Terraces—relict phosphoritic limestone bank-margin hardgrounds and escarpments extending from Boca Raton to Key West at depths of 200 to 600 m; and 7) Southwest Florida Lithoherms—dozens of 15m tall *Lophelia* lithoherms at 500 m in the eastern Gulf of Mexico (Reed et al. 2004, 2005a, 2006). Only a small percentage of these sites has been investigated beyond fathometer transects; each new exploratory expedition discovers new sites. Many more coral sites are likely, and the full extent of topographic features on the Blake Plateau remains unknown. Similarly, the distribution of possible DWCEs along the southern margin of the Florida peninsula south of Miami and along the Florida shelf margin in the Gulf of Mexico are largely uninvestigated.

Increasingly sophisticated mapping technology, such as ship- and Autonomous Underwater Vehicle (AUV)-mounted multibeam sonar systems with backscatter data, side-scan sonar systems, and sub-bottom seismic profilers can be used to provide detailed bottom imagery with resolution to 1-3 m. A simple light-weight digital camera system can also be lowered during fathometer or AUV transects of topographic features to provide first-order ground-truthing (i.e., to determine presence/absence of corals) (see Grasmueck et al. 2006, in review). Geographic Information Systems (GIS) can be used to integrate mapping data with other geo-spatial information (e.g., fishing pressure, management areas, biological, geological, physicochemical observations, geophysical structure, hydrodynamics) to generate detailed and precise maps and datasets and foundation for robust system analyses, predictions, and management protocols. Only a small portion of this region has been mapped using ship based multibeam sonar (S. W. Ross et al. 2006, unpubl. data); maps from the North Carolina coral mounds and a portion of the Stetson Banks revealed numerous new features, suggesting that the coral habitat is much more extensive than previously thought. Only a few days of multibeam mapping (Ross et al. 2006 cruise) provided more bottom type data than had been accumulated in 6 years of previous cruises.

TASK 1: Inventory existing literature and data with a focus on expanding work within existing (proposed) Coral Habitats of Particular Concern (CHAPCs) by:
a. Completing the Southeastern United States Deep Sea Corals (SEADESC) Initiative (Partyka et al. in press) and integrating data into Council IMS, and
b. Completing and integrating data sources identified by deepwater portion of the Southeast Area Monitoring and Assessment Program (SEAMAP) -- Recovery, Interpretation, Integration and Distribution of Bottom Habitat Information for the South Atlantic Bight, 200-2000m.

TASK 2: Rank areas to be mapped within proposed CHAPCs and potential DWCEs outside CHAPCs by:
a. Identifying data gaps based on above inventory,

b. Obtaining SAFMC input to rank priority areas for investigation, and
c. Conducting an *ad hoc* workshop to rank gaps based on proposed CHAPCs as well as outlying areas.

TASK 3: Conduct acoustic seabed mapping, **and ground-truth with visual surveys within proposed CHAPCs and priority areas outside CHAPCs** . Begin with low-resolution over wide areas followed by high-resolution mapping of targeted area (e.g., multibeam echo sounder, sidescan sonar) and ground-truthing (e.g., ROVs, AUVs, towed cameras, cores, samples) based on SAFMC recommendations.

1B. Map human activities that may impact DWCEs.

As noted in the Justification/Background section above, fossil fuel development and bottom fishing represent the primary potential near-term threats to local DWCEs. The continuing depletion of coastal fisheries may expand fishing efforts into deeper habitats in search of valuable commercial species such as royal red shrimp (*Hymenopenaeus robustus*), other shrimps and crabs, wreckfish, and other fish species (some not yet exploited). One of these, the Warsaw grouper, is a candidate for designation as a threatened or endangered species.

TASK 1: Obtain Vessel Monitoring System (VMS) access and produce maps showing fishing effort by location.

TASK 2: Assess fishing pressure in and outside CHAPCs through analysis of fisheries-dependent (e.g., NMFS landings) and fisheries-independent data. Produce maps showing fishing effort by location.

TASK 3: Map non-fishing activities that may affect DWCE resources (e.g., dredging, cables, outfalls, run-off, shipping routes and energy development and exploration activities).

1C. Assess condition of DWCEs in the South Atlantic.

Assessing the health and status of deepwater corals in the southeastern U.S. is difficult because there is a general lack of criteria on what constitutes good or bad conditions in these systems and a lack of historical data for comparisons. Dead corals are abundant at almost all locations, but whether this is normal or not, is unclear. Whether reefs are declining, stable, or building cannot be judged without additional studies. It seems clear that fairly strong currents coupled with bottom temperatures below 12º C are needed and monitoring these conditions may be good starting points. There is concern that changing ocean pH may negatively impact deepwater corals (Guinotte et al. 2006), and this should also be considered in monitoring or impact assessment.

