Ecology of the Northeast Continental Shelf

Toward an Ecosystem Approach to Fisheries Management

Northeast Fisheries Science Center and Northeast Regional Office, National Marine Fisheries Service

foreword

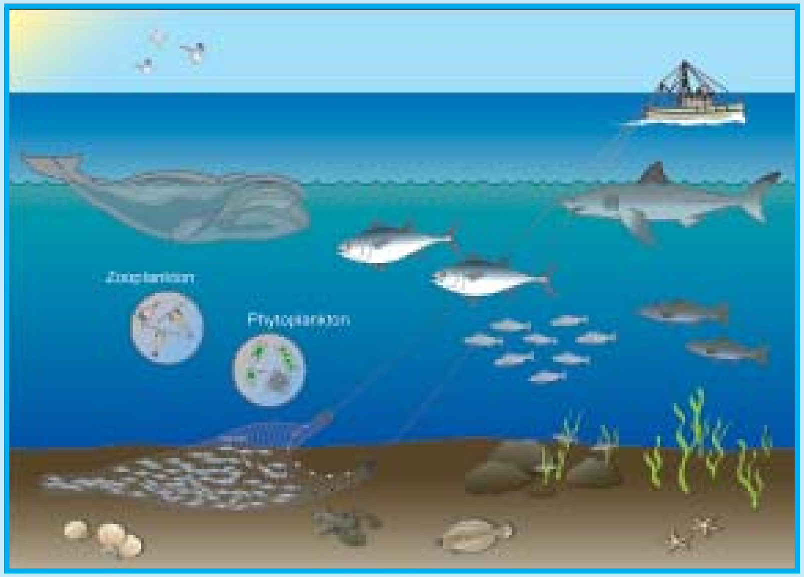
Around the world, many coastal nations are dealing with changes in marine fish and shellfish stocks as well as other sea life owing to alteration of critical habitats, over-use of ocean resources, bycatch, and the effects of climate variability. Thinking of the ocean and its life as an ecosystem provides a more realistic view of the underlying causes and effects of changes in living marine resources. Managing our use of the ocean's resources, including fisheries, on an ecosystem basis is becoming more possible as we learn how an ocean system works. Managing from an ecosystem perspective allows us to consider the effects of multiple factors and their interactions. In addition to fishing, other activities that might be included are coastal development, pollution, shipping, and oil and gas extraction.

In this booklet we describe the general concept of ecosystem-based management, the types of information available for the Northeast Continental shelf, and how we gather this information. To understand the ecosystem we need to consider factors such as climate and oceanography, habitat requirements, the biology of the system from the microscopic plants (or phytoplankton) at the base of the food web to the top predators (including humans), and the connections among all of these parts. We address each of these elements in turn to provide some of the background information that will be necessary to move toward an ecosystem approach to management.

What is an Ecosystem?

An ecosystem is a geographically specified system of organisms (including humans), the environment, and the processes that control its dynamics.

Ecosystems are both complex and continuously changing. Humans and their institutions are integral parts of the ecosystem. Fish harvesters meet an important societal need by providing food from the sea. The ecosystems that produce seafood must be cared for both because of their intrinsic importance and to ensure this sustainable source of food for humans.



Fisheries ecosystems are complex and include tiny plants and animals at the base of the food web (phytoplankton and zooplankton) all the way up to top fish predators, marine mammals and sea birds. Humans are an integral part of the ecosystem.

What is an Ecosystem Approach to Management?

The recently released U.S. Ocean Action Plan strongly endorses the development of an Ecosystem Approach to Management. The action plan builds on the recommendations of the U.S. Commission on Ocean Policy which noted:

> *"U.S. ocean and coastal resources should be managed to reflect the relationships among all ecosystem components, including human and nonhuman species and the environments in which they live. Applying this principle will require defining relevant geographic management areas based on ecosystem, rather than political, boundaries."*

An Ecosystems-Based Management Strategy should be:

- collaborative
- incremental
- adaptive
- geographically specific
- account for ecosystem knowledge and uncertainty
- consider multiple external factors
- balance diverse societal objectives

Because of the importance of geographical considerations in ecosystem approaches to management, in our descriptions we have emphasized spatial patterns and processes for different elements of the ecosystem to help guide these decisions.

Developing Ecosystem-Based Fishery Management in the Northeastern U.S.

Fisheries management off the Northeastern U.S. has usually, but not exclusively, focused on individual species. In fact, some elements of an ecosystem approach were implemented on the Northeast Continental Shelf more than 30 years ago by the International Commission for Northwest Atlantic Fisheries (ICNAF) based on research at the Northeast Fisheries Center.

ICNAF was an international treaty organization that governed fishing in international waters outside the territorial seas of most of the North Atlantic countries until the mid-1970s, when 200-mile limits were established by most of its member nations. In 1972, ICNAF put its "two tier" management system in place. This system recognized that there was an overall level of productivity and sustainable yield for the ecosystem as whole which depended on the inter-relationships among the parts. The upper tier set management targets based on this system-wide productivity. Next, management targets were set for individual species with the requirement of not exceeding the overall system targets. Under these groundbreaking programs, recovery of a number of depleted groundfish stocks was initiated by the late 1970s.

The Time is Right

Important building blocks for an ecosystem approach to management now exist within our current management structures. These include provisions for protecting essential fish habitat, reducing bycatch, and elements related to overall conservation goals under the Sustainable Fisheries Act and for protecting non-target species under the Marine Mammal Protection Act and the Endangered Species Act.

By drawing on the lessons of the past showing the importance of biological interactions and bycatch, and combining them with the ecosystem management elements now in place, we can make substantial progress toward defining an ecosystem approach to fishery management on the Northeast continental shelf. Because the properties of an ecosystem are different than those of its parts, this approach will necessarily differ from single-species based management. It will require us to consider tradeoffs in management — for example between forage fish and their predators – but past experience shows it can be done.

The development of a full ecosystem approach to fisheries management in this area will require a dialogue among all interested parties in order to define specific objectives. Tapping the ecosystem knowledge of different groups is essential to help specify goals, to evaluate the current state of the system, and to explore the options for management. Choosing the right management tools with wide support among all parties will be critical.

