The Shelf Break Ecosystem off the Northeastern United States: Current Issues and Recommended Research Directions
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Development of a multi-disciplinary, multi-year, cooperative/collaborative research program to study ecosystem dynamics of the New England shelf break as they relate to fisheries science and resource management

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Report Prepared by Steering Committee:

Glen Gawarkiewicz
Gareth Lawson
Margaret Petruny-Parker
Paula Fratantoni
Jonathan Hare

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Executive Summary

The shelf break region south of New England, comprising the outer continental shelf and upper continental slope, is a highly dynamic and productive marine environment. It is an important habitat for fish and other marine life such as squid and marine mammals. The shelf break supports an extensive, year round commercial and sport fishing industry. Oceanographic factors contributing to the high productivity include strong currents and upwelling, large seasonal changes in stratification and temperature, and large cross-shelf temperature differences between the continental shelf and slope. Recently, unusual conditions including extreme temperature anomalies in 2012 and energetic Gulf Stream encounters in 2011 raise the issue of how climate change may be affecting this complex ecosystem. An improved understanding of ecosystem dynamics and the impact of a rapidly changing shelf and slope environment will be critical to informing decisions regarding marine resources and sustainability. This is vital as the commercial fishing industry adapts and prepares for changes in the abundance and distribution of marine resources.

In an effort to examine these challenges and provide new perspectives and collaborations, a workshop was convened in January 2013 in Warwick, Rhode Island to discuss the present state of our understanding of the shelf break ecosystem and prioritize directions for future cooperative research. The focus area was defined as being bounded by the 30 fathom/60 m isobath and the 500 fathom/1000 m isobath and Hudson Canyon to the west and the Great South Channel to the east. A select group of biological/chemical/physical oceanographers, ecologists, fisheries scientists, and members of the commercial fishing industry gathered to share perspectives on this focus area and discuss how their combined experience and expertise could be used to increase our understanding of the processes affecting the shelf break ecosystem, and how future efforts could benefit both basic research and fisheries management.

The workshop focused on 1) long-term and recent observations of fishers and fisheries, 2) ecosystem dynamics, 3) climate change impacts, and 4) new technologies and their utility for the focus area. Fishers' observations included extensive knowledge of the abundance and distribution of important species, and also raised significant questions regarding both persistent patterns near hot spots (such as canyons) and trophic interactions and movements during recent warming events. Recent fluctuations and behavioral patterns in lobster, squid, spiny dogfish, and butterfish received particular attention.

The present state of understanding of primary productivity, energy flows, nutrient exchange between the continental shelf and slope, and transport and movement of organisms was reviewed and gaps in our understanding were identified. A particularly distressing gap is our lack of knowledge of basic natural history and life cycles of many commercially important species as well as the basic functioning of the ecosystem, notably including trophic interactions. Given these gaps in our knowledge, potential impacts of climate change are difficult to quantify. The recent warming in 2012 provides at least one example of how significant warming over the continental shelf (up to 5 Deg. C/9 Deg. F) for several months has affected various species. Among the issues necessary to examine in the context of climate change are movements, trophic interactions, acidification, behavioral changes, spatial distributions and abundance, and frontal processes and associated cross-
shelf exchange. Recent technological breakthroughs in sensor development and electronic tagging offer strong potential to address these challenges and were reviewed. The use of fishing vessels as well as fixed or mobile fishing gear to make repeated scientific measurements was strongly endorsed. Existing or planned infrastructure for the shelf break (e.g. the Pioneer Array and fishing vessels as sampling platforms) and NOAA-NMFS surveys in the region also offer substantial leverage.

The overarching conclusion of the workshop was that there is a clear and growing need to understand the basic processes and functioning of the New England shelf break ecosystem in the context of a changing ocean environment. Bringing to bear new technologies in a cooperative manner between the fishing industry and scientists is likely to be highly effective in terms of both exploiting mutual insights into ecosystem changes as well as developing mechanistic understanding of the dynamics for use in improving resource management in what may be unprecedented circumstances. **Emphasis should be placed on focused study of the natural history of commercially important species and their prey, their distribution and movement patterns, reproductive cycles, and responses to changes in the ocean environment including atmospheric patterns that strongly affect the continental shelf and slope.**

**Prioritizing key problems most likely to be tractable in the near future, the following list emerged for cooperative study: 1) trophic interactions, 2) movements, 3) hotspots, 4) phenology, and (5) inter-annual variability. These subject areas offer a possible work component structure for a cooperative inter-disciplinary program that will generate important insights and provide a more robust underpinning for resource management in the shelf break region.** The envisaged research program would be best implemented via a combination of new observations leveraging existing or planned capabilities (i.e., the fishing fleet, NOAA survey efforts, the OOI Pioneer Array) coordinated with new process studies on research vessels and designed to inform coupled bio-physical, habitat, and ecosystem models. Among the many exploited species targeted in the shelf break region, short-lived species, including squid and butterfish, offer a particularly attractive possibility for focus. These species are especially sensitive to inter-annual environmental variability. However, the stock assessment process takes a relatively long-time, making the results of the assessment, once approved, less applicable to these species.

Finally, the workshop exemplified the value of a cooperative approach and highlighted the fact that close coordination and communications between oceanographers, fisheries scientists (from both academia and government), and commercial fishers are necessary to produce important results in a timely, cost effective way. In developing an inter-disciplinary collaborative/cooperative research program, emphasis needs to be placed on developing sustained partnerships between scientists and members of the fishing community. Such a program would provide key information on the important New England shelf break region, but would additionally allow insight into shelf and shelf break dynamics along the East Coast and serve as a demonstration of the value of a fully cooperative and integrated approach. The sharing of differing perspectives and concerns about the shelf break region between the wide range of participants offers hope that dramatic new insights will emerge should these new partnerships be supported.
I. Background

The shelf break region south of New England, comprised of the outer continental shelf and upper continental slope, is a highly dynamic and productive area that provides a wide range of habitat for fish and other marine life such as cephalopods and marine mammals. This part of the ocean supports an extensive, year round commercial and sport fishing industry, and consequently, has important ties to the shoreside businesses located in southern New England and Mid-Atlantic coastal communities.