Live coral coverage is generally low on the majority of deepwater *Lophelia* reefs in this region (1-10%); however, cover varies from nearly 100% living coral on portions of some reefs to extensive areas of 100% dead coral rubble on others (Reed et al. 2005b, 2006, in review; Grasmueck et al. in review). The deepwater *Oculina* reefs off eastern Florida have been designated a habitat area of particular concern (HAPC) for the protection of the coral habitat since 1984 (Reed 2002b, Reed et al. 2005b). A portion also has been designated a marine protected area (MPA) for management of the snapper grouper complex. Even so, extensive areas of the *Oculina* reefs have been severely impacted by both legal and illegal bottom trawling since 1984 (Koenig et al. 2005, Reed et al. 2005b, in review). Some areas in the northern section of the MPA that were documented as thriving reefs by photo transects in the 1970s had been found to be reduced to 100% rubble during submersible dives in 2001 (Reed et al. in review). However, some of the reefs in the southern portion that had been protected since 1984 are still thriving. So far we have no evidence that commercial bottom trawling has occurred on the *Lophelia* reefs in this region of the western Atlantic, and so it is still speculative as to whether the cause of the high percentage of dead coral could be due to natural senescence of the reefs, paleoclimatic factors, coral pathogens, or other unknown factors.

TASK 1: Identify and quantify natural and anthropogenic stressors (e.g., disease, gear impacts, energy development and exploration, nutrients, sedimentation, ocean disposal of dredge spoil, sewage sludge, paleoclimatic changes, temperature).
TASK 2: Conduct biological and environmental monitoring of indicator species at different scales.
a. Identify potential indicator species for deepwater corals and associated species and
b. Identify monitoring programs for those species.
TASK 3: Monitor impacts of episodic events (e.g., changing currents, temperatures, pH, sediment dynamics, food dynamics).

<u>Objective 2: Describe the physiographic environment of DWCEs.</u>
2A. Describe abiotic features (i.e., hydrographic, chemical) of DWCEs.
The waters and seafloor of the continental margin of the southeastern U.S. have been investigated for over a century and a half, beginning with work by the U.S. Coast Survey and U.S. Navy (e.g., Agassiz 1888). The Gulf Stream, a principal oceanographic feature of the region, is among the most thoroughly studied of marine systems, and the physiography and underlying geology of much of the region are well documented. However, apart from instantaneous localized observations made during submersible or ROV operations -- and broad-scale datasets and models of geologic structure, hydrography and physicochemical parameters -- little if any information exists about how abiotic factors directly affect and control local DWCEs. No time-series data of the environmental factors (e.g., bottom currents, turbidity, upwelling, temperature, dissolved oxygen or sedimentation rates) have been collected on DWCEs that would contribute to understanding DWCE distribution, growth, and the composition and dynamics of associated assemblages. However, annual records of hundreds to thousands of years that are relevant to abiotic conditions in these habitats may be contained in several species of deepwater corals (see Williams et al. in press; Druffel et al. 1995; Holmes et al. unpubl. data). This research should be continued. Although much work has been done on the southeastern U.S. margin, relatively little is known about basic parameters compared to the mid-Atlantic and north Atlantic costs of the U.S. There is a need to conduct physical and chemical monitoring at multiple spatial (individual mound to regional) and temporal (tidal to decadal) scales, including identification of episodic oceanographic events (e.g., intrusions, upwelling) and physical disturbances (e.g., turbidity plumes, storms).

TASK 1: Inventory existing deepwater (seafloor) data sources in the South Atlantic region (e.g., Ocean Observing System, OOS).
TASK 2: Identify required data sets and observing technologies (e.g., OOS, benthic landers).
TASK 3: Establish and carry out a deepwater monitoring plan for CHAPCs in partnership with the Southeast Coastal Ocean Observing Regional Association (SECOORA), starting with a pilot observing station at a fairly well-described DWCE.

2B. Investigate the internal structure of DWCEs, particularly in relation to overlying hydrodynamic and physicochemical conditions, and changing climate over time.

TASK 1: Conduct sub-bottom acoustic profiling survey over various DWCE habitats
TASK 2: Based on profile surveys, target specific DWCE types for follow-up coring from surface to base mounds

Objective 3: Describe and inventory biota of DWCEs.
The dominant biogenic architectural components of local DWCEs are the azooxanthellate, colonial scleractinian corals *Lophelia pertusa* and *Enallopsammia profunda*, with *Madrepora oculata* and *Solenosmilia variabilis* occurring as isolated colonies (Reed 2002a, b). Both constructional DWCEs and non-biogenic hard substrates (e.g., Miami and Pourtalès Terraces) provide habitat for a wide diversity of sessile macrofauna including solitary Scleractinia, gorgonians and soft corals (Octocorallia), black corals (Antipatharia), hydrozoan corals (Stylasteridae) and sponges (Demospongiae and Hexactinellida), which in turn provide habitat and living space for a relatively unknown but biologically rich and diverse community of associated organisms, including fishes, anemones, zoanthids, crustaceans, mollusks, echinoderms, polychaete and sipunculan worms, and foraminiferans (Ross and Nizinski in press).

Qualitative studies of the DWCEs off the southeastern U.S. identified 142 taxa of invertebrates and 58 species of fish directly associated with these coral habitats (Reed et al. 2006). The deepwater fauna of the east Florida margin includes at lest 53 species of Scleractinia (Cairns and Chapman 2001), ~15 stylasterids (Cairns 1986) and dozens of octocorals. The deep Gulf of Mexico fauna includes 84 Scleractinia (Cairns and Chapman 2001; Cairns in prep.), 5 stylasterids, and 115 octocorals (Cairns in prep.). Because Florida, and the Straits of Florida in particular, represents an important biogeographic boundary where different deepwater faunas meet to generate the greatest known species richness in the western (and perhaps entire) Atlantic Ocean (Carpenter 2002), it is expected that the complex three-dimensional habitats of local DWCEs will include important biodiversity "hotspots." However, current taxonomic information is scattered in the primary specialist literature. The fish fauna of the region (at least 98 species identified on and around deepwater coral habitat) was reviewed by Ross and Quattrini (in press and in review), but only preliminary notes of other fauna from scattered locations exist. This region may harbor a number of new species associated with deepwater corals, some described (e.g., McCosker and Ross in press; Fernholm and Quattrini in review) and some soon to be described (e.g., Nizinski et al. unpubl. data).