Table of Contents

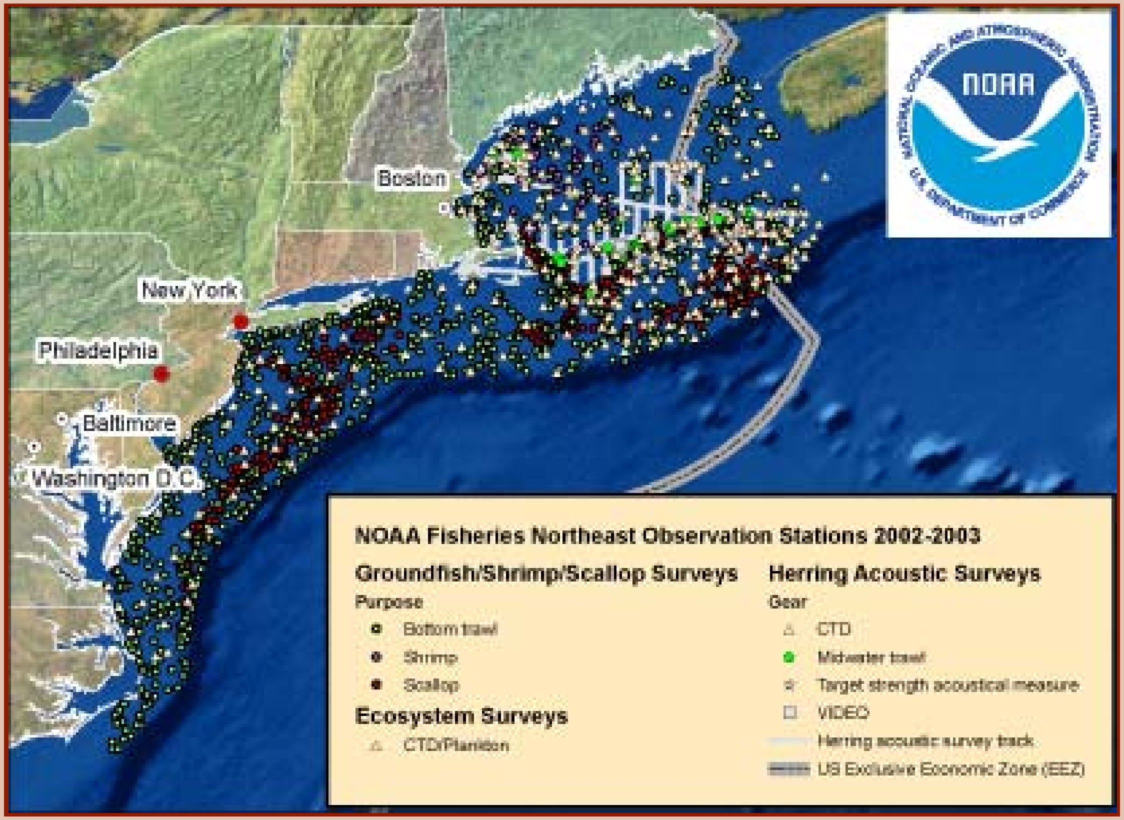
monitoring the ecosystem

Understanding the changes in marine ecosystems in response to natural and human-related factors requires a broad-based monitoring program drawing on many different instruments and sampling systems. It must encompass the physics, chemistry and biology of the seas as well as the human dimension. Essential elements of an integrated ocean observing system have been in place for many decades on the Northeast Continental Shelf. New elements are continually coming on line with the establishment of ocean observatories, and the development of regional ocean-observing system partnerships throughout the region. The later sections of this booklet depend critically on information derived from these observing system components.

Ecosystem analyses at the Northeast Fisheries Science Center have drawn on a broad spectrum of individual monitoring programs targeted at different parts of the system. These include the use of satellite observations that provide continuous and broad-scale coverage of sea surface temperature and phytoplankton production, annual or semiannual surveys to provide snapshots of change in different components of the system over time, and programs designed to track human activities by measuring how much fish and shellfish are caught and where fishing occurs.

Bottom trawl surveys in this region are among the largest-scale and longest-running programs of their type in the world. They have provided an invaluable way of tracking change. To date, nearly 30,000 stations have been sampled, from Cape Hatteras to the Gulf of Maine, in spring and autumn. These surveys were conceived from the start as part of a broad-based ecosystem monitoring program. Changes in the abundance and size composition of all species captured by the gear have been monitored, and basic ecological information on their food habits has been collected. The diets of over half a million individual fish, representing more than 100 predator species, have been examined to provide insights into the food web. Information on other factors ranging from the incidence of disease to basic oceanographic measurements are also collected at the same time.

Monitoring other parts of the ecosystem requires other sampling tools. Special survey programs for shellfish are carried out for this purpose. These

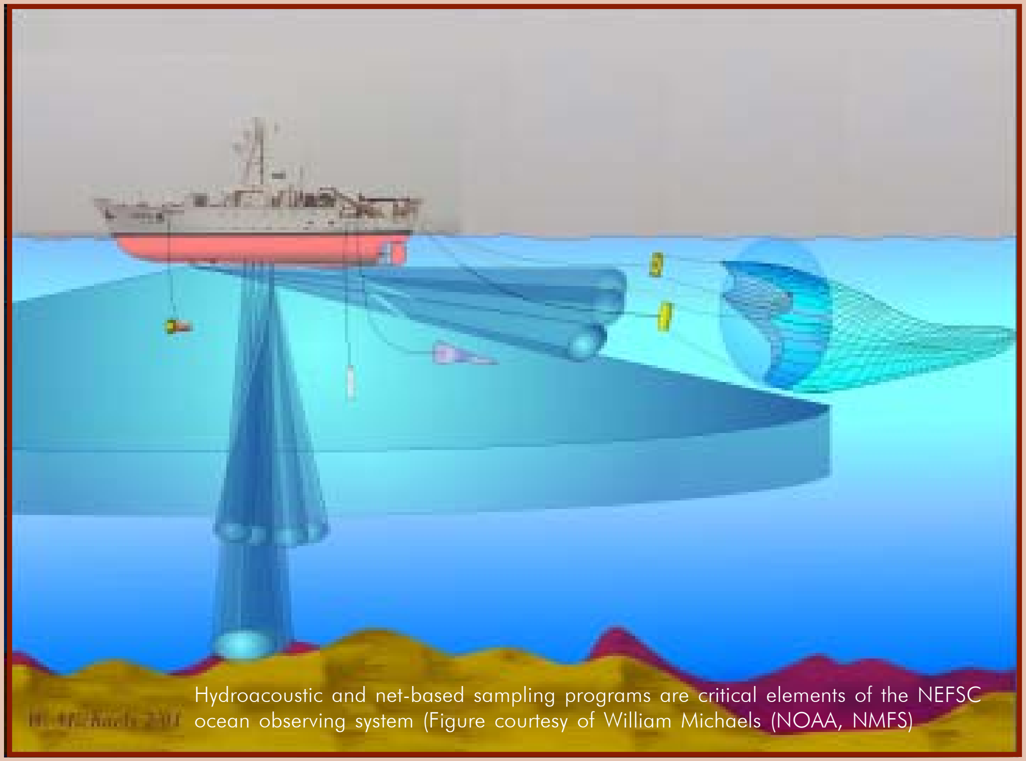


Sampling locations for NEFSC shipboard ocean observing system elements for fish, shellfish and plankton. Not shown are extensive survey programs for marine mammals and sea turtles. Figure courtesy of Tim Haverland (NOAA, NMFS).

too collect a broad range of ecological information on bottom-dwelling species.

In addition to trawls, fish communities are also monitored using echosounders. These hydroacoustic surveys typically focus on schooling fishes such as herring, but many other applications are now being explored. These include mapping the seafloor itself to determine the distribution of different habitat types.

Piecing together the ecological inter-relationships among the various parts of the ecosystem requires information on changes in phytoplankton and the small drifting animals (zooplankton) that serve as food for fish and other species. Longstanding programs to monitor zooplankton have been carried out with over 25,000 stations sampled seasonally since 1977 using plankton nets. A device called the Continuous Plankton Recorder



Hydroacoustic and net-based sampling programs are critical elements of the NEFSC ocean observing system (Figure courtesy of William Michaels (NOAA, NMFS)

(CPR) has also been used. One of the longest running such program involves commercial tankers that tow CPRs along standard shipping routes, providing critical information on changes in the available food supply. New acoustic and optical tools and sampling devices are coming on line to assist in this effort.

Sampling programs designed to monitor changes in marine mammals, turtles, sea birds and top predators such as sharks, tunas, and billfish provide key insights into the ecosystem as a whole while also allowing special attention to threatened and endangered species that require particular protection.

Finally information on the role of humans in the ecosystem comes from catch reports supplied by fishers and interviews with them and by scientific observers placed on fishing vessels. The willingness of fishers to share this information is a vital component of our overall efforts to monitor change in the ecosystem. Fishers also play an important role through their involvement in cooperative research programs where their ecosystem knowledge is invaluable in designing and carrying out monitoring programs and special studies.

