Identifying critical information needs and developing institutional partnerships to further the understanding of Atlantic deep-sea coral ecosystems

Kimberly A. Puglise, Robert J. Brock, John J. McDonough III

U.S. National Oceanic and Atmospheric Administration, Silver Springs, MD 20910, USA
(kimberly.puglise@noaa.gov)

Abstract. The deep-sea (>200 m) represents the largest portion of the ocean, but it is probably the least understood because of the technological challenges and financial resources required to explore and research this environment. With the advancement of underwater technology, astonishing images of deep-sea corals living at depths from the surface to greater than 1000 m are now becoming available to both policy makers and the public. More specifically, in the North Atlantic Ocean, these images have led many countries to begin to assess the distribution, status, health, and potential threats faced by these important ecosystems, which appear to be connected by the uniting influence of the Gulf Stream and its associated currents. Since deep-sea coral ecosystems extend beyond national boundaries and encounter similar threats, it was determined that a cooperative effort on both sides of the Atlantic could be beneficial to maximize available resources, share expertise, and exchange data to rapidly increase scientific understanding of deep-sea coral ecosystems. Thus, an international *Deep-Sea Corals Workshop* was held to identify critical information needs related to: locating and mapping deep-sea corals; understanding more about coral biology and ecology; and using specific deep-sea coral species as indicators of climate change. Priority information needs identified at the workshop were the need to: (1) conduct both low- and high-resolution mapping to locate and characterize deep-sea coral habitats; (2) conduct research on factors that influence deep-sea coral life history patterns; (3) examine how they function as habitat for fish and invertebrate species; (4) develop a comprehensive inventory of deep-sea coral species; and (5) further efforts to analyze past climate changes and to improve climate forecasting models. Described herein are: the results of the *Deep-Sea Corals Workshop*; other events with a focus on deep-sea corals; and potential pathways to increase U.S.-international collaborative partnerships.

Keywords. Deep-sea coral, institutional partnerships, North Atlantic

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Introduction

In the United States, deep-sea corals are emerging as a highly visible marine policy issue. Although initially described over two centuries ago in Norwegian waters (Pontoppidan 1755) and over a century ago in North American waters (Verrill 1862), it wasn't until the past twenty years that deep-sea corals began to draw interest from the marine policy community. This growing political interest in deep-sea corals stems from an increase in the documentation of: (1) their association with high abundances of rich and diverse fish and invertebrate communities, including some commercial species (Jensen and Frederiksen 1992; Husebø et al. 2002; Reed 2002); and (2) impacts from anthropogenic and natural processes on deep-sea corals and the species that depend on them (Koenig et al. 2000; Fosså et al. 2002; Hall-Spencer et al. 2002; NRC 2002).

Habitat-forming deep-sea corals have been shown to be associated with both fish and invertebrate species (Jensen and Frederiksen 1992; Krieger and Wing 2002; Reed 2002). *Lophelia pertusa*, a reef forming deep-sea coral, was described as being closely associated with ca. 298 species (Jensen and Frederiksen 1992); and *Oculina varicosa*, the ivory tree coral, located off the coast of Florida was found to be associated with commercially and recreationally important fish species, including the gag (*Mycteroperca microlepis*) and scamp (*Mycteroperca phenax*), groupers, the greater amberjack (*Seriola dumerili*), and snappers (Koenig et al. 2000; Koenig 2001; Reed 2002). Deep-sea corals appear to offer species critical complex habitat in areas that lack defined topography. Fishermen have observed that more fish are located in coral areas than adjacent areas that lack high relief, complex habitat. In Norwegian waters, Husebø et al. (2002) noted that redfish (*Sebastes marinus*), ling (*Molva molva*), and tusk (*Brosme brosme*) were larger and more abundant around deep-sea corals than compared to non-coral habitats. A similar relationship between fish and corals has also been documented in Alaska's Aleutian Island Chain, where rockfish (*Sebastes* spp. and *Sebastolobus alascanus*), Atka mackerel (*Pleurogrammus monopterygius*), flatfish (Bothidae and Pleuronctidae), and a gadid (*Theragra chalcogramma*) were observed to be associated with gorgonian and octocoral habitat (Heifetz 2002; Krieger and Wing 2002).