3A. Qualitatively and quantitatively describe the composition, diversity, assemblage organization and distributional patterns of DWCE benthic and water column fauna (invertebrates and vertebrates).

TASK 1: Develop a network of taxonomic experts and support comparative studies (e.g., validation, or inter-regional comparisons).
TASK 2: Assess biodiversity of all groups at different spatial scales (including molecular approaches for phylogeny, phylogeography, genetic connectivity, population dynamics and species boundary assessment).
TASK 3: Make products accessible through appropriate databases (e.g., Council's Internet Mapping Server, Ocean Planning and Information System, OPIS; Southeast Regional Taxonomic Center, SERTC; Coral Reef Information System, CORIS; Census of Marine Life).

3B. Determine relative abundance and occurrence of economically and ecologically important species associated with DWCE.

Sampling will require the use of multiple, standardized methods to allow for counting of individual species. Techniques will need to be adapted based on the fauna of interest and locations to be sampled (e.g., water column, benthic, surface). Methods may range from visual/video surveys with selective collections to quantitative sampling using coring devices or nets.

PHASE II: DETERMINE ECOLOGICAL ROLE OF DWCE, INCLUDING THE ROLE OF DEEPWATER CORAL HABITAT AS ESSENTIAL FISH HABITAT EXPAND UNDERSTANDING OF STRUCTURE-FORMING SPECIES' BIOLOGY AND ECOLOGY

Justification/Background

The southeastern United States may have the most extensive aphotic DWCEs in U.S. waters (Hain and Corcoran 2004); however, these large habitats are poorly documented and understood. Based on available data, DWCEs appear to occur abundantly on the southeastern United States slope (Stetson et al. 1962; Paull et al. 2000; Popenoe and Manheim 2001; Reed et al. 2005a, 2006; Ross and Nizinski in press). Prior to this century, these unique habitats had not been examined in detail in this region because of the great depths at which they are found, the rugged bottom topography, and extreme currents (e.g., Gulf Stream).

Ongoing research on DWCE in the southeastern United States has been based on the premise that these habitats are ecologically important and productive, yet very little is known about their ecological roles. The southeastern United States harbors over 100 deepwater coral species (Ross and Nizinski in press.), some of which create extensive, complex reef structures. These complexes are hotspots of increased biodiversity. Many coral species are very long lived (hundreds to thousands of years), and serve as natural repositories of data on climate, ocean physics, and ocean productivity (Adkins et al. 1998; Williams et al. 2006; Williams et al. in press). However, research on this topic is just beginning as is research on population and community genetics. There are no studies on trophic ecology or energetic models for DWCE of the southeastern United States.

Deepwater coral habitat now appears to be more important to northwestern Atlantic slope species than previously known. However, it is unclear whether this habitat is essential to selected fishes or invertebrates or whether they occupy it opportunistically (Rogers 1999; Auster 2005; Costello et al. 2005). Coral thickets, coral rubble, and the less structured nearby non-reef habitat all support diverse faunas in the southeastern United States (Reed et al. 2002, Reed et al. 2005a, 2006; Ross and Quattrini in press.). Analyses indicate that many species of fishes (Ross and Quattrini in press.) and invertebrates are closely associated with the unique deepwater reef habitat (Reed et al. 2006), including commercially-exploited deepwater species (e.g., wreckfish and golden crabs) and potentially exploitable species (e.g., royal red shrimps, blackbelly rosefish, bericiform fishes, eels). However, reef-invertebrate associations may be more opportunistic than those found in certain fishes (Ross et al. unpubl. data), but more data are required to confirm these associations.

Our understanding of DWCEs within the U.S. EEZ has progressed rapidly over the past decade, primarily though a series of exploratory cruises that have provided information on the distribution and general characteristics of these valuable resources. The next steps involve addressing ecosystem function and resilience to change, both anthropogenic and natural. In the South Atlantic region, DWCEs dominated by *Lophelia pertusa* and *Enallopsammia profunda* create extensive and complex structural framework which provides settlement substrate and microhabitat for a diverse benthic fauna. An understanding of individual and population level biology of these foundation species is a pre-requisite to effective ecosystem management. All ecosystems are subject to disturbances of various types, both natural and anthropogenic. Pristine ecosystems are generally resilient to disturbance, meaning that they can return to an original state via natural recovery processes. Resilience is an important ecosystem characteristic that needs to be fostered and protected via proactive management. As far as we know, the DWCE of the southeast region are relatively unimpacted; this could change rapidly with the advent of new energy proposals (liquefied natural gas ports and pipelines), development of deepwater fisheries and more subtle impacts such as pH reduction through global alterations in CO^2 cycles. Increasing our understanding of the biology of the keystone species, at an individual and population level will provide baseline data from which to assess ecosystem response to future stressors. At the individual level, factors such as growth rate, skeletal density, and fecundity can change in response to environmental stress.