Elements of the Northeast Fisheries Science Center Observing System:

- Satellite Oceanography
- Oceanographic Moorings and Buoys
- Plankton Sampling Program
- Continuous Plankton Recorder Program
- Bottom-Trawl Surveys
- Hydroacoustic Surveys
- Sea Scallop Surveys
- Surfclam-Ocean Quahog Surveys
- Northern Shrimp Surveys
- Marine Mammal Surveys
- Apex Predator Surveys
- Sea Turtle Surveys
- Cooperative Industry Surveys and Research
- Fishery Observers

ecosystem drivers

Climate

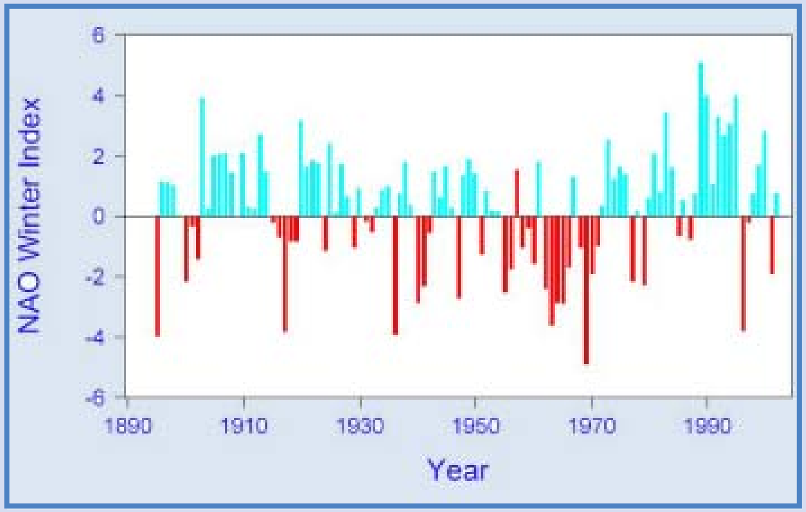
The North Atlantic Oscillation

Climate and weather patterns over the North Atlantic are strongly influenced by the relative strengths of two large-scale atmospheric pressure cells – the Icelandic Low and a high pressure system generally centered over the in the eastern Atlantic. A deepening of the Icelandic Low is accompanied by a strengthening of the Azores High and vice versa. This see-saw pattern is called the North Atlantic Oscillation (NAO) and a simple index of its state is given by the difference in sea level pressure between the Azores and Iceland in winter (December- February).

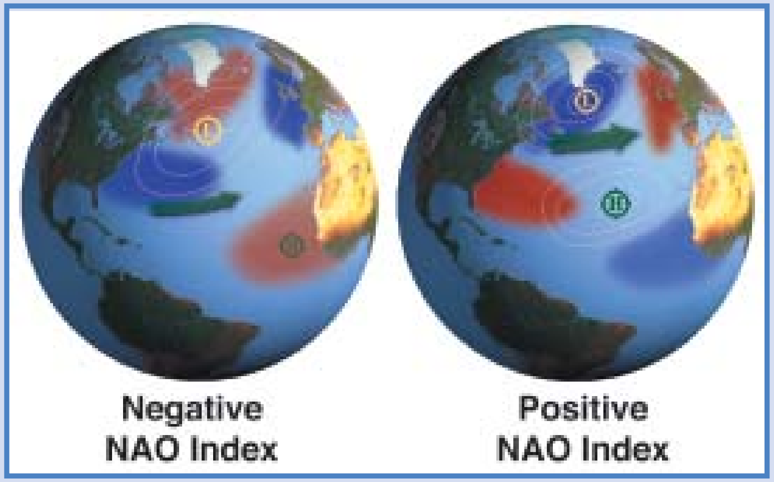
When the NAO index is high, we see an increase in westerly winds, and in precipitation over southeastern Canada, the eastern seaboard of the United States, and northwestern Europe. We also see increased storm activity tracking toward Europe. Water temperatures are markedly low off Labrador and northern Newfoundland, and warm off the United States. Conversely, when the NAO index is low, we have decreased storminess, and drier conditions over southeastern Canada, the eastern United States, and northwestern Europe. Water temperatures are warmer off Labrador and Newfoundland, but cooler off the eastern United States. These changes in the state of the North Atlantic Oscillation tend to persist over many years.

Over the last several decades, the NAO has primarily been in a positive state (strong high pressure over the Azores). We have experienced warm water temperatures during this period, particularly in nearshore areas. This temperature increase closely tracks the change in the NAO index. For example, the NAO index and water temperatures measured at Woods Hole over the last 30 years are high correlated.

When the NAO is in a positive state, the transport of Labrador-Subarctic Slope Water (LSSW) is relatively low, and it does not reach our area. When the NAO is in a negative state however, the LSSW penetrates to the Mid-Atlantic



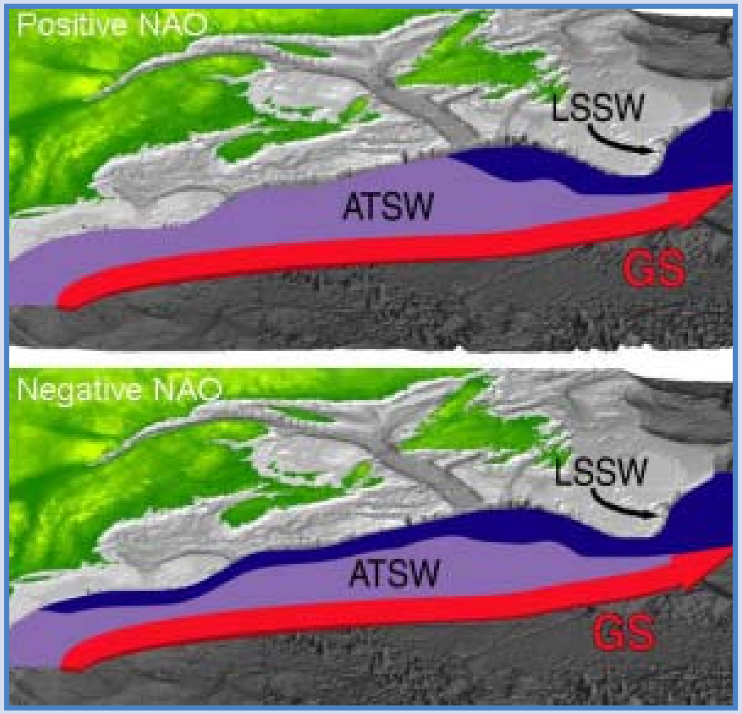
The winter North Atlantic Oscillation Index (sea level pressure difference between the Azores and Iceland during December-February



Atmospheric pressure cells and temperature patterns over the North Atlantic representing conditions when the North Atlantic Oscillation is in positive and negative phases. Areas shaded red indicate warmer than average water temperatures; those shaded blue experience cooler than average water temperatures. The arrows indicate the strength of westerly winds.

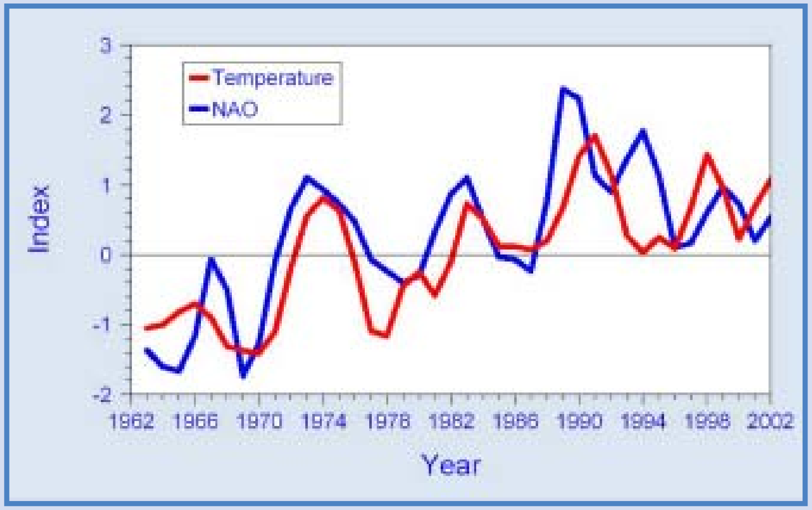
Why it Matters - When Climate Varies

Changes in climate can affect marine ecosystem structure and function in a number of ways. First, changes in atmospheric temperatures affect water temperatures as well. Second, changes in precipitation and runoff from land affect the saltiness (salinity) of the water. Third, alteration in the strength and direction of winds affects ocean currents and also the mixing of the water column. These factors in turn directly affect the basic oceanography of the area. The fact that we see changes in the North Atlantic Oscillation that tend to persist for a decade or more means that we can potentially experience changes in the basic hydrography of the system and management strategies may require adjustment if we experience extended periods of altered system productivity.