The shelf break region is a complex oceanographic environment because of a strong current system (the shelf break jet), persistent upwelling, and vigorous forcing from synoptic weather systems and the Gulf Stream. Complicating this already complex system are unusual conditions that may be related to larger scale climate change. For example, during the winter and spring of 2012, warm temperature anomalies over the continental shelf south of New England were at least 2°C (3.6°F) for several months. In addition, increased fresh water inputs, both locally and from the Gulf of Maine and Scotian Shelf, have increased stratification. The National Marine Fisheries Service (NMFS) issued an ecosystem advisory noting the unprecedented thermal anomalies over the continental shelf as well as some ecosystem impacts, including the early development of the spring phytoplankton bloom and the northward displacement of cod in the Gulf of Maine. These advisories typically cover only the shelf region where NMFS observations are concentrated and extrapolating to the shelf break with its complicated dynamics is difficult, but the NMFS data highlight both the drastic recent environmental anomalies and a gap in existing monitoring activities. Potential impacts from ocean acidification are also producing concerns in this region.

Changes of the physical environment within the shelf break region have had impacts on the marine life and ecosystem, many of which are either unknown or poorly understood. From a fisheries management perspective, it is becoming increasingly important to be able to quantify these changes and understand their impacts on fish distribution and abundance. This includes changes in ecosystem dynamics e.g. trophic interactions, seasonal patterns of movement, spatial distribution of habitats for different species, and phenology (seasonal timing of different events). An improved understanding of the changing ocean environment and ecosystem dynamics in the shelf break region will be critical to better informing marine resource management decisions, and subsequently achieving sustainable marine resources. Those dependent on these resources for their livelihoods will need to be able to prepare and adapt.

In an effort to examine these challenges and to begin charting a path toward improved understanding of the continental shelf and shelf break area south of New England, a workshop was convened in January 2013 in Warwick, Rhode Island (workshop participants and agenda in Appendices 1&2). A select group of biological/chemical/physical oceanographers, ecologists, fisheries scientists, and members of the commercial fishing community gathered to share perspectives on this part of the ocean and discuss how their combined experiences and areas of expertise could be brought together to increase our understanding of the processes at work for the benefit of fisheries management.
For the purposes of discussion for this workshop, the shelf break region south of New England was defined as the area between the Great South Channel and Hudson Canyon between the 60 m (30 fathom) and 1000 m (500 fathom) isobaths (Figure 1). The continental slope in this area is incised by a number of canyons that generally do not extend across the continental shelf (although note that Hudson Canyon, in contrast, does extend across the continental shelf in the Hudson Shelf Valley).

The goal of the 1.5 day workshop was to identify and discuss key research elements that would serve as a guiding structure for a multi-disciplinary, multi-year cooperative/collaborative research program to study continental shelf and shelf break ecosystem dynamics as they relate to fisheries science and resource management in the designated focus study area off the southern New England coast. An important task was to identify and develop new partnerships and set priorities for future research in the shelf break region south of New England, including a critical assessment of the utility of several new technologies.

The following sections of this workshop report summarize discussions and identify the priorities for future research in new partnerships comprising the fishing industry, academia, and fisheries scientists in the region.

**Figure 1** – The shelf break study area as defined for the purpose of discussion at the workshop, extending from the Great South Channel to Hudson Canyon between the 60 m (30 fathom) and 1000 m (500 fathom) isobaths. [Map: A. Malek, CFRF-URI]
II. Present Status and Urgent Issues

II.A. Fisheries and fishers’ observations

It was estimated that 452 commercial fishing vessels access the shelf break focal region considered at the workshop, encompassing roughly 1600 crew members (Mattera, 2013). This commercial fishing fleet operates out of some 13 home ports from Cape Cod, Massachusetts south to Cape May, New Jersey, targeting a variety of fish species including squid (Doryteuthis pealei and Illex illecebrosus), silver hake, red hake, butterfish, tilefish, scup, black sea bass, summer flounder, John dory, Atlantic mackerel, monkfish, American lobster, red crab, Jonah crab, swordfish, tunas, sharks, mahi mahi, and marlins. Fishing vessels target this part of the east coast shelf/shelf break year round, using a variety of gear types including bottom and mid-water trawls, lobster traps, crab pots, longlines, gillnets, and rod and reel (Mattera, 2013). Commercial fishing efforts follow seasonal migration patterns and fishery governance regulations, and are supplemented by recreational fishing efforts in this area as well. Day to day at sea observations, along with historical knowledge of bottom types, seasonal fish movements, and market conditions, drive fishing activities and resultant harvests.

Management of these shelf break fisheries is achieved through a combination of seasonal quota allowances, closed areas, and gear-restricted areas determined by the New England (Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut) and Mid-Atlantic (New York, New Jersey, Delaware, Pennsylvania, Maryland, Virginia, and North Carolina) Fishery Management Councils under the Magnuson-Stevens Act. Marine mammals and sea turtles associated with the New England shelf break are protected under the Marine Mammal Protection and Endangered Species Acts, and assessed by NOAA-NMFS. Aside from certain gear-restricted areas specific to the shelf break, management of marine resources at the shelf break are not treated separately from resources of the continental shelf as a whole. Recent Ecosystem Status Reports published by the NOAA-NMFS Northeast Fisheries Science Center, however, do find the shelf break emerges as a separate ecological production sub-unit within the Northeast Shelf Large Marine Ecosystem based on the statistical analysis of a variety of physiographic and lower trophic level datasets.

Workshop discussions focusing on the pursuit of particular species by panelists and their colleagues in the fishing industry revealed extensive knowledge about oceanographic conditions and species abundance and distribution over time. These discussions also highlighted a list of unanswered questions and revelations about changing conditions, especially in relation to lobster, squid, and butterfish.

Lobster

The observations of lobstermen indicate a number of important aspects concerning the distribution, migrations, and population structure of lobster (Homarus americanus) in the shelf break region. Bathymetric features, notably canyons, are observed to play an important role. Smaller-sized and more abundant lobsters are found on the west side of Hydrographer Canyon than on the east, where other fish species more typical of Georges Bank also tend to be present. This observation leads them to hypothesize that the canyon
may represent a boundary delineation between Georges Bank and Southern New England fish communities.

Lobstermen observations also reveal the presence of juvenile lobsters in the shelf break area, an observation that contradicts lobster biologists’ understanding of typical juvenile lobster habitat. Lobstermen speculate juvenile lobster offshore might result from changing settlement areas, possibly associated with changing current patterns or with an offshore shift in the spawning grounds of female lobsters in response to warming inshore waters. Lobstermen have long thought that some lobsters tend to migrate more than others, based on observations of whether one side of a lobster claw is white (an indication that the individual has been moving along the bottom dragging its claw). Observations of this feature, and individuals lacking this feature (referred to as “groundskeepers”), lead lobstermen to wonder whether migratory patterns are changing and/or whether stock delineations are more complex and/or more numerous and separate than previously thought, including the notion that inshore and offshore lobsters are less connected and more distinct than currently characterized.