Deep-sea corals are long-lived, slow growing, fragile, and are facing an uncertain future in all ocean basins (Andrews et al. 2002; Risk et al. 2002). Assessments of deep-sea corals have shown that damage to deep-sea coral habitats in many areas has occurred or may occur from fishing associated bottom trawling, bottom-set fishing gears (e.g. bottom long-lines and gill nets), oil and gas exploration and drill cuttings, mineral mining, cable laying, dredging, and sedimentation (Butler and Gass 2001). Of the known impacts, fishing associated damage from bottom trawling appears to have the largest impact on deep-sea coral ecosystems (Koenig et al. 2000; Fosså et al. 2002; Hall-Spencer et al. 2002; NRC 2002); resulting in several countries establishing area closures to bottom trawl fisheries (EC 2003, 2004; DFO 2003; pers. communication with J.H. Fosså, 16 Mar 2004).

The purpose of this paper is to document recent activities to further the understanding of deep-sea corals in policy and scientific forums, including

international meetings containing deep-sea coral subject matter that detail critical information needs for deep-sea corals, as well as current management strategies. Additionally, the need to develop an integrated, Atlantic-wide approach to locate, study, and manage deep-sea coral habitats influenced by the Gulf Stream (Fig. 1) is discussed and encouraged.

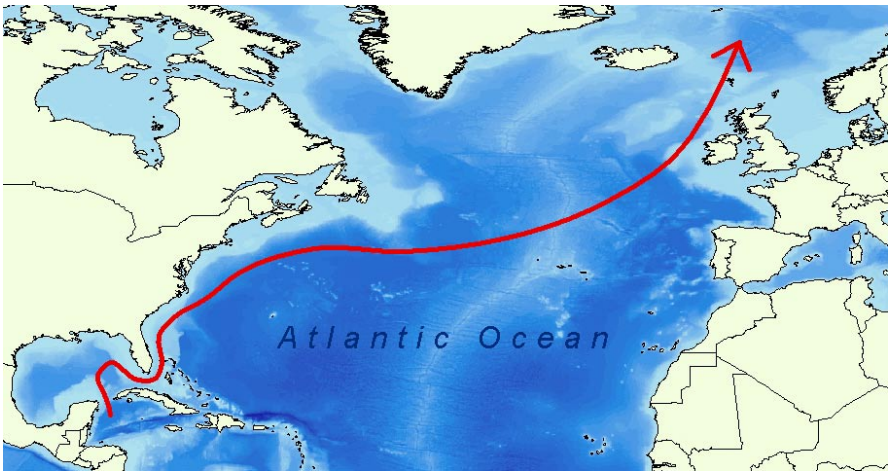

Fig. 1 The Gulf Stream current originates in the Gulf of Mexico and carries a current of warmer water through the North Atlantic Ocean, where it terminates

Recent events focusing on deep-sea corals

Deep-sea corals, unlike shallow-water tropical corals, have suffered from the "out-of-sight and out-of-mind" syndrome because they are not easily accessible by scuba diving. However, interest has increased considerably in recent years with the production of high quality images and videos of deep-sea coral communities. For example, in the late 1990's, public interest sparked by video images of Sula Reef in Norway, the largest known reef of *Lophelia pertusa* at that time, ultimately led to closure of the reef to all fishing gears (per communication with J.H. Fosså, 2004).