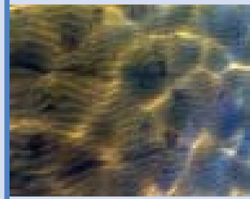


Water mass positions during positive and negative phases of the North Atlantic Oscillation including the Gulf Stream (GS), Labrador-Subarctic Slope Water (LSSW) and Atlantic Temperate Slope Water (ATSW) components

Bight, displacing Atlantic Temperate Slope Water (ATSW) further offshore. The NAO index was low during the mid-1950s to early 1970s and we have seen two major drops in the NAO index over the last decade. These resulted in the penetration of cool, fresh, low nutrient Labrador Subarctic Slope water off the eastern United States after a lag of about 18 months – the time it takes for the LSSW to reach our area from northern Canadian waters.

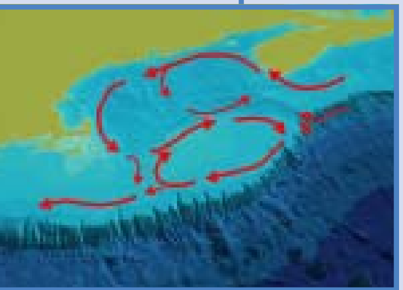


Relationship between the North Atlantic Oscillation index and water temperature at Woods Hole (both series smoothed using a low pass filter)



ecosystem drivers

Oceanography



Mean surface circulation in the Gulf of Maine, Georges Bank and northern Mid-Atlantic Bight

The oceanography of the Northeast Continental Shelf is shaped by a number of factors including the flow of water from Canada into our region, the influence of major river systems, tidal forces, and the earth's rotation. Hydrographic characteristics such as temperature patterns and oceanographic features such as current circulation and the position of frontal zones affect every aspect of the ecology of the system, including the distribution patterns of species at all levels of the food web, the basic biology of individual species, and dispersal and migration pathways among other considerations.

Water Sources and Circulation

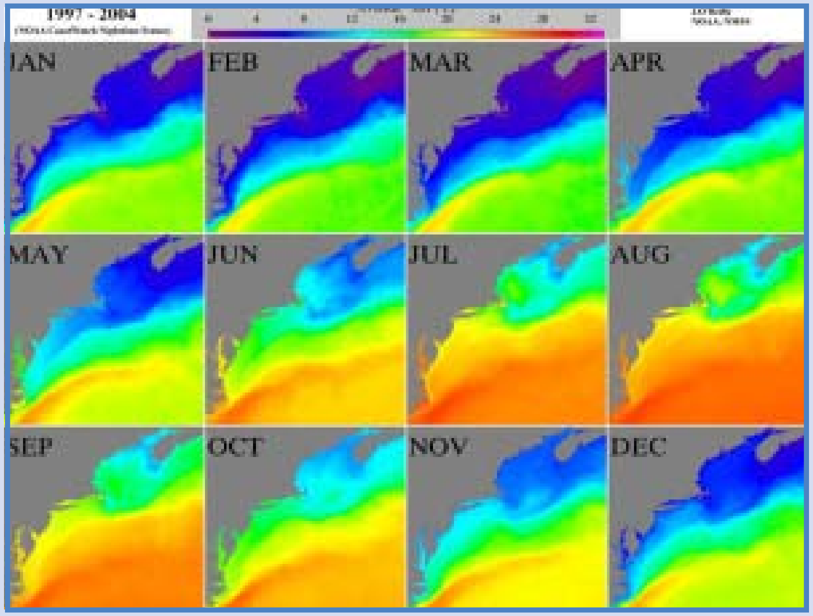
Water enters the Gulf of Maine over the Scotian Shelf and through the deep Northeast Channel, where it forms a general counterclockwise circulation pattern. Smaller-scale circulation patterns may form over several of the features of the Gulf of Maine including some of its deep-water basins. Some of this water exits the gulf through the Great South Channel to the south, while some continues to the northwest where it flows onto Georges Bank in a clockwise circulation gyre. The flow in the mid-Atlantic Bight is generally southwesterly, although it is variable and may reverse direction at times.

Major river systems flowing into the Gulf of Maine and into the Mid-Atlantic Bight have important consequences for flow patterns. The counterclockwise flow in the Gulf of Maine is due in large measure to tides and the effect of five major rivers that flow into it. The outflow of the Delaware Bay, Chesapeake Bay, and Pamlico Sound estuaries have major influence on the circulation in the Mid-Atlantic Bight. Freshwater inputs onto the Northeast Continental Shelf not only influence currents but also the layering (or stratification) of the water column when surface waters are less dense than bottom waters.

The Gulf Stream exerts important influences on the shelf, particularly through the formation of meanders and eddies. Warm core rings – meanders that separate from the Gulf Stream and form a clockwise rotation pattern – can draw large volumes of water off the shelf, along with the small animals (including fish larvae) in that water.

Water Temperature

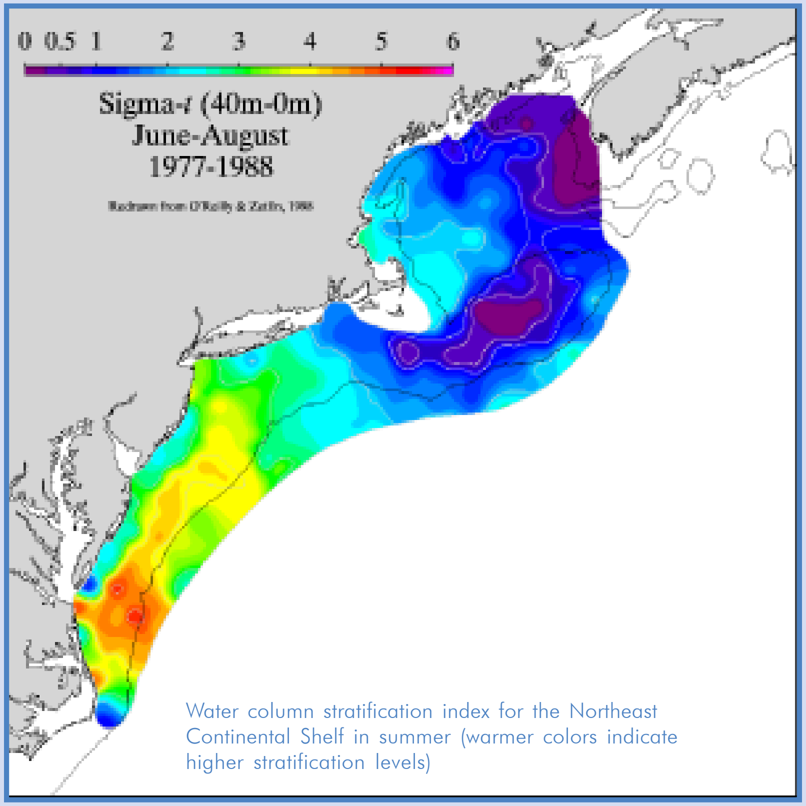
Geographical and seasonal differences in water temperature on the northeast shelf are pronounced, with important implications for the species inhabiting different sections of the shelf. For example, the fish communities of the Mid-Atlantic Bight are dominated by sub-tropical and temperate species, while the much cooler Gulf of Maine-Georges Bank region supports a temperate and cold water fish community.



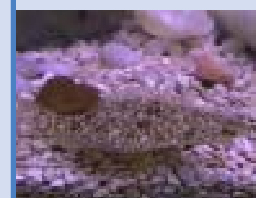
Average monthly sea surface temperature patterns on the Northeast Continental shelf and adjacent slope-basin areas from satellite imagery (warmer colors indicate higher temperature levels)

Why it Matters - Oceanography Sets the Stage

We have seen that there are distinctive circulation features that define broad oceanographic domains on the shelf. In addition, there are distinctive differences in factors such as temperature and stratification that also differ spatially. Persistent trends in climate forcing have been observed and these are linked to some aspects of the hydrography of the region. The increase in sea water temperatures has affected the distribution of some species, with a northward shift for some southern species. Increased temperatures also increase the strength of stratification, affecting turnover of nutrients and the possibility of anoxic events in some areas. Changes in temperature and wind fields can also affect the position of frontal zones and influence circulation patterns. These factors set the stage for the ecology of the area and fundamental features of the biotic community.