*Squid*
Two species of squid are targeted in the Mid-Atlantic region, longfin squid (*Doryteuthis pealei*) and Northern shortfin squid (*Illex illecebrosus*). Squid are of particular economic importance to the Rhode Island fleet: in 2010, squid landings in Rhode Island comprised 54% of all total squid landings in the northeast, with a value of approximately $10 million (Hasbrouck et al., 2011). Squid are harvested by fishing vessels of various sizes. Smaller, inshore fishing vessels target squid in the small mesh trawl fisheries during the time of the year that the squid are typically found inshore, while larger vessels target squid further offshore year round.

Fishers relay that patterns of abundance and the timing that squid appear inshore is shifting from year to year. In 2012 squid were plentiful inshore but less abundant offshore when they would be typically. Changes in spawning behaviors have also been observed. Squid “egg mops” have typically appeared in July but recently have been observed as early as April. They also observe that, while in past years squid have been present until November-December, more recently squid are no longer found after September. These observations lead fishers to wonder whether changes in the timing of seasonal transitions (phenology) are impacting the squid migration and spawning cycles.

*Butterfish*
Butterfish (*Peprilus triacanthus*) have in the past few decades been very significant to southern New England fishing vessels, but due to shifting demand in foreign markets and changes in management there has not been a directed fishery in recent years. Fishers are now indicating that this highly patchy species is abundant, especially in the area from Block Canyon east to Georges Bank along the 60-fathom (120 m) contour. Butterfish, and other short-lived species such as squid, mackerel, and herring, may be particularly susceptible to changing environmental factors from year to year, as well as being an integral part of the food web. As a consequence, real time data and field observations of the fish, fishery, and environment are particularly important to improving our understanding of their natural history and varied abundance.
Recent cooperative research conducted by a team of academics from Rutgers University paired with NOAA-NMFS scientists and participants in the squid and butterfish fisheries has provided new insight into the habitat use of both butterfish and longfin squid. Data on environmental conditions from the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS, a regional component of the US Integrated Ocean Observing System) and NOAA-NMFS abundance survey data, coupled with the understanding of both scientific and fishing industry knowledge of squid and butterfish ecology (i.e., movement patterns, habitat preferences, thermal preferences) collected at a focused workshop led to the development of regional-scale habitat models (e.g., Manderson et al., 2011). Predictions made by the model based on real-time data from the ocean observing system were tested at-sea with fishing industry partners, demonstrating that the model could predict times and regions where butterfish abundance was likely to be high at scales of tens of kilometers. The model is currently being used to recalibrate indices of population trends based on the amount of habitat sampled in NOAA-NMFS surveys and to guide the design of new adaptive industry-led surveys. In addition to providing valuable new information on two data-poor fisheries, this project demonstrates the value of a cooperative approach and of leveraging ocean observatory data.

Other observations
The ranges of a number of shelf break species have been observed to be shifting, perhaps in response to changing environmental conditions. Fishers and fisheries researchers report large abundances of spiny dogfish (Squalus acanthias) throughout the study area discussed. Recent research suggests that this species may have a higher tolerance for a wider range of temperatures, giving it an advantage in terms of adapting to warming water temperatures (Sulikowski et al., 2012). Fishers also report that several species are now found further offshore in deeper water. This includes monkfish (not as many in waters shallower than 60m), and flounder species. Smaller tilefish usually found in shallower water are now found mixed in with the large ones further offshore, in deeper water (D. Farnham, pers. obs.). Species such as cod and skate are also reported as coming further south and species such as spot coming north. These observations are consistent with analyses of NEFSC trawl survey data suggesting that the distributions of some species may be shifting northward (e.g., black sea bass, summer flounder), while others appear to be shifting towards the south (e.g., cod)(Friedland, 2013). Marine mammals are being reported by the fishing industry as much more prevalent.

Implications
Discussions among workshop participants led to a number of conclusions from the standpoint of fisheries. Based on the ongoing observations of the fishing industry, there appear to be “hotspot” areas in the shelf break system that are especially important sites for fishing activity. These may correspondence to areas of enhanced energy transfer, biodiversity, and abundance. At the same time, habitat conditions appear to be changing and potentially becoming fragmented, perhaps accounting in part for changing fish movements and patterns.

Overall, a central conclusion concerned the general lack of data and clear need to learn more about the basic natural history of commercially important species in the shelf break
area, including spawning cycles, movement patterns, predator/prey relationships, temperature ranges, growth rates, critical habitat areas, and stock delineations, as well as the response of these to environmental variability. Discussions among workshop participants highlighted the notion that achieving sustainable fisheries management is integrated with the goal of achieving ecosystem based management, for which a more comprehensive understanding is required of shelf break dynamics, including the connections between physical, chemical, geological, and biological processes.

Involvement of the commercial fishing industry was viewed as an opportunity to expand the scope of field work in a cost-effective fashion; to utilize industry observations to identify key research questions and recognize when major events may be happening; and to provide more real time data and monitoring to develop and support a more comprehensive understanding of this region of the ocean. Ultimately, such information could be used in developing predictive ecosystem-based models and to provide a more robust underpinning for fisheries management.

II.B. Ecosystem dynamics

The shelf break is generally considered to be a region of important biological productivity, supporting large zooplankton aggregations, important commercial fisheries, and a variety of marine mammals. In general, however, the combination of biological and physical factors that make the shelf break favorable habitat for these organisms and the flow of energy from lower trophic levels to commercial species remain poorly understood. Issues associated with shelf break ecosystem dynamics are thus both timely and important.

Physical oceanography

A key feature of the shelf break is the thermohaline shelf break front separating the highly productive, cooler, fresher, and southwestwards-flowing waters of the continental shelf from the warmer and saltier waters of the continental slope and the northeastwards-flowing Gulf Stream beyond. The shelf break front supports a persistent surface–intensified shelf break jet and large cross-shelf and vertical gradients in temperature, salinity, and nutrients. The along-shelf patterns in cross-shelf and vertical gradients are not well described. The shelf break thus represents a boundary region and exchange processes between the shelf and slope, and associated impacts on nutrient dynamics, primary productivity, energy flow, and transport of organisms, constitute key research questions.