As international interest and information on deep-sea corals continued to expand, it became clear that the United States needed to assess the importance of deep-sea corals within its jurisdiction. Subsequently, the U.S. National Oceanic and Atmospheric Administration (NOAA), the agency responsible for managing marine living resources in the United States, scheduled a "meet and greet" session for deep-sea coral scientists attending the *Symposium on Effects of Fishing Activities on Benthic Habitats* (Tampa, FL: November 12-14, 2002) to become acquainted with the international community of deep-sea coral researchers, assess the types of research being conducted, and establish potential areas for international collaboration. During the two-hour *Deep-Sea Corals Collaboration Planning Meeting* (Tampa, FL: November 14, 2002) five common research themes surfaced and were identified as: (1) mapping the distribution of deep-sea corals; (2)

ecology of organisms associated with deep-sea corals; (3) physiology of deep-sea corals – indicators and responses to change; (4) taxonomic studies; and (5) paleo-retrospective analyses. The overwhelming interest of the participants in establishing more formal collaborations and assessing deep-sea coral research for information gaps led to the development of a workshop on deep-sea corals.

The *Deep-Sea Corals Workshop* (Galway, Ireland: January 16-17, 2003) was hosted by the Irish Marine Institute and organized by NOAA and the National University of Ireland, Galway, in response to the *Deep-Sea Corals Collaboration Planning Meeting* (McDonough and Puglise 2003). The workshop brought together an international group of researchers from the United States, Canada, Ireland, the United Kingdom, Belgium, Germany, Sweden, and Norway. The objectives of the workshop were to further identify and assess the critical information needs associated with the common themes developed at the *Deep-Sea Corals Collaboration Planning Meeting* and to identify current and future research projects or forums to advance international collaboration particularly in the Atlantic.

Critical information needs

The five common deep-sea corals research themes defined at the *Deep-Sea Corals Collaboration Planning Meeting* were further refined into three categories of critical information needed to enable a better understanding and management of deep-sea coral ecosystems (McDonough and Puglise 2003). The three critical information categories were:

Locating and mapping deep-sea corals. As a first step in building an information base, deep-sea coral habitats need to be located, charted, and characterized in terms of their distribution, diversity, and abundance. In addition, a comparison must be made between deep-sea coral habitat locations and commercial fishing areas to assess potential impacts. Two levels of mapping are required: (1) low-resolution (>10 m pixels) large-scale mapping for broad areas where no information currently exists; and (2) high-resolution (<10 m pixels) mapping in key areas where deep-sea coral habitats may be threatened. Priority low-resolution mapping areas identified by the workshop participants included Pulley Ridge (Gulf of Mexico, U.S.), the *Lophelia pertusa* banks (southeastern U.S.), the Grand Banks and George's Bank (northeastern U.S. and southeastern Canada), Skagerrak (Sweden), and the canyon heads off France. High-resolution mapping is needed in areas such as Stellwagen Bank (northeastern U.S.), the Northeast Passage (Canada), Rockall Bank (Ireland), and the Røst Reef (Norway).

Understanding deep-sea coral biology and ecology. Several fundamental questions regarding the physiology of deep-sea corals, their ecological role, geographic distribution, and genetic differences have yet to be answered. Priority information needs were those identified as critical to developing a better understanding of the: (1) ecological role of the corals, including their functioning as

habitat for fish and invertebrate species; (2) abiotic and biotic factors that influence deep-sea coral growth, reproduction, and distribution; and (3) food web and species interactions, including estimating deep-sea coral and fish stock abundances. In addition, a comprehensive species inventory is needed to establish a baseline for future deep-sea coral characterization efforts. Researchers agreed that although this work could be carried out anywhere that deep-sea corals are known to exist, it would be helpful to conduct it in coordination with the mapping efforts described above, as well as in areas that are currently closed to fishing.