Water column stratification index for the Northeast Continental Shelf in summer (warmer colors indicate higher stratification levels)



Stratification

Seasonal changes in temperature and the salinity on the shelf strongly control stratification–the layering within the water column. Basically, water that is colder and saltier is more dense than warmer, fresher water and forms the lower layer. Less dense water sits on top unless mixed by winds and tides. Stratification affects the turn-over of nutrients that support the base of the food web. Once this stratification becomes established each year (in late spring-early summer), the mixing of nutrient-rich bottom water is impeded, and nutrients are rapidly depleted in surface waters in some areas.

Strong geographical differences in stratification in summer are evident on the northeast shelf. With the rapid increase in water temperatures in the central to southern Mid-Atlantic Bight, and the input of fresh water from the major estuaries, this area is strongly stratified. This can have important effects on oxygen levels in this region, since the turn-over of bottom waters is critical in replenishing the oxygen supply. In years of strong stratification, oxygen depletion has been observed, particularly in the mid-Atlantic region, leading to high mortality of bottom-dwelling animals and changes in the distribution patterns of more mobile animals. In contrast, the shallow waters on the central crest of Georges Bank remain well-mixed throughout the year, because of very strong tidal forces and the influence of winds. Intermediate levels of stratification are found in the northern Mid-Atlantic Bight and in the western Gulf of Maine.

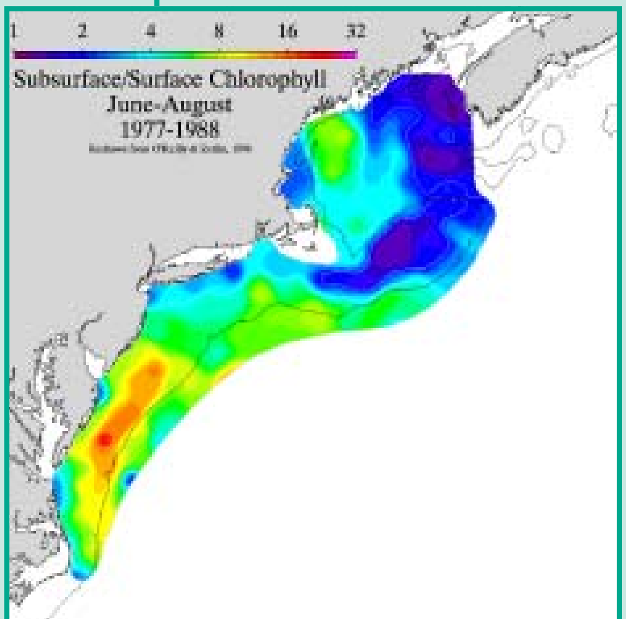
Frontal Zones

Other important hydrographic features on the shelf with direct implications for its ecology include frontal zones — areas of sharp discontinuities in water mass characteristics. Areas where water masses driven by tidal forces converge are often important feeding locations for many species because small plankton prey items are often concentrated there by physical forces. Similarly, a frontal zone develops between the cooler, fresher water over the continental shelf and the warmer, saltier water over the continental slope. The shelf-slope front also tends to be an area where predators concentrate seeking their prey. These include marine mammals and the top fish predators.

fueling the ecosystem

Phytoplankton: The Base of the Food Web

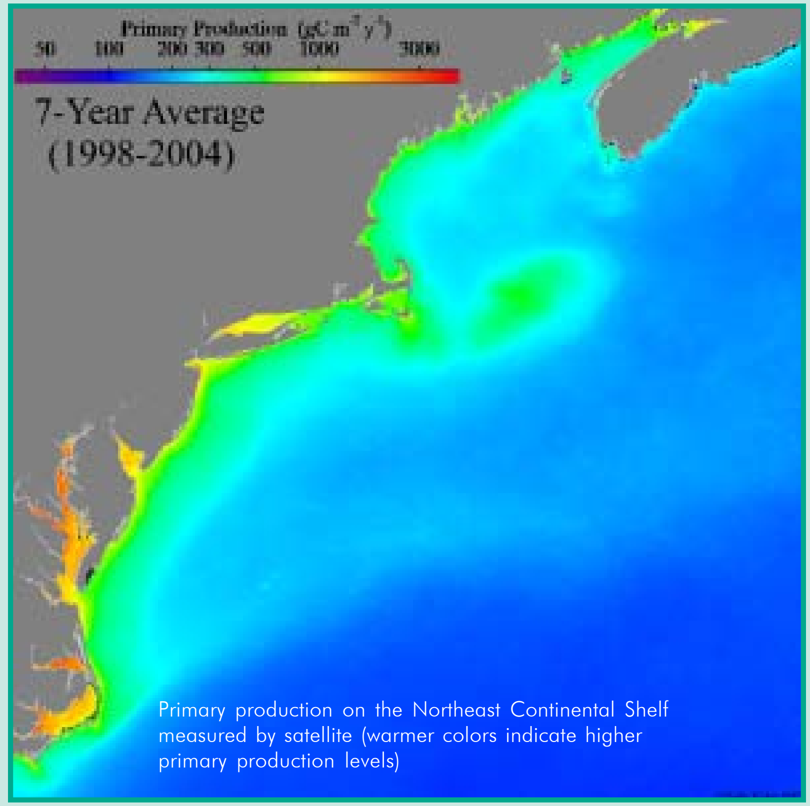
Ultimately, how much fish and shellfish can grow in a given area depends on the amount of energy fueling the base of the food web. Energy from sunlight is 'captured' by plants and converted into plant tissue which, in turn, serves as food for many species. On the continental shelf, phytoplankton are responsible for this 'primary production'. In shallow waters where sunlight reaches the bottom, larger plants, including seaweeds and sea grasses, are also important primary producers. Regional differences in primary production are evident on the Northeast continental shelf. The highest levels are found on Georges Bank and in the immediate nearshore areas (particularly in the Mid-Atlantic Bight) and in the major estuaries where nutrients from land (such as nitrogen and phosphorus) essentially fertilize the sea water. The primary production levels in the deep-water areas of the Gulf of Maine are the lowest observed on the Northeast shelf. Intermediate levels are found on the mid-shelf region of the Mid-Atlantic Bight, and in coastal areas of the Gulf of Maine.



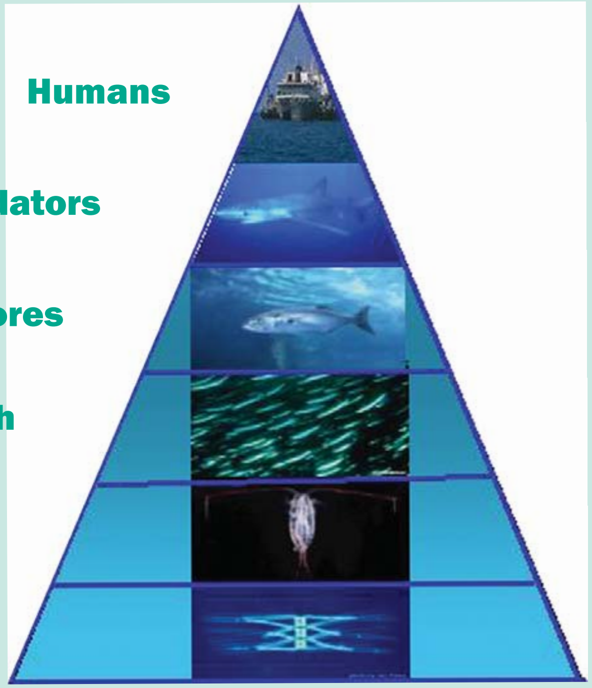
Ratio of surface to subsurface chlorophyll, the plant pigment used in converting sunlight to plant material

On the shelf itself, primary production is strongly influenced by oceanographic processes, which govern the availability of nutrients. The central crest of Georges Bank stands out as an example of these processes. Nutrient-rich bottom water reaches the Bank through upwelling and other mechanisms, and the strong tidal mixing in the shallow central region of the Bank ensures that the nutrients can be distributed throughout the water column.

During stratified conditions, bacteria become an important factor. As noted earlier, stratification limits the nutrient exchange from bottom-waters. However, bacterial activity releases nutrients from dead plants and other material. This recycling of nutrients dominates the primary production processes at this point, and involves a fundamentally different pathway for energy flow and a very different community of primary producers.