The shelf break region south of New England has been the site of numerous large science programs in the 1980's and 1990's including the Shelf Edge Exchange Program (SEEP) from the Department of Energy and the Shelf break PRIMER experiment from the Office of Naval Research. The main focus of many of these earlier programs, as well as the forthcoming Ocean Observatories Initiative (OOI) Pioneer Array Observatory, however, has been on physical oceanography, with less emphasis on biological processes. From these and other studies, certain significant and recurring exchange processes have been identified, including instabilities and associated meandering and eddy fluxes in the shelf break front (e.g. Lozier et al., 2002; Gawarkiewicz et al., 2004); interactions of warm-core rings found in the slope waters formed by meanders in the Gulf Stream with the shelf break front including streamer formation (e.g. Bisagni, 1983; Ramp et al., 1983; Joyce et al., 1992;
Gawarkiewicz et al., 2001); response to wind forcing including upwelling and the effects of winter storms and hurricanes (e.g. Lentz et al., 2003; MacKinnon and Gregg, 2002, 2005); and intrusions of saline slope waters at the depth of maximum stratification within the seasonal pycnocline (e.g. Boicourt and Hacker, 1976; Aikman and Posmentier, 1985; Lentz, 2003). A schematic diagram illustrating many of these physical exchange processes appears in Figure 2.

**Figure 2** – A schematic diagram of important physical processes in the shelf break region south of New England.

*Primary productivity and nutrients*
Chlorophyll abundance on the New England continental shelf is generally highest in coastal regions and decreases offshore. Seasonally, phytoplankton blooms are associated with the onset of water column stratification in spring. At the shelf break, enhanced levels of chlorophyll both at the surface and sub-surface have been observed via *in situ* and satellite methods (Marra et al., 1982; Ryan et al., 1999a,b). Chlorophyll levels are not always enhanced at the shelf break, however (Hales et al, 2009), and the evidence for a spring bloom has been equivocal. Nutrient dynamics in the shelf break region are poorly constrained but, along with phytoplankton abundance, are strongly influenced by shelf break exchange processes. Recent modeling efforts suggest enhanced primary productivity at the shelf break in spring and summer associated with upwelling of nutrient-rich slope
water (Zhang et al. 2013); in order to match model predictions with the low levels of chlorophyll obtained from satellite climatology, however, high levels of zooplankton grazing were required, pointing to a tightly coupled system with abundant zooplankton playing an important role in top-down control.

Key questions thus remain concerning cross-shelf break gradients and exchange in nutrients and phytoplankton productivity, abundance, and community/size composition. Controls on phytoplankton over seasonal and inter-annual time-scales (e.g., nutrients, light, grazing, advection) likewise require further study and measurements.

Lower trophic levels
At the New England shelf break, patterns in the distribution and abundance of zooplankton are relatively poorly understood, in comparison to shelf break regions elsewhere (e.g., off the West Coast of the US where the shelf is narrower and the shelf break more easily reached) as well as in comparison to the New England continental shelf and the slope (where studies of warm-core rings have provided much information on species composition, abundance, and vertical distribution).

Among zooplankton, the copepod species Calanus finmarchicus plays an especially important role in shelf ecosystems of the North Atlantic, sustaining a variety of fish and marine mammal species. C. finmarchicus is present at the New England shelf break and slope, although its abundance, seasonal/inter-annual fluctuations, and vital rates are not well known, in contrast to shelf regions and slope waters of the Scotian Shelf (e.g. Miller et al., 1991; Heath et al., 2004; Head and Pepin, 2007). Euphausiids are also a key component of the North Atlantic ecosystems (Parsons and Lalli, 1988). Large and dense aggregations of euphausiids have been reported in New England shelf break canyons and have been speculated to subsidize the productivity of shelf-associated fisheries for zooplanktivorous fishes and squid (Greene et al. 1988). The forces underlying these aggregations are not known although the interaction of active vertical movements with convergent or divergent flow is thought often to be an important mechanism for the formation of zooplankton aggregations in regions of abrupt topography such as shelf breaks (Genin, 2004). The strong internal wave activity typical of the New England shelf break may also play a role in transporting and concentrating zooplankton (Stevick et al., 2008) while at larger scales processes such as meanders in the shelf break frontal jet and warm-core rings likely modulate zooplankton distributions (e.g., Joyce et al., 1984; Huntley et al., 2000).

The micronekton community (i.e., small mesopelagic fishes, shrimp, and squid) likely plays an important role in the shelf break ecosystem, as consumers of zooplankton (Longhurst and Harrison, 1989) and as prey for higher trophic levels (Corten, 2001; Fock et al. 2004; Sutton et al., 2008). In the Mid-Atlantic Bight and Scotian shelf break regions, mesopelagic fishes are an important component of the ubiquitous deep-scattering layer and form dense aggregations along the slope, spreading offshore (Sameoto, 1988; Hartel et al., 2008; Gartner et al., 2008).

The shelf break front plays an important role in separating plankton communities from the shelf and slope (Cox and Wiebe 1979) but exchange across the front is an important component of the life history and dynamics of many species. Larvae of shelf species,
including cod and haddock, are advected across the shelf-break front and off the shelf (Myers and Drinkwater 1989), whereas larvae of southern species are advected across the shelf-break front and onto the shelf (Hare and Cowen 1991). Numerous mechanisms have been identified included pycnocline intrusions, warm-core ring streamers, shelf break eddies and directed horizontal swimming (Cowen et al. 1993, Hare et al. 2002). Variability in these cross-frontal exchange processes could be an important component of population variability is a range of species.

Multiple outstanding questions remain concerning the dynamics of lower trophic levels at the shelf break, including controls on their distribution and abundance (e.g., bottom-up vs. top-down control, local vs. remote forcing), vital rates, trophic interactions, and linkages to commercial fisheries. Large zooplankton and micronekton are also highly mobile and likely play a role in the active flux of carbon between shelf, shelf break, and slope regions. Likewise, the scientific community’s understanding of benthic-pelagic coupling remains limited, but such coupling is likely to be important, given the high abundances of detritus found at the shelf break and its canyons, the abundance of benthic detrivores (notably lobster), and the abundance of vertically migrating zooplankton and micronekton that often spend extended portions of the day in close association with the bottom.

Fish and marine mammals

In comparison to lower trophic levels, more is known about the movements, abundance, and distribution of many fish species at the shelf break from catch data and fisheries independent surveys. Frontal regions are often targeted by higher predators, and the shelf break is seasonally frequented by a variety of highly migratory species including swordfish, tunas, and sharks (Podesta et al., 1993; Lawson et al., 2010). Fine-scale patterns in fish movements and behavior are less clear, however. Similarly, the predator-prey interactions of commercial fishes with lower trophic levels at the shelf break have received little attention, and much of the basic information on diets, predation rates, and energy flow, as well as how these may be changing, remain unknown.