Using specific deep-sea corals as indicators of climate change. Paleo-retrospective and prospective analysis may be a tool to separate natural oscillations from anthropogenic effects. Information derived from paleontological studies may also assist resource managers in determining whether changes seen in fish stock assessments are likely the result of natural variations in climate, oceanographic conditions, and/or anthropogenic stressors. Deep-sea corals may provide a unique record of temperature changes and serve as a good climate change proxy because they: (1) have a worldwide distribution from shallow waters to the abyssal depths (>6000 m) and from polar to equatorial latitudes; (2) appear suitable for disequilibria dating; and (3) contain relatively stable skeletal growth rates over a period of decades to centuries (Smith et al. 1996, 2000). Priority information needs to further efforts to analyze past climate changes and to improve forecasting models are to: (1) collect high-quality oceanographic data along the Gulf Stream and associated currents to better understand existing conditions as related to climate and corals; (2) collect deep-sea coral samples for paleoclimate analysis from discrete areas along the Gulf Stream and associated currents to better understand the relationship between past oceanographic currents and the growth rate of corals; and (3) conduct controlled growth experiments to calibrate geochemical signals and relevant water mass properties.

Additional information needs not identified at the *Deep-Sea Corals Workshop*, but of particular concern as deep-sea coral related activities expand are:

Defining the difference between deep-sea corals and shallow-water corals. As interest in deep-sea corals increases within the marine policy community and with the public, it has become apparent that a clear and concise definition is needed to differentiate deep-sea corals from their tropical counterparts (i.e., shallow-water corals) due to differing management strategies and requirements. A simple way to artificially separate cold, deep-sea corals from tropical, shallow water corals is by temperature and/or depth. Although the term “deep-sea corals” is commonly used, the term “cold-water corals” is actually more precise because some deep-sea corals can be found in “cold,” but shallow waters. However, within the U.S., where both shallow-water corals and deep-water corals exist, the term “deep-sea corals” is commonly used to signify the fact that these corals live predominately in deeper waters, “out-of-sight and out-of-mind” of those responsible for managing

them. Thus, a suggested definition for deep-sea coral ecosystems for future policy development is:

> *Deep-sea coral ecosystems occur deeper than 50 m, often consisting of both reef-like structures and/or thickets, and other species of organisms associated with these deep-sea coral habitats, and the nonliving environmental factors that directly affect deep-sea corals, that together function as an ecological unit in nature.*

Understanding the vulnerability and resilience of deep coral habitats to various anthropogenic threats. As anthropogenic activities expand into deeper waters, it is critical to document the effects on seafloor habitats, as this information is the foundation for developing sound policy and making wise management decisions.

Obtaining access to state-of-the-art advanced underwater technologies. Deep-sea coral habitats, unlike their shallow water counterparts, require specialized types of underwater technologies (e.g. remotely operated vehicles, human occupied submersibles, autonomous underwater vehicles, and advanced technical diving) to identify, map, understand, and manage them. As a result, building institutional capacities in advanced underwater technologies will be necessary to expand exploration and research activities related to deep-sea coral ecosystems.

Current and future collaborations

Recognizing the importance of developing an integrated approach to implement exploration, research, management, and education and outreach strategies for deep-sea corals, and build on existing regional initiatives, such as the European Fifth Framework Programme's *Atlantic Coral Ecosystem Study* (Freiwald et al. 2000; Grehan et al. 2001), participants of the *Deep-Sea Corals Workshop* identified future key events where deep-sea coral issues could be discussed and formal collaborations established. Table 1 lists events occurring since the *Deep-Sea Corals Collaboration Planning Meeting* that included significant discussions on deep-sea corals. Highlights from the events list are: (1) a presentation to the United States House of Representatives Oceans Caucus (Washington, D.C.: 14 March 2003), which provided an opportunity for international and U.S. scientists to make a case for continued support for exploration, research, and management related to deep-sea corals; (2) the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (New York City, NY: June 2003), which focused discussions around threats to vulnerable marine ecosystems (e.g., seamounts and deep-sea coral areas) and governance issues of high seas marine protected areas; and (3) the *Second International Symposium on Deep-Sea Corals* (Erlangen, Germany: 9-12 September 2003) in which researchers presented results of their work on deep-sea corals and continued discussions of upcoming opportunities for collaborative efforts.