Primary production on the Northeast Continental Shelf measured by satellite (warmer colors indicate higher primary production levels)



Trophic pyramid for a typical continental shelf system

Why it Matters - Bottom-up Effects

We have seen distinctive geographical differences in basic ecosystem characteristics on the Northeast shelf involving the base of the food web. The differences are related to the basic oceanography of the region involving the renewal of nutrients and factors such as nutrient runoff in the nearshore areas. As we define subareas for ecosystem management on the Northeast shelf, these considerations will become particularly important. Because we can expect different levels of overall productivity in different regions, our expectations for sustainable catches for the different areas must be scaled accordingly.

Energy Flow

Think of the flow of energy through an ecosystem as an energy pyramid. The amount of energy is greatest at the base of the food web where the primary producers turn sunlight into plant life. Energy is transferred through successive steps called trophic levels. The amount of energy available at each step is progressively less, because the transfer is not completely efficient and because of other losses from the system. Energy remaining at the top of food web ultimately controls the production of living marine resources found there.

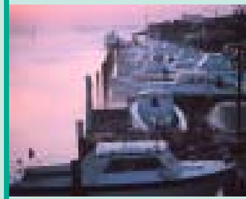
Secondary producers rely on phytoplankton for food. Tiny crustaceans and other animals called zooplankton graze on the phytoplankton, turning plant tissue into animal material. Shellfish such as scallops and clams also feed on phytoplankton, filtering these microscopic plants from the water.

.

The zooplankton are fed upon by a number of different species, including schooling fishes such as herring and mackerel, but also by some types of whales. Fish species like cod, silver hake, bluefish, and dogfish in turn prey on the schooling fish and similar species. These so-called piscivores (fish eaters) are prey to yet higher level predators such as sharks, tuna and billfish.

Humans, of course, prey on a number of these trophic levels. We also compete with other predators for these food items. As both predators and competitors, we can have both direct and indirect effects on the food web. The direct effects involve the removal of prey items; the indirect ones include unintentional alteration of the basic structure of the food web, and modifying the relative balance of natural predators and their prey and by other means.

The reality of how an ecosystem works of course is more complicated than a simple energy pyramid. Instead of a food chain with direct pathways, we have a complex food web with many connections. Understanding these interactions is critical in developing ecosystem approaches to management.



habitat and benthos

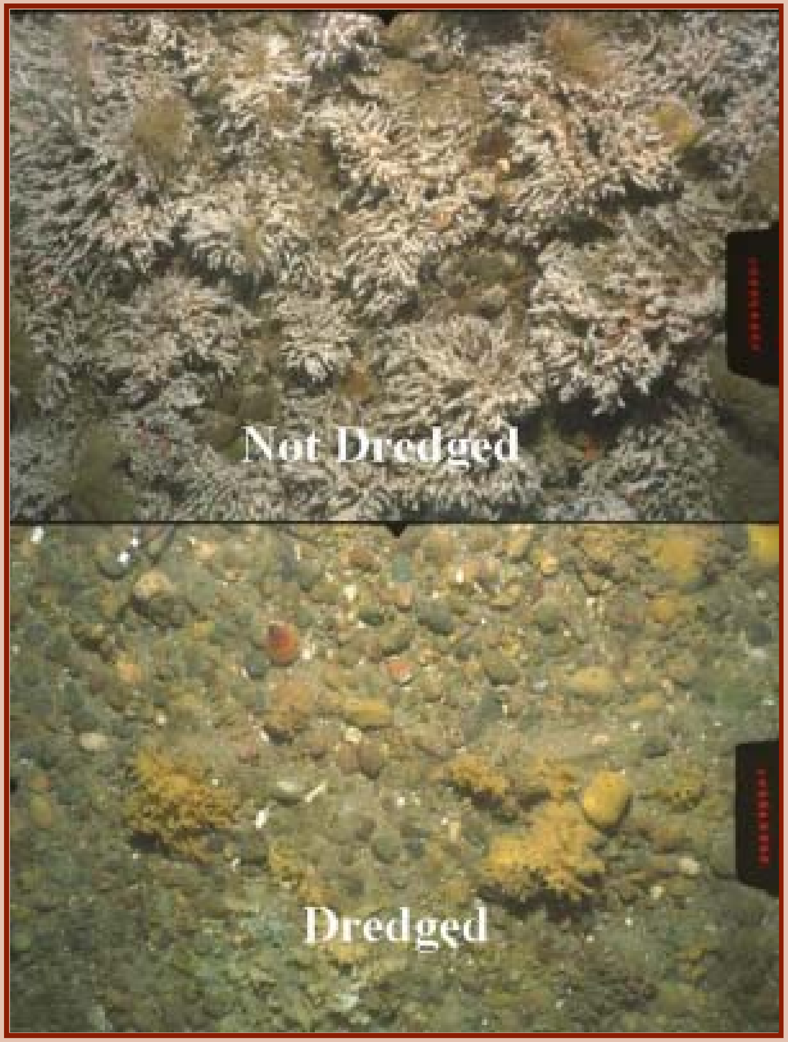
Seabed habitats comprise a complex mosaic of bottom features and associated animal communities. Often, habitats are "biogenic, that is, formed by the animals themselves – for example, reefs formed by hard and soft corals. These may also provide shelter for other species, including fish. Areas that are structurally complex as a result of geological features or biogenic structures often support highly diverse biological communities. Some of these habitats are also particularly vulnerable to disturbance by natural forces and human activities. It is for this latter reason that habitat protection has assumed an important role in current fishery management.

Habitat protection is a cornerstone in the development of ecosystem approaches to fishery management. The ecosystem approach is inherently geographically specific, and therefore naturally linked to considerations of habitat and local seascapes. The specification of "habitat areas of particular concern" under current management measures shows how fine-scale information on habitat and associated biological communities can be used to protect critical areas.

Life on the Bottom

The animals that live on the bottom or in the sediments are called benthos. As with the other ecosystem components we have looked at so far, there are

Many fish species depend on areas of high habitat complexity that provide food and shelter



Differences in bottom communities in an area subject to dredging and an area with no dredging

distinctive geographical differences in the distribution of the benthos. The biomass (total weight of all species) per unit area is lowest in the central Gulf of Maine and on the continental slope. It is relatively high on Georges Bank,

Why it Matters - Carrying Capacity and Habitat

The interest in defining essential fish habitat in the Sustainable Fisheries Act centers on the role that habitat plays in the productivity of living marine resources. Habitats provide food and shelter for many species and therefore directly affect their productivity. If we lose habitat, the ability of the ecosystem to support these animals is diminished. The so-called carrying capacity of the environment depends on the availability of appropriate habitat, among other factors. The response of the population to regulatory changes may depend strongly on the habitat. If the habitat has been damaged, then the recovery of a depleted resource species could strongly depend on whether recovery of the habitat is possible and on its rate of recovery.

There is also a clear connection between the benthos and other parts of the system. For example, some species that spend much of their lives in the water column make excursions to the seafloor to feed on bottom-dwelling animals. We, therefore, have a coupling between the productivity of the benthos and of species that prey on benthic animals.

the Mid-Atlantic Shelf region and the immediate nearshore region of the Gulf of Maine. This distribution of benthos largely reflects the food supply that reaches the bottom. Benthic production is curtailed in deep waters, strongly influenced by energy inputs into these areas.

Many benthic animals support important commercial and recreational fisheries. In fact, many of these species are among the most valuable resources in the region. Clams, oysters, scallops and other molluscs as well as lobsters, crabs, and sea urchins are all economically valuable benthic species. Many of these species have undergone wide fluctuations in abundance over the last several decades with potentially important effects on the ecosystem structure as a whole.

Deep-water coral communities are thought to be highly vulnerable to disturbance by human activities

Essential Fish Habitat

Recognition of the critical role of habitat is reflected in the specification of the Essential Fish Habitat (EFH) requirement of the Sustainable Fisheries Act. Identification and protection of EFH is required under the Act. EFH is defined as:

> *"...those waters and substrates necessary to fish for spawning, breeding, feeding or growth to maturity. For the purposes of interpreting the definition of essential fish habitat, "waters" include aquatic areas and the associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; "substrate" includes sediment, hard bottom, structures underlying the waters, and associated biological communities; "necessary" means the habitat required to support a sustainable fishery and the ecosystem.*

life in the water column

While many species live most or all of their lives on or near the seafloor, a rich community of animals spends their lives in the water column itself. This is called the pelagic part of the ecosystem. Planktonic species, schooling pelagic fishes, marine mammals, sea turtles and top predators inhabit an environment primarily defined by current systems, frontal zones, and other oceanographic structures. These ever-changing features of the physical geography of the sea are every bit as important to the ecosystem as a whole as are seabed habitats.