The shelf break is also important seasonal habitat for a variety of marine mammal species, some of which are exclusively associated with the shelf break and slope for much of the year, including various odontocetes such as beaked, sperm, and pilot whales (Waring et al., 2001, 2006). The shelf break also serves as a migratory corridor for large whales, including North Atlantic right whales (Firestone et al. 2008). Marine mammals, as well as other protected species including sea turtles, are relatively well censused at the shelf break via a long-standing assessment program (Waring et al., 2006), but the overall role of marine mammals in the shelf break ecosystem, environmental influences on their distribution and migrations, and trophic interactions, have not been well studied.

Understanding the role of deep-water coral is fishery habitat is a recent challenge complicated by the relative inaccessibility of these areas. The region’s deepwater corals are also found along the shelf break (Watling and Auster 2005). The overall habitat-related distribution of a species must be studies to evaluate the importance of specific habitats and the habitats of many shelf-break species are poorly described as is their relationship with deepwater coral (Auster 2005). Recent work continues to identify deep-water corals in the area, especially in the vicinity with canyons (NEFSC 2012). The Mid-Atlantic and New
England Fishery Management Councils have established a framework for coordination and cooperation toward the protection of deep sea coral ecosystems (MAFMC 2013). The importance of canyons, deepwater corals, and other shelf break habitats needs to be further evaluated and compared to understand the distribution, abundance, and dynamics of fishery species in the region.

Canyons
There is growing evidence that New England shelf break canyons are sites of particularly high biological productivity and abundance across trophic levels, a phenomenon also observed for canyons elsewhere (e.g., Croll et al. 2005). A variety of fishing activities is also often concentrated at canyon heads, including fishing for lobster, butterfish, and other species. Euphausiids are especially abundant in canyons (Greene et al. 1988) where they appear concentrated at canyon heads; the possible importance of canyons in concentrating other lower trophic levels, such as meso-pelagic fish, has yet to be determined. Multi-species assemblages of baleen whales have also been reported feeding on euphausiids in canyon regions (Kenney and Winn, 1987). Data at scales suitable for testing statistically whether marine mammals prefer canyons in this region are few and equivocal, but at least beaked whales appear to be more abundant in canyons (Waring et al. 2001), and studies of the Scotian Shelf have likewise found strong canyon associations for many of the same odontocetes that frequent the New England shelf break (Gowans and Whitehead 1995). Based on anecdotal reports from amateur ornithologists, canyons are also important sites for seabirds.

Understanding the bio-physical factors leading to this enhanced productivity and multi-specific assemblages of top predators at canyons constitutes an important problem, relevant to fisheries and spatial management, and may result in an ability to predict such hot-spots. Circulation in canyons is complicated and not well characterized, with inwards flow of deep water typically occurring along the northeastern side of the canyon, but subject to reversals under certain wind conditions. Internal waves and internal tides are important mixing processes likely leading to enhanced mixing in canyons, especially at the canyon head. More numerical modeling efforts will be required to resolve such processes and their impact on biological processes, employing more realistic bathymetry than has been typical of regional modeling efforts to date.

II.C. Climate change and potential impacts
The recent warming of the continental shelf south of New England in the first six months of 2012 has focused attention on the impacts of temperature change in the northeast. Data from the National Data Buoy Center shows significant warming from the Gulf of Maine to Cape Hatteras (Figure 3, taken from Chen et al., 2013).
High-resolution hydrographic observations are not available from this time period south of New England, however, an Office of Naval Research field program north of Cape Hatteras did sample the shelf break front intensively during May, 2012 and provides some insight into the effects of warm anomalies on the shelf break front. North of Cape Hatteras, temperature anomalies of 4-5°C (7-9°F) over the continental shelf resulted in greatly diminished temperature contrasts between continental shelf and slope water masses. In turn, this warming decreased the density over the continental shelf and increased the density difference across the front. The increase in the density difference led to a very strong shelf break jet velocity of 1.2 knots (0.6 meter/sec). Presumably, the enhanced along-shelf velocities increased the magnitude of the upwelling within the front, but this was not directly measured and remains as speculation at this point.

Figure 3 – Near surface ocean temperature anomalies (relative to 2000-2010 mean) taken from NDBC buoys in the Gulf of Maine, Nantucket Shoals, south of Long Island, and Chesapeake Bay mouth (in descending order) from 2011-2012. Note the large warm anomalies that begin in 2011-2012 and continue through September 2012 in all regions. Taken from Chen et al., 2013.
Observations from the fishing industry south of New England have been described earlier in Section II.A. Some ecosystem effects of the warming are reported in NOAA Ecosystem Advisory for the Northeast Large Marine Ecosystem (Friedland, 2012). In September and October of 2012, surface temperatures were 2-3°C warmer than average throughout the Northeast U.S. Shelf ecosystem; bottom-temperatures were 2-3°C warmer than average in the Georges Bank / Gulf of Maine area, but were more spatially variable in the Mid-Atlantic area (Figure 4). The spring bloom, reflected in the chlorophyll concentration, was high in 2012 compared with recent years and occurred earlier than usual. The spring bloom was fully developed by March and in some areas occurred as early as February. Warm water thermal habitat areal extent was the largest recorded to date, while the cold water thermal habitat was the lowest recorded to date. Zooplankton biomass was higher than recent years in spring.

The warm conditions in 2012 affected fish migration patterns, with bluefish and striped bass appearing much earlier than usual off Cape Cod. Lobsters within the Gulf of Maine molted six weeks earlier than usual, which had an impact on the price of lobster with so many unshelled lobster caught in the spring. At this point, little is known about the impact of this warming on important ecosystem dynamics near the shelf break such as trophic interactions, acidification, changes in behavior, spatial distributions and abundance, and frontal processes and cross-shelf exchange. It is unclear at this point what caused such anomalous warming, although recent work has shown that anomalous heat fluxes from the atmosphere to the ocean were an important factor (Chen et al., 2013).

While we have focused on the spring of 2012 to highlight important effects of warming of the continental shelf, longer-term trends also indicate warming and freshening of the
continental shelf. It is important to note that global circulation models which make climate predictions are generally relatively coarse in spatial resolution and do not resolve many important continental shelf processes or spatial patterns. This makes continuing observations of the continental shelf and slope ecosystems vital in terms of understanding both short and long-term changes affecting the shelf break domain.