Resilience at the population level may be largely dependent on the genetic composition and richness. Genetic and genotypic diversity provide scope for species to adapt to changing conditions such as warmer temperatures and/or altered pH. Branching corals such as *L. pertusa* and *E. profunda* reproduce asexually via fragmentation (i.e., branches break off and reattach to the substrate to form a new colony that is genetically identical to the parent). It is important to understand the extent of genotypic diversity present in *L. pertusa* populations to assess their potential for adaptation to global changes. Understanding patterns of genetic connectedness (i.e., gene flow) is important to contextualize and predict larval recruitment pathways, and ultimately to incorporate such information into design of deepwater coral HAPCs.

Considering the above, research priorities of locating, describing, and mapping deepwater corals and conducting basic biological studies in these habitats are necessary baseline data for developing appropriate management schemes. The goal of research described herein is to address major data gaps to facilitate management of deepwater coral habitat and allow increased understanding of its role in deepwater ecology.

Objective 1: Describe logistic and coordination efforts that could improve the efficiency and effectiveness of deepwater coral biological studies.

Given the expense and difficulty of studying deepwater organisms it is prudent to consider aspects of coordination of data collection within the scientific community that would enhance the value and effectiveness of all possible observations and samples over a wide range of objectives. For example, video footage is probably the most common data collected from deepwater coral habitats, but it is not collected in a standardized format that will allow comparison of information from different sites or cruises (e.g. size, percent cover, proportion live/partial mortality, growth or color morphs). A handbook of 'Deep Sea Coral Collection Protocols' by Etnoyer et al. (2006) has been compiled in an effort to standardize data collection from deepwater coral habitats. This will be available on-line in the near future, and includes protocols for video and photographic documentation as well as sample preparation for different purposes. A cooperative effort among the scientific community to abide by common protocols will potentially increase the utility of data collected during each expedition Another example of cooperation among groups that would maximize cruise time would be to formalize a chain-of-custody or clearing house for samples (e.g., corals, associated animals, pieces of skeleton etc.) that are collected during research cruises, and are not used by the cruise scientists. This would partition material to as many types of studies as possible (e.g., live material for lab experiments, ethanol-preservation for genetic analysis, surface treatments for microbial studies, tissue fixative for histological study, etc.) and make use of samples that would otherwise not be processed.

TASK 1: To the extent possible, use standardized protocols for data collection so that information may be exchanged among investigators and agencies.
TASK 2: Develop standardized chain-of custody for samples to optimize use of opportunistic or excess samples from deepwater coral habitats.

Objective 2: Describe the population dynamics, movements and habitat associations of both economically and ecologically important species (including potentially exploitable species) associated with DWCEs.
Many aspects of the ecology and biology of deepwater coral communities of the southeastern U.S. are either unknown or poorly understood, especially as it pertains to population dynamics. Population dynamics data are essential for understanding the historical and current status of populations, as well as modeling future population projections. For example, understanding how populations respond to extractive activities (fisheries) or respond to natural mortality requires knowledge of age and growth rates. Such studies are integral to understanding how populations might respond to climate change.

Information on spawning seasonality and locations are important for protecting reproductive integrity. Reproduction data (e.g., fecundity and spawning behavior) are needed to understand and model population fluctuations. Putting boundaries on population parameters requires studies on gene flow. Although determining barriers to gene flow that may isolate populations has been problematic for marine species (Palumbi 1994), various slope species exhibit unexpected degrees of population heterogeneity (Rogers 2002). Appropriate genetic techniques could facilitate inferences regarding organism dispersal and recruitment dynamics. Such data have important implications for how populations sustain themselves.

Many studies of the various aspects of population dynamics should concentrate (at least initially) on economically important, potentially economically important, and key ecological species. Although an appropriate species lists needs to be developed, these taxa of interest should include wreckfish, scorpionfishes (particularly blackbelly rosefish), alphonsinos, roughies, conger eel, red crabs, shrimps, galatheid squat lobsters, squids, and sponges. To date the only species of this grouping that has published information for the southeastern U.S. slope is the wreckfish (Sedberry et al. 1994; Weaver and Sedberry 2001; Vaughn et al. 2001). For most deepwater reef organisms of the southeastern United States there are no published data on age, growth, reproduction, genetic structure, movements, recruitment, and habitat relationships.

Note: Sampling for trophodynamic patterns (see objective 3) could easily be adapted to gather data for most population dynamics aspects below. While this might require little additional funding for field efforts, accessory funding for laboratory analyses and reporting would be needed.

2A. Determine the habitat relationships between deepwater corals and the species associated with them.
The lack of habitat association data hampers our understanding of deepwater reef communities and the roles of complex habitats in structuring or maintaining deepwater

communities. If fauna are less explicitly associated with habitats in deepwater, this supports the hypothesis that slope fauna are more opportunistic because the deep sea environment has fewer resources (compared to the shelf). However, in contrast to the northwestern Atlantic (Auster 2005), data support hypotheses that southeastern U.S. deepwater coral banks host a unique, probably obligate, fauna and that the reefs concentrate food resources (Ross and Quattrini in press.). How deep does this pattern extend and is it true throughout the southeastern United States' slope?