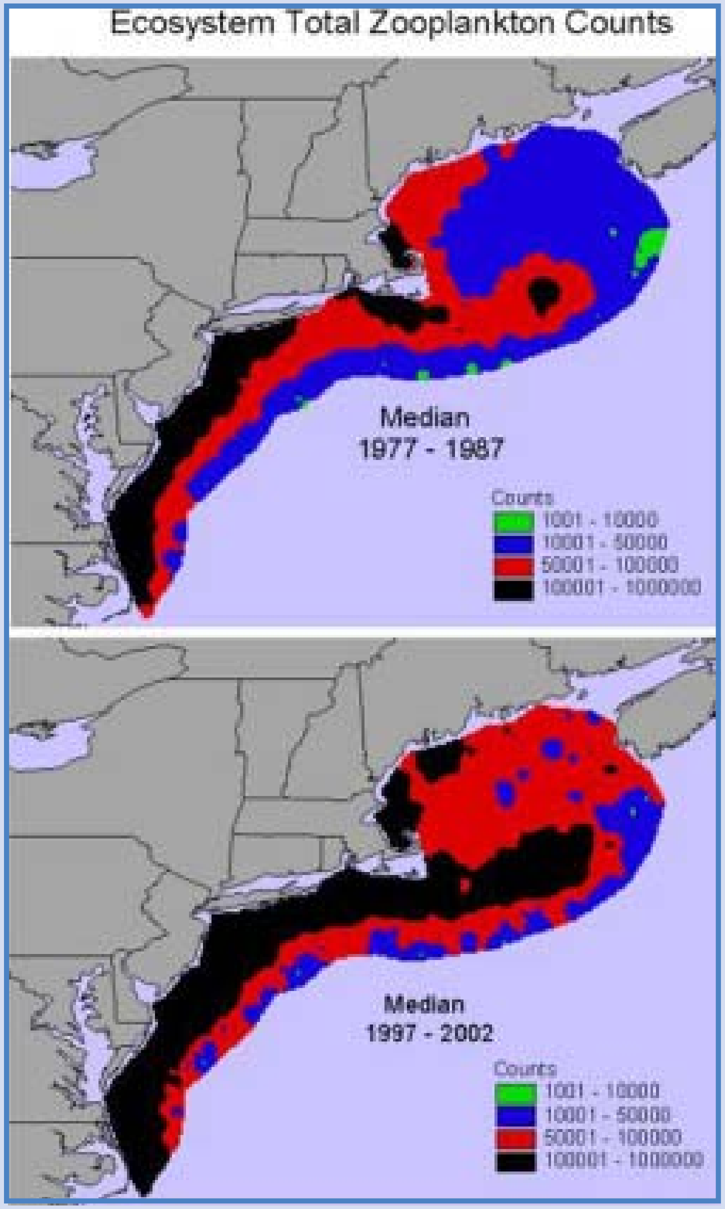
Zooplankton

As with the phytoplankton, we see distinct geographical patterns in the distribution of zooplankton species. These patterns mirror the distribution of primary production to a significant degree. The highest zooplankton counts are found in the nearshore regions of the mid-Atlantic Bight and on the central crest of Georges Bank. The lowest counts occur in the Gulf of Maine and on the shelf edge in general. We have observed changes over time in the structure of the diverse communities inhabiting the water column. For example, a generally increasing trend in overall zooplankton abundance has been observed on the Northeast Shelf since the mid-1980s.

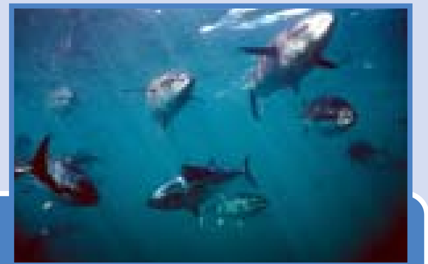
Changes in the relative abundance of different zooplankton species over time have also been observed, with certain groups favoring warmer water temperatures now dominating the system. In areas such as the North Sea, it has been suggested that changes in the composition of plankton communities are linked to recruitment success of species such as cod, since larval cod prey on zooplankton.

Food and Survival

In recent years, we have also seen shifts in the timing of when key zooplankton species populations start to peak during the year. The small crustacean *Calanus finmarchicus* is one of the most important species in the planktonic copepod community throughout the North Atlantic. The period



Spatial distribution patterns of zooplankton numbers over two time periods 1977-1987 and 1997-2002



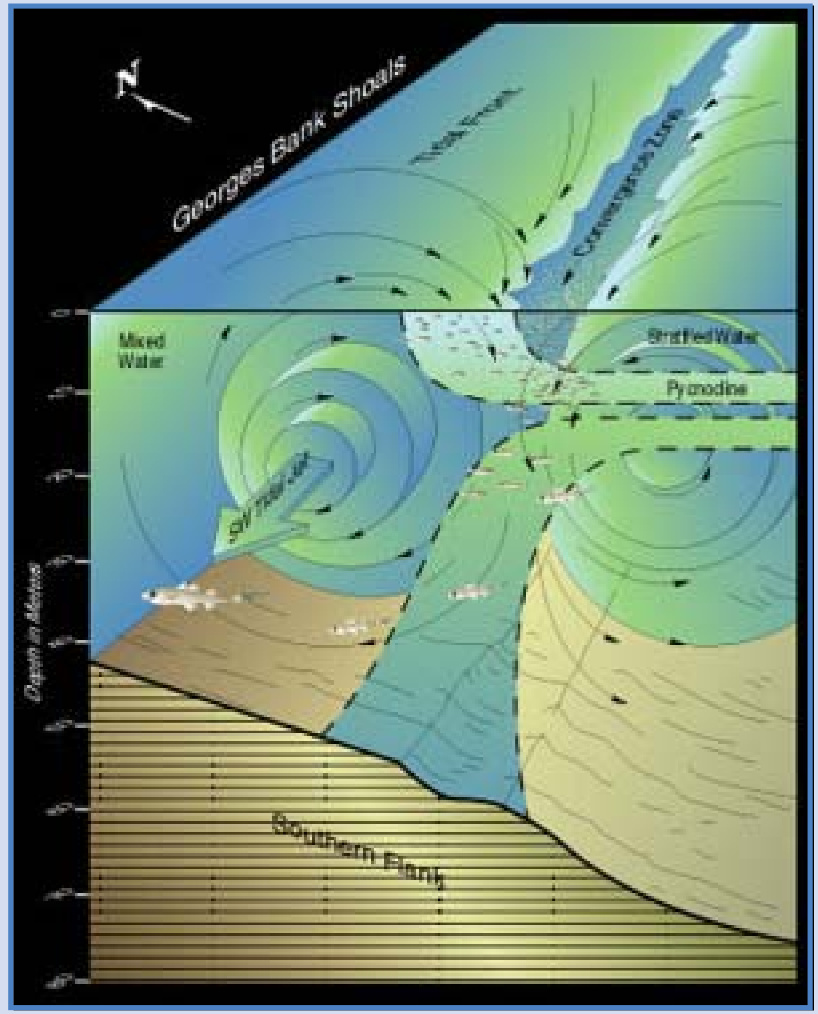
Apex predators such as bluefin tuna are key members of the pelagic ecosystem

Why it Matters – A Bridge Between Large and Small

Understanding events in the water column is key to determining changes in the survival of young fish – recruitment – and also important transfer of energy between different parts of the system. Zooplankton are a bridge to larger animals in the system from fish to whales. Factors affecting their abundance can make the difference between good and poor survival for these groups. Again, oceanographic features figure prominently in defining the pelagic ecosystem, emphasizing the importance of understanding the system in its entirety from physics to biology and on to the human dimension.

of peak abundance of this species in the Gulf of Maine and on the Scotian shelf has shifted to earlier in the spring, and lasts longer than has been typical in the past.