For more general discussion of the potential impacts of climate change on fisheries in the United States, the Third National Climate Assessment Report (Chapter 24- Ocean and Marine Resources, pp. 835-864) provides a concise discussion of future impacts on marine resources. (This is available on the web at http://ncadac.globalchange.gov/). A general discussion of the use of global circulation models to project future climate change impacts on living marine resources appears in Stock et al. (2011). Changing spatial distributions of various fish species in response to climate change is described in Nye et al. (2009). Temporal variability in sea surface temperature in the northeastern United States is investigated by Friedland and Hare (2007). Regime shifts in the Northwest Atlantic are discussed in Greene et al. (2013). Coupled climate-population projections to date suggest that thermal habitat and productivity of Atlantic cod will decline in the ecosystem (Fogarty et al. 2008) whereas thermal habitat and productivity of Atlantic croaker will increase (Hare et al. 2010). Additionally, thermal habitat of cusk, a deepwater species found along the shelf-break is projected to decrease (Hare et al. 2013).

Ocean acidification is another potential concern over the continental shelf and slope in the shelf break region. A general description of pH for the east coast of the United States appears in Wang et al. (2013). Ocean acidification may affect shellfish and crustacean growth rates. At present there is a need for more high-resolution measurements of pH in the shelf break region.

II.D. Ocean monitoring and new technologies

Ocean observing technologies
Recent breakthroughs in sensor development have greatly improved our observational capabilities and knowledge of both the marine environment and its biota, including the distribution of organisms as well as their movement and behavior across trophic levels. A number of new sensors and technologies are available for real-time monitoring and assessment of the shelf break environment and ecosystem. Inexpensive, miniaturized high-accuracy sensors are available to measure hydrographic quantities like temperature and salinity. Similarly, new sensors in biogeochemistry such as optical nitrate sensors and pH sensors have enabled new perspectives on nutrient and carbon cycling. Phytoplankton abundance and community composition can be characterized over fine temporal scales using optical devices like the Flow Cytobot. New image-forming optical systems have been developed for quantifying zooplankton abundance, which show great promise for autonomous deployment. For larger zooplankton and fish, multi-frequency and emerging broadband active acoustic systems allow the quantification of distributions in continental shelf and slope environments and the study of behavioral variability. Sophisticated electronic tagging technologies for larger organisms (e.g., fish, lobster, marine mammals, etc.) involving acoustic telemetry, satellite reporting, and/or data-archiving capabilities
have also provided new opportunities for understanding the movements, habitat use, biogeography, and stock structure of marine organisms. New tools in molecular ecology such as Next Gen sequencing (i.e., low-cost, high-throughput sequencing of DNA and RNA) are available for studies of population genetics, stock structure, and physiological responses/adaptations to environmental conditions. In addition to traditional analyses of stomach contents, analyses of stable isotopes (e.g., carbon, nitrogen) can also be used to provide insight into food web structure.

**Models**

Current-generation coupled bio-physical models can also be used to derive sampling plans for these biological and biogeochemical sensors, via Observing System Simulation Experiments (OSSE), and to place the resulting measurements into larger, integrated spatial and temporal scales, including the forecasting of future ocean conditions. Ultimately, such models might be coupled to fisheries stock assessment models, allowing a consideration of more ecosystem components than classic stock assessments and providing information over the short time frames necessary for short-lived species.

**Platforms and opportunities**

A variety of sampling platforms and approaches are available that might be leveraged towards cost-effective shelf break monitoring across temporal and spatial scales. Fishing vessels offer extensive time on the water, and ocean sensing technologies deployed from such vessels, or mounted on fixed (e.g. the NEFSC’s Environmental Monitors on Lobster Traps program, eMOLT, Manning and Pelletier 2009) or mobile fishing gear (e.g., Gawarkiewicz et al., 2012, and the CFRF Lobster Research Fleet pilot “On-Deck Data Program”), can be used to collect environmental data over broad spatial scales and with extensive temporal coverage. A variety of NOAA-NMFS surveys regularly visit the shelf break region (e.g., ECOMON oceanography surveys, Ship of Opportunity Program, Atlantic Marine Assessment Program for Protected Species, bottom trawl surveys, etc.). Data collected routinely during these surveys already provides important information on the shelf break system, and deployment of additional, non-mission instrumentation (e.g., underway acoustics, ADCP, flow-through water sampling) could enhance the scope of data collection substantially.

Existing and forthcoming ocean observatories furthermore provide valuable time-series observations: regional Integrated Ocean Observation Systems (IOOS) supported by NOAA have been operating for multiple years, providing key data on environmental conditions. The NSF-funded Ocean Observatories Initiative’s Pioneer Array will be installed at the continental shelf break south of New England beginning in 2014, providing extensive important data on hydrography and circulation, as well as some information on nutrients, phytoplankton, and lower trophic levels. Autonomous mobile platforms operated through these observing programs and by individual research groups extend the spatial and temporal scales of monitoring beyond those feasible through either fixed-site observatories or traditional ship-based surveying. The framework provided by these observatories and mobile assets provides a valuable opportunity for associated process-oriented cruises to examine upper trophic levels, ecosystem processes, and linkages to fisheries.
Communication

New methods are available to allow the communication and coordination required for effective cooperative research between academic, governmental, and fishing industry partners. Scientific information can be conveyed to the fishing industry through web-based means; systems already in place through organizations such as MARACOOS allow two-way communication and the necessary rapid delivery of new information. Social and other electronic media can be used for rapid coordination of scientific efforts, as well as to enlist ‘citizen scientists’ enthusiastic about participating in ocean research. Existing infrastructure used by the NEFSC Ship of Opportunity Program to communicate data collected via merchant vessels through the Global Ocean Observing System could also be leveraged and/or extended in developing methods for near-real time data transmission from the fishing fleet and other platforms.

III. Research Needs and Recommendations

The overarching conclusion of the workshop was that there is a clear, growing, and urgent need to understand the basic functioning of the shelf break ecosystem in the context of a changing ocean, bringing to bear new technologies in a cooperative way in order to produce the best science in support of fisheries management. There was consensus around a number of common themes emerging from the workshop discussions about which a collaborative research program might be developed.