Table 1 Events from November 2002 to September 2003 that included significant discussions on deep-sea coral ecosystems

Date	Meeting	Location
Nov 2002	Deep-Sea Corals Collaboration Planning Meeting	Tampa, FL, U.S.A.
Jan 2003	Deep-Sea Corals Workshop	Galway, Ireland
Mar 2003	U.S. House of Representatives Oceans Caucus Luncheon	Washington, DC, U.S.A.
Jun 2003	United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea and Discussions on Threats to Vulnerable Marine Ecosystems	New York City, NY, U.S.A.
Jun 2003	Workshops on High Seas Biodiversity Conservation and Ecosystem-Based Management	Cairns, Australia
Aug 2003	10th Deep-Sea Biology Symposium	Coos Bay, OR, U.S.A.
Sep 2003	World Parks Congress	Durban, South Africa
Sep 2003	Second International Symposium on Deep-Sea Corals	Erlangen, Germany
Sep 2003	Ocean Margins Deep-Water Research Consortium Meeting	Paris, France

Management strategies

Within the United States, the principal legislation governing the management of fisheries is the *Magnuson-Stevens Fishery Conservation and Management Act* (Magnuson-Stevens Act 1996). In 1996, the Magnuson-Stevens Act was amended to include legislation to protect ecologically important fisheries habitat or essential fish habitat (EFH). This amendment known as the *Sustainable Fisheries Act* stipulated that waters and substrate necessary to a fish species for spawning, breeding, feeding and growth to maturity should receive increased protections (Sustainable Fisheries Act 1996). The amended Magnuson-Stevens Act requires federal agencies to identify EFH for managed species and document measures that will conserve and enhance the habitat necessary for fish to carry out their life cycles (Fluharty 2000). The U.S. through its Regional Fisheries Management Councils have used the Magnuson-Stevens Act to prohibit destructive fishing gears in areas that possess vulnerable and ecologically important deep-sea coral habitat (e.g., the *Oculina Habitat Area of Particular Concern*). The 315 km^2 (92 nmi^2) *Oculina Habitat Area of Particular Concern* (HAPC) was closed beginning in 1984 to mobile trawling gear. In 1994, this ban was expanded to all mechanically disruptive bottom gear (i.e., bottom trawls, long-lining, dredging, and traps) to protect *Oculina varicosa*, an

azooxanthellate coral known to exist only in this particular location (South Atlantic EEZ 2003). In 2000, legislation was enacted that expanded the *Oculina* HAPC to 1029 km^2 or 300 nmi^2 (Reed 2002).

In response to documented trawling damages to deep-sea corals, Canada, Norway, and the European Union also recently established area closures that prohibit bottom trawling in areas known to contain deep-sea corals. In 2002, Canada designated the Northeast Channel Coral Conservation Area off Nova Scotia (Williams and Meyers 2002). This 424 km^2 deep-sea coral area prohibits all bottom trawling in order to protect deep-sea corals and associated groundfish species (Fenton et al. 2002). Canada has also used the provisions in the Oceans Act (Canada 1996) to put forth a proposal to designate another deep-sea coral area off Nova Scotia, the Sable Gully, as a marine protected area (DFO 2003). In 2003, the Norwegian Ministry of Fisheries issued prohibitions on bottom trawling along the Røst Reef off the Norwegian coast. These regulations protect the world's largest known (35 km long x 3 km wide) deep-sea coral reef of *Lophelia pertusa* (per communication with J.H. Fosså, 2004). In August 2003, the European Union banned deep-water trawling for a six-month period in an area off Scotland known as the Darwin Mounds (EC 2003). The deep-water trawling ban for Darwin Mounds was extended in February 2004 (EC 2004) for an additional six months to allow time for a more permanent protection of the habitat by amending Council Regulation (EC) No 850/98.