TASK 1: Characterize habitat associations of invertebrate and fish faunas on and surrounding DWCEs. Sampling should include the full geographic and depth ranges of this habitat in the southeastern U.S., as well as all seasons. Direct observation methods (submersible or ROV) coupled with collections of habitat and fauna are the best way to sample these rugged areas for habitat association data (see Parker and Ross 1986; Sulak and Ross 1996; Ross and Quattrini in press.). It is important in this task to sample non-reef and non-coral habitats in order to adequately judge degrees of habitat association.

2B. Determine the migratory pathways of the economically and ecologically important species associated with DWCEs.

TASK 1: Characterize both the vertical and horizontal movements (at different spatial and temporal scales) of species associated with DWCEs, including all relevant life history stages. To infer vertical movement, sample the water column for species associated with DWCE at various depths over the appropriate time scale. To infer horizontal movement (especially of benthic species), sampling would be required that is logistically difficult (tagging) in the deep-sea, intensive, and expensive. In the near-term, the inference of horizontal movements may not be feasible.

2C. Determine the age structure and growth rates of economically and ecologically important species associated with DWCE as well as the sex ratio within each species.

TASK 1: Collect the full size range (juvenile to adult) of the species available within the study site across seasons.
TASK 2: Determine appropriate aging methods based on taxa examined and age samples.
TASK 3: Construct growth models.

2D. Determine the recruitment processes for the economically and ecologically important species associated with DWCE.

TASK 1: Conduct high-intensity temporal sampling using appropriate methods (e.g., settling plates and traps) to determine larval settlement processes including sites, periodicity, and relevance to oceanography. For traps, samples should be collected by setting multiple settlement traps within the deepwater coral habitat of interest and the adjacent non-reef habitat. Replication and placement of the settlement traps is critical for determining whether settlement is random or based on specific cues. It would be important to record various physical data (e.g., current, temperatures) near these samples.

TASK 2: Determine larval duration, distribution, and vertical migration in the water column. Sample the water column for species associated with DWCE at various depths over the appropriate time scale. For fish species, determine daily ages of fishes from otoliths to determine larval duration. Understanding horizontal and vertical water column physics is important here, and if appropriate models are not available, they should be developed (see next task).

TASK 3: Model the information collected under the two previous tasks with horizontal scale physics (e.g., currents) to improve the understanding of recruitment processes and population connectivity.

2E. Examine the reproductive biology of economically and ecologically important species associated with DWCE.

Characterize the spawning seasonality and reproductive potential of the species of interest by collecting the full size range (juvenile to adult) of the species available within the study site. Adequate sampling will require collection of data on monthly or quarterly intervals and ensuring that there are sexual differences in the population. Samples should be analyzed for sex, reproductive state, and fecundity (for females only). Method details may vary by taxa examined.

2F. Determine the genetic structure of the economically and ecologically important species associated with DWCE.

TASK 1: Sample coral and associated species at a regional scale to make inferences about the mechanisms structuring local assemblages (e.g., community genetics). Using a community genetics approach (Agrawal 2003; Neuhauser et al. 2003; Whitman et al. 2003), patterns of genetic structuring should be compared among taxa and with environmental variables. This study should also include examining the genetic structuring of fauna closely associated with *Lophelia* and other habitat-forming corals and sponges, such as galatheid "crabs" (*Eumunida picta*), eunicid polychaetes (Roberts 2005), urchins and some fishes. If associations between *Lophelia* and co-occurring invertebrates are strong, similar genetic patterns may result, suggesting that similar mechanisms may influence community structure of associated organisms.

Objective 3: Describe food web dynamics of DWCEs.

To assess natural and anthropogenic impacts, the degree of connectivity among ocean zones (e.g., benthic, abyssal, and neustonic) must be better understood. The execution of research within these zones has lead to an implicit assumption of compartmentalization. However, ocean waters and many of their inhabitants regularly move across perceived boundaries, and systems are much more connected than previously reported (Knight et al. 2005) as evidenced by improved tracking of animal movements and energy flow (trophodynamics).

Input of energy to the deep seafloor was thought to be from the top down and mostly passive. In the northeastern Atlantic, the energy source of *Lophelia pertusa* is derived from particulate matter drifting down from the upper water column (Duineveld et al. 2004), but trophic data for the broader community are lacking. A hypothetical trophic web was developed for the deepwater *Oculina* ecosystem which consists of the coral biogenic refuge for hundreds of species of invertebrates and fishes which in turn receives plankton/particulate input from the Florida Current (Gulf Stream) and cold-water upwelling events providing influxes of nutrients (George et al. in review). It is likely that active vertical movements of animals provide a substantial, regular flow of energy through the water column to the seafloor (Kinzer 1977; Genin 2004; Gartner et al. in review). Such movements may be diel, ontogenetic, or both and move resources in both directions, variously impacting a large section of the water column.

During past submersible observations (coupled with depth-discrete sampling) off the southeastern U.S. large concentrations of mesopelagic (midwater) fauna were noted on the bottom near deepwater (360 to 700 m) coral banks (Gartner et al. in review). Mesopelagic fauna were observed acting as both predator and prey of benthic organisms. Whether this activity is sporadic or whether various animals depend on such interactions is unknown. If the migrating mesopelagic fauna is a major conduit of energy through the water column, human (or other) perturbations of the bottom and midwater faunas may have significant impacts on pelagic fishes, seabirds, and marine mammals through effects on trophic relationships. However, open ocean ecological coupling (expressed by food web inter-connection among benthic and water column nekton) is poorly studied.