III.A. Scale and focus

The shelf break region under consideration is embedded within the greater Northeast U.S. Shelf Large Marine Ecosystem, closely linked both to the continental shelf and to the slope waters and open ocean. A nested approach is most appropriate to understanding the functioning of this system, with observations and studies conducted at fine-scales complemented by consideration of broader scale processes; such an approach is particularly important in disentangling local vs. remote forcing of the system and for examining climate processes. In a spatial sense, the shelf break study region proposed here for detailed examination extends from Hudson Canyon to Georges Bank, but with consideration also given to the larger scale of the greater shelf break region from Cape Hatteras to the Grand Banks and to the interaction of the shelf break with the shelf and slope. In a temporal sense, both short- and long-term processes are of interest, requiring examination of existing historical datasets as well as collection of new high-resolution data.

Multiple key gaps remain in understanding of the shelf break ecosystem and the research program envisaged here would focus on determining the basics of the shelf break ecosystem and its fisheries. A clear need exists to learn more about the basic functioning of the ecosystem and its bio-physical coupling, the natural history of commercially important species and their prey, as well as their distribution, movement patterns, and reproductive cycles, including the response of these to environmental variability and directional climate change. Addressing these gaps will provide important information for stock assessment and ecosystem models and provide a more robust underpinning for fisheries management.
Among the many exploited species targeted in the shelf break region, short-lived species, including squid and butterfish, offer a particularly attractive possibility for taxonomic focus; such species are presently poorly assessed and hence managed, and the short nature of their life cycles make them especially sensitive to environmental variability.

III.B. Research topics

Although a multitude of issues were raised, workshop participants agreed upon a core set of inter-related research topics identified as being most pressing and tractable.

Trophic interactions
Basic information is lacking concerning food web dynamics, including the diets and rates of interaction of the various predators with their prey and competitive interactions among species. Such information is critical to habitat and ecosystem models, particularly as efforts continue towards ecosystem-based management of regional fisheries. Of particular interest are the linkages between lower trophic levels and commercial fishes and protected species. Traditional analysis of stomach contents as well as newer methods employing genetic analysis of stomach contents, stable isotopes, and fatty acid analysis offer key opportunities to address this knowledge gap. Rate studies such as grazing experiments will be necessary to gain insight into food web dynamics and rate processes.

Movements
The migrations, responsive movements, planktonic dispersal, and other movement patterns of shelf break associated commercial species and prey are only poorly understood. An examination of the across- and along-shelf movements of key species is needed to delineate stock boundaries, examine energy exchange between off-shelf and shelf regions, and understand inter-annual variability in fish distributions in light of the changing ocean environment. New electronic tag technologies (e.g., satellite-reporting tags, acoustic tags) as well as conventional tagging approaches are available for studying animal movements, and can leverage the various platforms available in the shelf break region (e.g., by placing receivers for acoustic tags on observatories, autonomous vehicles, fishing vessels, etc.). Complementary approaches such as methods for population genetics can further contribute to an enhanced understanding of population structure.

Hotspots
Regions of enhanced abundance and biological activity exist within the overall shelf break system and understanding the combination of biological and physical processes underlying such hotspots constitutes a key challenge. Canyons are a clear example of apparent hotspots as a variety of fisheries preferentially target canyon heads, where multi-specific assemblages of lower trophic levels and top predators (marine mammals, seabirds, etc.) also often occur. A mechanistic understanding and predictive capability concerning the factors leading to the enhanced productivity of canyons represents an important research goal.

Phenology
Understanding the timing of events including blooms, seasonal arrivals and departures of species, patterns of food availability, and reproduction is key to any ecosystem study. In
contrast to the better-studied shelf system, such processes are poorly understood at the shelf break. Basic data on nutrients (time-series, along- and across-shelf sections), seawater chemistry (including pH), primary productivity, and species distributions are required to examine seasonal patterns. Ocean observatories, notably the Pioneer Array, are particularly well poised to provide such data at small scales, while satellites provide samples at the large scale. To a large extent, understanding phenology will require an improved understanding of the basic biology of shelf break fish and prey species, including their life history, habitat preferences, and environmental tolerances.

**Inter-annual variability**

Variability in the processes described above between years constitutes a crucial question and many shelf break commercial species experience mostly unexplained inter-annual fluctuations in abundance. Observations made over multiple years, complemented by historical data and models, will be necessary to tease apart remote vs. local forcing and natural vs. climate change drivers in environmental influences on productivity, energy flow, trophic interactions, and species distributions and abundance.

**III.C. Implementation strategy**

The inter-disciplinary nature of the research themes identified here stresses the importance of an inter-disciplinary approach to implementing the proposed research program, with close coordination and communication across levels of investigation.

**Partnerships**

It was the firm opinion of the workshop participants that a cooperative and collaborative approach bringing together academic, governmental, and fishing industry partners represents the way forward most likely to engender success. A variety of government agencies, both federal (e.g., NOAA-NMFS, USGS, BOEM) and state, have interests and mandates that include the shelf break region. The region holds strong appeal to academic scientists due to its complexity, economic importance, and comparative lack of previous study. The shelf break is also home to important fisheries and sustains the livelihood of fishing industry participants from multiple states. Bringing together these perspectives, as evidenced by the fruitful nature of the workshop discussions, provides complementary expertise and experiences leading to new ideas and insight.

**New observations**

New observational work of the shelf break region will be required, designed to leverage existing and forthcoming capabilities, notably NOAA-NMFS survey activities, ongoing cooperative research administered by CFFRF and the NEFSC Cooperative Research Program, and the Pioneer Array. Note: The latter will make valuable observations at fine scales and high resolution that can be used to anchor supplementary observations targeting larger scales. As designed, the Pioneer Array is mostly not intended to sample higher trophic levels including zooplankton, fish, and marine mammals. The research program envisaged here would leverage the wealth of data to emerge from the Pioneer Array in order to examine the key outstanding questions concerning ecosystem processes and fisheries dynamics identified at the workshop and described above. In this way, the Pioneer Array Program will thus be integrated with real world management needs.
Coordinated process studies on research vessels represent an obvious means of addressing the identified research priorities. The fishing fleet can also be used as a cost-effective sampling platform, both as vessels of opportunity for deployment of instruments incidental to fishing activities (e.g., 'Castaway' CTDs) and as opportunities for collaborative projects targeting questions of mutual interest to fishing vessel operators and scientist partners. Autonomous platforms represent another key opportunity for shelf break observation. Emerging biological sensors (e.g., sidescan sonar, multi-frequency acoustics, image-forming optics) deployed from AUVs and gliders offer substantial promise for ecosystem monitoring.