Institutional partnerships

A considerable amount of progress has been made toward establishing United States-international collaborative partnerships. In Spring 2002, NOAA and the Irish Marine Institute added deep-sea corals to a list of priority collaborative efforts as part of the Joint Statement of Understanding to establish and guide collaborative efforts related to marine research entered into in 1995. This decision led to the development of both the *Deep-Sea Corals Collaboration Planning Meeting* and the *Deep-Sea Corals Workshop* (McDonough and Puglise 2003), and continues to serve as the basis for developing future collaborative efforts.

In order to take advantage of the increased interest in establishing international collaborative partnerships, researchers and resource managers involved in the development and refinement of the critical information needs described herein have discussed and identified four potential pathways of international collaboration: (1) developing a *State of the Deep-Sea Corals Report* to organize existing knowledge on deep-sea coral habitats, the perceived threats they currently face, and elucidate on the critical information required for making management decisions; (2) identifying current and future exploration, research, and education projects with potential for international collaboration; (3) developing an *International Deep-Sea Corals Action Plan* to provide a blueprint for participating nations to collaborate on exploration, mapping, research, public awareness, and management of deep-sea corals in international waters; and (4) conducting an *International Transatlantic Expedition* to explore and research deep-sea coral habitats.

As currently conceived, the primary goal of the *International Transatlantic Expedition* would be to explore and research deep-sea coral habitats along the path of the Gulf Stream and associated currents. This includes both the reef-building type corals such as *Oculina varicosa* and *Lophelia pertusa* that are found along the continental shelf break and slope, as well as the soft corals that are often found in association with seamounts. The *International Transatlantic Expedition* would focus on the following at-sea objectives: (1) conducting multibeam and side-scan sonar surveys; (2) developing real-time maps and 3-D computer simulations; (3) conducting oceanographic observations; (4) collecting rock and sediment samples; (5) conducting visual surveys using digital still and video cameras; (6) collecting discrete samples of specific deep-sea coral species; (7) collecting samples of associated fish and invertebrates; (8) deploying a suite of *in situ* instruments to monitor conditions over time; and (9) conducting targeted research projects to answer hypothesis-driven questions relating to deep-sea coral ecosystems.

By using a consistent approach to gather, organize, and process these data, post-expedition progress could be made on conducting studies and developing products such as peer-reviewed publications, data atlases, integrated web-based databases, and other products that meet the goal of characterizing and understanding deep-sea coral habitats in terms of biogeographical changes, recruitment patterns and transport of larvae, habitat function (associated species abundance, diversity, and interaction), and natural and anthropogenic impacts. The collection of these data in a consistent manner will also provide an unprecedented opportunity to further efforts to use deep-sea corals to determine how past changes in ocean currents influence global climate change, and to use this information for refining climate change projection models.

Planning of this expedition has not been formalized as of yet. However, preliminary discussions have occurred among representatives from the United States, Canada, Norway, and the member countries of the European Union that have an active interest in deep-sea coral issues.

Conclusions

Scientists in Europe, Canada, and the U.S. continue to discover, characterize, and research deep-sea coral ecosystems. The workshops, policy, and research forums described herein provide a foundation for guiding future exploration, research, and management efforts. In order to maintain the momentum that has been established, to make progress in a consistent and collaborative manner, and to capitalize on international partnerships, it is critical that the dialogue continues to expand. As human activities spread offshore into areas inhabited by deep-sea corals, and public and political interest continues to grow, efforts such as developing a *State of the Deep-Sea Corals Report* and conducting an *International Transatlantic Expedition* will be critical for answering questions regarding their global distribution, abundance, biology, and ecological role as refugia for fish and invertebrates to spawn, feed, and grow to maturity. Furthermore, the development of an *International Deep-*

Sea Corals Action Plan could provide a blueprint for countries to collaborate on exploration, mapping, research, public awareness, and management of deep-sea corals in the international waters of the North Atlantic Ocean.

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