Research described here will begin to define faunal connectivity in terms of trophic linkages over and around DWCE. Characterization of trophodynamics and benthic-pelagic interactions of organisms associated with deepwater corals would provide important information on food resources and sources, feeding periodicity, and how various habitats from the bottom to the surface are linked. In addition to traditional diet analyses of collected specimens, stable isotope ratios (of carbon, nitrogen, and possibly sulfur) of deepwater coral area organisms (whole water column) would establish trophic signatures that help define community relationships (Thomas and Cahoon 1993; Kwak and Zedler 1997; MacAvoy et al. 2001). From these data we could answer important questions about the broad impacts to a particular habitat or group of organisms from natural or anthropogenic events. An added advantage of a trophodynamic study is that the process of collecting organisms to describe feeding relationships can provide valuable additional data (e.g., species-habitat associations, distributions, abundances, sizes, reproductive states, etc.).

3A: Characterize the trophodynamics and the benthic-pelagic interactions of organisms associated with deepwater coral habitat using both traditional and novel approaches.

The traditional approach is to capture organisms, determine species, and analyze their stomach contents.

A novel approach to couple with the above method is to analyze stable isotopes in the tissues of the captured fauna. Naturally occurring isotopic concentrations in various tissues identify sources of dietary components (e.g., from plankton or benthic sources) provided there is a good understanding of the isotopic signatures of potential food sources.

Sampling should be conducted using the appropriate temporal and spatial scales.

Temporal scale: For the traditional approach, it is important to collect data on a seasonal basis and if possible on a diel basis because stomach content data reflect only a snap-shot of the diet of a species. Sampling for the novel approach method can be conducted at any time of the year because isotopic signatures represent an integration of diet over time in the tissues.

Spatial scale: For both the traditional and novel approaches, organisms should be collected in both the water column above the deepwater coral habitat of interest, within that habitat itself, and in the adjacent benthic non-reef habitats. Since reef habitat varies throughout this region, the ideal sampling scheme would have replicate samples collected from a minimum of three previously studied sites between Cape Lookout and the Florida Straits in which preliminary analyses have suggested differing benthic populations.

Objective 4: Describe relationships among DWCE composition, structure and distribution and abiotic and biotic factors.

4A. Identify relationships between the distribution and development of DWCEs and abiotic and biotic factors.

As noted previously, no time-series data exist on the hydrographic or physicochemical characteristics of the water column associated with DWCEs in the region. Detailed data on temporal and spatial patterns and ranges of variation in abiotic factors, e.g., temperature, salinity, dissolved gases, hydrodynamics (bottom currents, upwelling, tides, eddies), turbidity levels and the nature of suspended material, represent a baseline of information required for understanding DWCE composition, growth, structure and distribution. Similarly, no data exist on the composition of seston (i.e., plankton, suspended organic detritus and inorganic particles) available to DWCEs or the patterns, abundances and rates of its import to DWCEs. Such data are critical to understanding DWCE trophodynamics and growth patterns.

TASK 1: Collect time-series data of abiotic and other water column factors using a variety of deployed instrument packages (e.g., time-lapse cameras, current meters, CTDs, sediment traps, larval settlement panels).

TASK 2: Conduct multivariate analyses of abiotic factors versus organism distributions and DWCE structure.

4B. Develop models to enable predictions of DWCE status and trends.

TASK 1: Identify suitable models and conduct model-data comparisons to validate models specifically for DWCE application:

a. Ocean circulation (physical, chemical parameters) and

b. Sedimentation.

4C. Determine long-term temporal (decadal to epochal scales) relationships between DWCE structure and distribution relative to overlying hydrodynamic regime.

Although the broad-scale geology of the region is reasonably well understood, no cores have been taken through local DWCEs that might contribute to understanding their development, particularly with respect to climate change. Such coring (or drilling) was quite valuable in determining the origins and history of deepwater coral banks in the northeastern Atlantic (Williams et al. 2006).

TASK 1: Examine historical records of pollution, productivity, climate and oceanography across the South Atlantic region.

TASK 2: Determine age, growth and senescence of DWCE (bioherms and lithoherms) by:

a. Radioisotope and amino acid racemization analysis of corals,
b. Cores of coral mounds and
c. Sub-bottom profiling across mounds and hard bottoms.

Objective 5: Describe reproductive strategies (gametogenic cycles, sex ratio, fecundity, larval development modes) of priority structure–forming groups, including scleractinians (*Lophelia pertusa*, *Enallopsammia profunda*, *Madrepora oculata*), octocorals, antipatharians and Stylasterines.