**Models**
Multiscale, data assimilative models will be required for improving nowcasting and forecasting of the shelf break coupled biological-physical system. Pioneer Array data will provide key information for model parameterization, and design of new observational work must take into consideration model needs. Key issues include linking the results of General Circulation Models in a nested fashion with shelf and bio-physical processes. Habitat models similar to those developed for butterfish and squid in the Mid-Atlantic Bight (Manderson et al., 2011) should be developed for other shelf break commercial species. These habitat models can be coupled with the regions operational forecasting models to provide forecasts of species distributions, which can inform fishers and researchers alike. Equally important will be the development of data and model visualization approaches and metrics to inform ecosystem and stock assessments. Current investigations within the Northeast Fisheries Science Center's Ecosystem Assessment Program into ecosystem modeling and metrics for Integrated Ecosystem Assessment (IEA) show great promise (Ecosystem Assessment Program, 2009) and should consider explicitly the shelf break system.

**Communication and coordination**
Additional mechanisms must be established for regular, two-way communication between the research community and members of the fishing community who work at the shelf break. Possible short courses or web-based learning approaches could be used to teach fishers, and members of the public generally, about current research and techniques. Web-based portals would allow fishing industry participants to communicate rapidly with researchers about changes to the shelf break system and vice-versa. New web tools might be developed for display of industry- and science-provided information.

### IV. Benefits of the Planned Research Program

The cooperative research program envisaged here carries a number of important benefits, both regionally and nationally:

- Building a cooperative approach combining the expertise, experience, and infrastructure of academic, governmental, and industry partners offers the best opportunity to produce high quality research results that are readily applicable to real world problems.
• A fundamental, mechanistic understanding will be achieved of a complex coupled bio-physical system, as well as its response to climate change. Better at sea observations and data collection will enhance the development, calibration, and verification of ecosystem models.

• Development of a multi-disciplinary, collaborative research program centered on fishery issues and concerns provides a much needed opportunity to improve the best available science on which fisheries management decisions are based by improving understanding of the shelf break ecosystem in a changing ocean environment, and the impacts of human interactions within that system.

• Marrying standard fishing practices with the deployment of state of the art monitoring technology provides a cost-effective way to advance fisheries science as well as oceanographic studies in general. Involvement of fishing industry members in research also offers an opportunity to reduce potential use conflicts between research and fishing activities and to help enable members of the commercial fishing industry to assist with stewardship of the oceans.

• By developing and implementing a multi-year, interdisciplinary research program in the proposed focused study area, participants will be piloting a new collaborative approach that can serve as a model for use elsewhere. Work accomplished within the designated study area will also be considered in the broader context of shelf/shelf break dynamics along the east coast, advancing a regional understanding as well.
Appendix 1 – Workshop Attendees

Steering Committee

- Glen Gawarkiewicz (Woods Hole Oceanographic Institution, WHOI)
- Gareth Lawson (WHOI)
- Margaret Petruny-Parker (Commercial Fisheries Research Foundation, CFRF),
- Jonathan Hare (National Oceanic and Atmospheric Administration, NOAA)
- Paula Fratantoni (NOAA)

Participants

Fishing Industry:

- David Spencer (CFRF)
- Fred Mattera (CFRF)
- Donald Fox (Commercial Fisherman)
- Dan Farnham (Commercial Fisherman)

Academia:

- Mike Roman (U. Maryland)
- Tom Miller (U. Maryland)
- Bill Boicourt (U. Maryland)
- Jamie Pierson (U. Maryland)
- Huijui Xue (U. Maine)
- Andy Thomas (U. Maine)
- Graham Sherwood (Gulf of Maine Research Inst.)
- Joshua Kohut (Rutgers Univ.)
- Tom Grothues (Rutgers Univ.)
- Steve Lohrenz (U Mass.)
- Jim Bisagni (U. Mass.)
- Wendell Brown (U. Mass.)
- Simon Thorrold (WHOI)
- Heidi Sosik (WHOI)
- Dennis McGillicuddy (WHOI)
- Al Plueddemann (WHOI)
- Robert Todd (WHOI)
- Ke Chen (WHOI)
- Anna Malek (CFRF/U. Rhode Island)

NOAA Northeast Fisheries Science Center:

- John Manderson
- Jim Manning
- Mike Fogarty
- Debi Palka
- John Hoey
- Heather Haas
Appendix 2 – Workshop Agenda

Monday, January 07, 2013

1:00 pm Welcoming Remarks and Workshop Goals

1:15 pm - 2:45 pm – Overview Talks

• Fred Mattera - Overview of Commercial Fishing at the Shelf break South of New England

• Jon Hare - Overview of Science Problems at the Shelf break

• Josh Kohut - The power of partnership between science and the fishing industry in applied ecosystem science

2:45 - 3:00 pm Afternoon Break

3:00 - 4:30 pm - Defining the Issues- Recent Changes and Key Questions

• Panel Discussion with Commercial Fishermen- Peg Parker, Moderator

4:30 - 5:00 pm – Summary and Discussion of Day 2 Objectives

5:00 pm - 8:00 pm – Buffet Dinner and Informal Discussions

Tuesday, January 08, 2013

8:00 - 8:30am - Coffee and pastries

8:30 am - 9:00 am – Developing and Refining Science Themes

John Manderson- Insights into the dynamics of the shelf break front, winter habitat, and keystone forage populations gained through collaborations with fishermen

9:00 am – 10:00 am - Ecosystem Dynamics and Implications for Fisheries Management

Gareth Lawson, Moderator; Jon Hare, Rapporteur

10:00 am – 10:30 am - Morning Break

10:30 am – 11:30 am - Climate Change and Recent Impacts

Glen Gawarkiewicz, Moderator; Paula Fratantoni, Rapporteur

11:30 am – 12:30 pm - New Technologies and Approaches for Real-Time Monitoring and Assessment

Paula Fratantoni, Moderator; Glen Gawarkiewicz, Rapporteur

12:30 pm - 1:30 pm - Luncheon Buffet

1:30 pm – 2:30 pm – Open Discussion: Building a Collaborative Multi-Year Inter-Disciplinary Program
• Summary by Rapporteurs of Morning Discussion
• Prioritizing Questions; Integrating and Organizing Themes; Identifying Targets for Funding; Tasking/Outlining of White Paper

2:30 pm - 2:45 pm Afternoon Break

2:45 pm – 5:00 pm Continued Discussion: Building a Multi-Year Inter-Disciplinary Program
References