Gametogenesis has been described for several species of structure-forming scleractinians, from the Eastern and Western Atlantic and the Pacific. Generally they are gonochoristic (i.e. separate sexes), seasonal broadcast spawners, with small eggs, and probably dispersive larvae. This is the extent of our information for most of these species. *Lophelia pertusa* has been studied more extensively than other species, using samples from Norway, the Gulf of Mexico and the Florida Straits. Seasonality of gametogenesis appears to vary with location. The gametogenic cycle of samples collected from the Norwegian Fjords began in April and terminated with spawning in March the following year (Brooke and Jarnegren in prep.). In the Gulf of Mexico, however, gametogenesis begins in November and spawning probably occurs in late September/October (S. Brooke unpubl.). Fecundity of both sets of samples is high but quantified data have not yet been compiled. Research into reproduction of octocorals from Alaska and New England is also underway (Simpson unpubl), and some work has been done on reproduction in Alaskan stylasterines, which are all brooders and produce short-lived planulae (Brooke and Stone in review). Larval biology has been described for *O. varicosa* (Brooke and Young 2005) but not for any of the other deepwater corals.

Hydrodynamic models can provide probability distributions for larval dispersal under a variety of environmental scenarios but they require basic biological input data on parameters such as timing of spawning/larval release, larval duration, and behavior. Such data are not currently available for the southeastern U.S. deepwater corals but are needed to enhance the effectiveness of modeling efforts.

5A: Determine the gametogenic cycles and spawning periods for structure-forming corals.

TASK 1: Collect samples for histological examination. Characterization of these cycles requires repeated sampling at individual sites over time (e.g., monthly). Such sampling can be done opportunistically (i.e. haphazard collections during other cruises) but would be accomplished much more efficiently with targeted sampling effort.

5B: Determine larval development and settlement processes for structure-forming species.

TASK 1: Collect samples of important structure-forming species at the end of the gametogenic cycle to spawn for larval studies.

Objective 6: Describe patterns and processes of colony growth and mortality (e.g., calcification, carbon and energy budgets) of important structure-forming species, and determine how they are affected by environmental factors and stressors.

The growth of *L. pertusa* has been measured using various methods (Duncan 1877; Dons 1944; Freiwald 1998; Gass and Roberts 2006), which have estimated growth rates between 4-26 mm per year, with the most likely estimates at approximately 5mm per year (Mortensen and Rapp 1998). These methods have measured linear extension rather than calcification rates, but the latter could potentially be calculated from growth rates and skeletal density. Growth rates of some gorgonians and antipatharians have also been measured using rings in the gorgonian skeleton and isotopic analysis (e.g., Sherwood et al. 2005, Andrews et al. 2002, Risk et al. 2002; Williams et al. 2006) and in some cases the colonies are extremely old (hundreds to thousands of years) and have very slow growth rates (e.g., Druffel et al. 1995; C. Holmes et al. unpubl. data).

Field observations on distribution of *L. pertusa* indicate that the upper thermal limit for survival is approximately 12^{o}C, and laboratory studies on *L. pertusa* tolerance to temperature extremes corroborate these observations (S. Brooke unpubl. data). Preliminary experiments with heat shock proteins show expression of HSP-70 in response to exposure of temperature greater than 10^{o}C (S. Brooke unpubl. data). Experiments on tolerance to sediment load indicate that samples of L. pertusa from the Gulf of Mexico show >50% survival in sediment loads of 103 mgL-1 for 14 days, and can survive complete burial for up to 2 days (Continental Shelf Associates in review). Given the proximity of some coral habitats to oil and gas extraction sites, tolerance to drilling fluids and fossil fuels should also be investigated.

Further laboratory and field experiments are needed to examine the individual and interactive effects of environmental conditions such as temperature, sedimentation, and toxins. A range of responses or endpoints should be examined including more modern techniques such as cellular diagnostics. These include examination of levels of stress proteins produced by cells in response to external conditions such as heat shock proteins, ubiquitin, etc. There are general classes of cellular products that are known to be indicative of specific stressors such as nutritional stress, xenobiotics, metals, temperature. These techniques are being increasingly used in shallow coral systems as a more sensitive organismal response to stress (i.e. more sensitive than mortality). These responses should be measured in combination with more standard parameters such as growth, respiration, and fecundity.

Coral growth rates provide information on the rates of habitat production in DWCEs while coral mortality and bioerosion counterbalance this production with destruction. Understanding the positive and negative sides of this balance, particularly under the changes in environmental conditions that are anticipated in the coming decade or two, is crucial to the management and conservation of deepwater coral habitat and habitat function (e.g. fishery production).

6A: Determine rates of colony growth (i.e. habitat production).

TASK 1: Conduct *in-situ* tagging or staining and revisit individual colonies for selected coral species. This activity should be in concert with *in-situ* monitoring station such as a benthic lander or other instrumentation to allow correlation of coral growth performance with *in situ* environmental conditions. Radiometric aging and growth estimates should also be conducted for selected corals (e.g., antipatharians)

6B: Determine physiological responses to stress (sediment, temperature, pollutants, CO^2) and how growth rate is affected by environmental factors (i.e., how is habitat production affected by environmental factors?).

TASK 1: Conduct manipulative laboratory dose-response experiments on live coral colonies, where various responses (e.g., molecular biomarkers, growth, and respiration) to stress levels can be documented under controlled conditions. This requires collection of live samples and post cruise maintenance in a temperature-controlled facility.

6C: Determine temporal patterns of coral mortality and bioerosion (habitat loss).

TASK 1: Characterize succession of boring/bioeroding community in coral skeleton. Ideally the degree of bioerosion would be correlated with ageing data to obtain information on bioeroder succession.
TASK 2: Drill cores and age dead skeletons from a range of sites and physiographic features.
TASK 3: Develop techniques for amino acid racemization or other techniques with high temporal resolution.

<u>Objective 7: Describe the genetic characteristics of structure forming coral populations.</u>
Little is known about basic biology of deepwater coral species, including larval dispersal potential and connectivity between reefs (hence vulnerability). Given the difficulty of tracking movements of coral larvae, especially at depth, genetic methods hold great promise for estimating important factors in the longevity of deepwater reefs that could not otherwise be inferred from their biology. Levels of gene flow among adjacent sites, relative contributions of clonal (asexual) and sexual reproduction and inferences regarding larval dispersal and levels of historical connectivity obtained from genetic data can provide valuable insights for appropriate management of these unique habitats.

Codominantly inherited genetic markers are required to fully assess population structure and to estimate parameters such as gene flow, the extent of clonal reproduction, and possible hybridization. Microsatellites are codominant markers made up of short (2-6 bases), tandemly repeated units of DNA that do not code for gene products (i.e. are effectively neutral to selection) and vary in number of repeats between individuals. Due to the relatively high mutation rate observed in microsatellite DNA markers, they have been useful in analysis of population structure at a finer level than is possible using DNA genomic sequences, and have been remarkably successful at identifying recently diverged lineages in marine invertebrates (e.g. King et al. 2005). Given sufficiently large numbers of microsatellite markers and sufficient sampling coverage from throughout the species range, microsatellites can be utilized to obtain a precise measure of population structure, including an assessment of gene flow between populations, allowing identification of sources of recruitment and estimation of effective population size.

An analysis of population structure of *L. pertusa* from the northeast Atlantic and Scandinavian fjords, based upon microsatellites and nuclear ITS DNA sequences, concluded that very low levels of gene flow occurred between offshore and fjord habitats, and that population structure among fjords was substantial, indicating localized recruitment of larvae (Le Goff-Vitry et al. 2004a). This has significant conservation implications, because destruction of reefs may be permanent if they are unlikely to be re-seeded with new larvae. Attempts to utilize the microsatellite markers developed by LeGoff-Vitry et al. (2004b) for Western Atlantic *L. pertusa* have not been successful, so additional markers have been developed (C. Morrison et al. unpubl. data) for the southeastern United States and Gulf of Mexico. Generally, microsatellite markers are species-specific, and additional markers may need to be developed for other reef-forming species in the future. Preliminary results from *L. pertusa* collected in the southeastern U.S. and Gulf of Mexico revealed high variability in population structure, low clonality, and variation over small spatial scales (C. Morrison et al. unpubl. data). Such results indicate that loss of any living *Lophelia* could seriously impact genetic diversity.

7A: Determine the clonal structure of *L. pertusa* across spatial scales.

TASK 1: Conduct targeted sampling on small spatial scales to characterize patterns of genotypic structure at as many geographical locations as possible.

7B: Determine the extent of genetic connectivity among populations of *L. pertusa*.

TASK 1: Conduct combined opportunistic and targeted (to fill in gaps) sampling across the entire geographic and depth range of the species.

Objective 8: Determine the nature, patterns, and processes of communities of microbial coral associates.

The role of microbes (bacteria, fungi and archaea) in the biology of *L. pertusa* is essentially unknown and yet these organisms likely play an important role. In tropical shallow-water coral species, some microbes appear unique markers of the surrounding water column and may be associated with certain coral species or tissues (Rohwer et al. 2001, 2002), suggesting ecological interactions between the microbes and corals. Lacking algal symbionts found in shallow-water corals, deepwater corals may rely more heavily on microbes in order to remain healthy, such as fixing nitrogen, carbon cycling, chelating iron, producing antibiotics to ward off harmful bacteria, or other beneficial roles yet to be defined (C. Kellogg, pers. comm.). Microbes have been found to play key chemosynthetic roles in cold seep communities (e.g. Boetius et al. 2000; Knittel et al. 2005) that are often found in close proximity to *Lophelia* corals. Preliminary microbial data from Gulf of Mexico *Lophelia* colonies indicated a unique and diverse community that exhibited considerable variability (C. Kellogg, unpubl. data).

A combination of techniques will be necessary to characterize the microbial communities found within *Lophelia* corals. First, since the microbial community can change when exposed to varying pressures, temperatures and light conditions during sampling (C. Kellogg, pers. comm.), some corals should be fixed at depth in order to establish a baseline dataset. This will require special, sterile sampling devices for submarine or ROV work. Both culturable (capable of growing on agar plates), and non-culturable (assayed through DNA sequencing) microbes should be surveyed from *Lophelia* in as many locations as possible. Characterization of microbes from Gulf of Mexico *Lophelia* is on-going and will provide interesting comparisons with *Lophelia* from the Southeastern Atlantic coast (C. Kellogg, pers. comm.). Molecular probes targeting certain microbes may eventually allow fast assessment of presence or absence of associated microbes. Other coral species and other fauna closely associated with corals should be sampled for microbial communities as well and comparisons made among microbes found in different species.

8A: Identify the symbiotic microbial community of coral colonies in different places and environmental conditions.

TASK 1: Conduct microbial screening of opportunistic coral (and other species) samples.
TASK 2: Target sampling with "clean" *in-situ* sampler.

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