These changes can have direct effects on fish populations. The number of very young fish surviving in the water column varies tremendously from year to year as a result of a large number of physical and biological factors. A storm or a warm core ring can sweep young fish off the shelf, they may be eaten, or adequate food may not be present. All these are examples of natural factors that affect survival rates. If an adequate food supply is available for growth of fish larvae, the chance of their survival is increased. Conversely, a poor match in space and time between the larvae and their zooplankton food can mean starvation for the young fish.



Representation of tidal mixing front on Georges Bank. Frontal zones are areas of high concentration of plankton and fish

Living at the Front

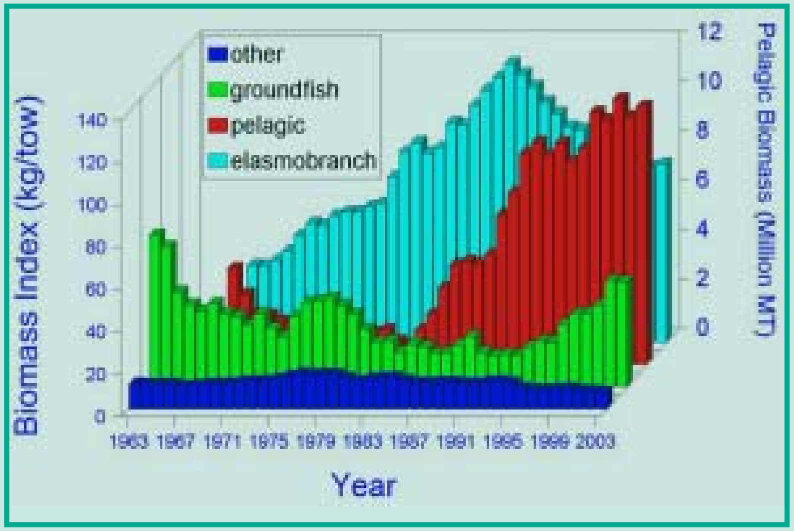
As we have noted, many species forage in oceanographic structures such as frontal zones where their prey are concentrated. For example large shoals of herring are often found at tidal mixing fronts where high densities of their zooplankton prey are found. In turn, fishing activities are often concentrated in these areas to capitalize on these natural associations between predators and their prey for commercially important species.

fish communities

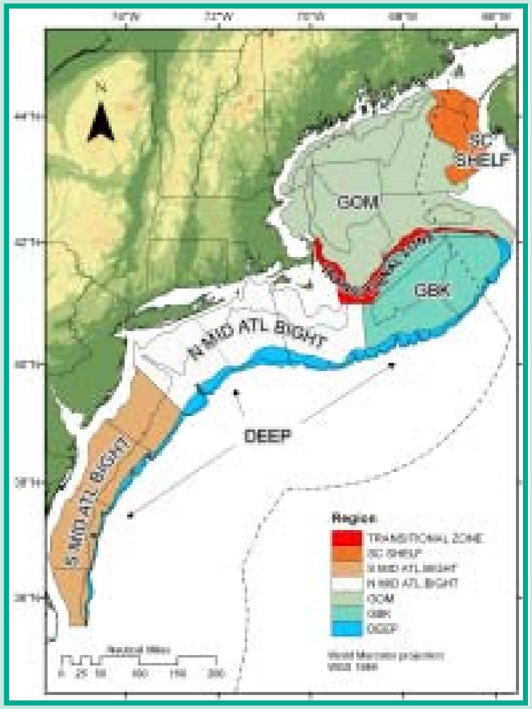
Both fish harvesters and researchers recognize that there are a number of areas where fish species consistently occur together. We find that there are recognizable fish communities found in the Gulf of Maine, Scotian Shelf, Georges Bank, the Northern Mid-Atlantic Bight, Southern Mid-Atlantic Bight, on the edge of the continental shelf, and in the transition zone between the Gulf of Maine and Georges Bank. Finer subdivisions can be identified within each region, but the broad-scale patterns provide important insights into fish community structure.

Biodiversity

We can also see that there are geographical regions with higher numbers of species (or species richness). For example, an examination of research vessel trawl catches shows that certain areas support more fish species than others, and that these sites tend to be related to topographic features such as sharp depth gradients. If we measure the average number of species caught in trawl surveys over time, we see a generally stable overall pattern for the shelf as a whole. However, when we examine subareas, some differences emerge. For example, on Georges Bank, we see an increase in the number of species caught over the last decade – in part reflecting an increase in more southern species found on the bank.



The relative abundance of different groups of fishes on the Northeast Continental Shelf has shown dramatic fluctuations over the last forty years

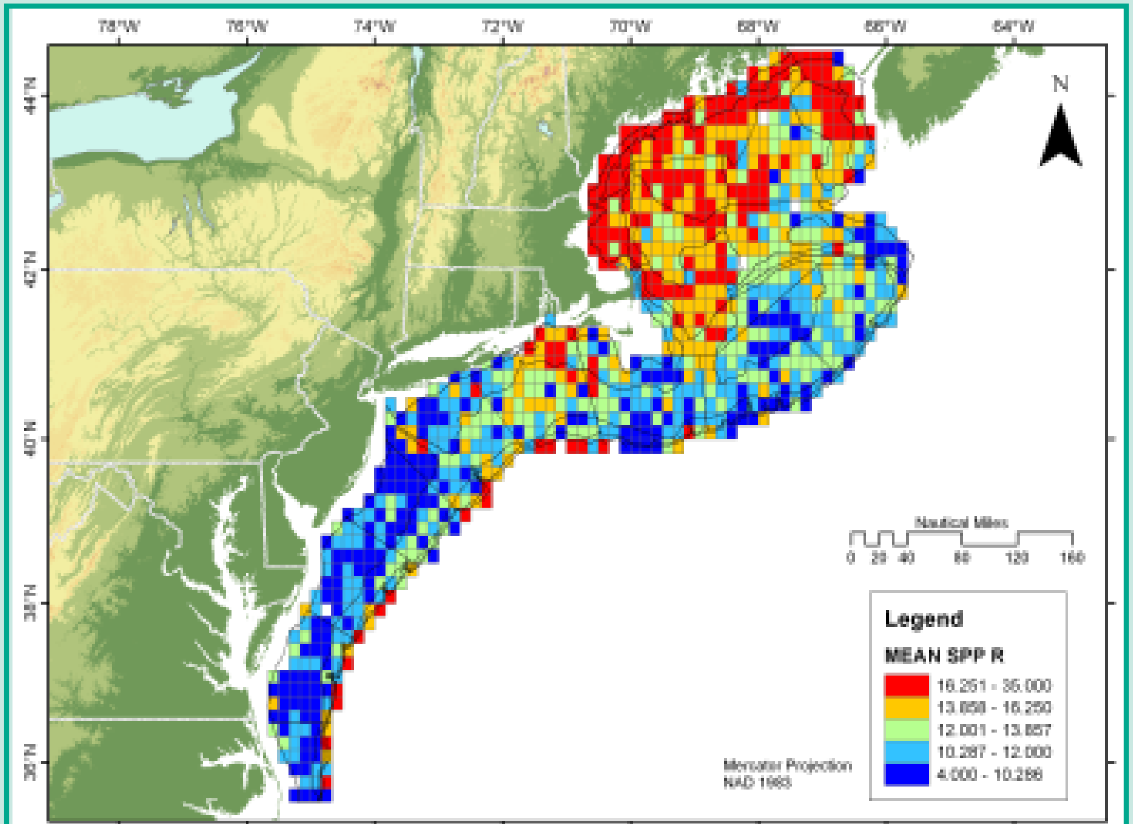


Analysis of NEFSC bottom trawl survey data indicates that groupings of fish occur in well-defined regions. The major areas identified all consistently show distinct assemblages of fish

Trends in Species Groups

Dramatic changes in the relative abundance of different species groups have been observed over time. During the early 1960s, the abundance of northeastern groundfish species began a period of sharp decline as a result of overexploitation. Under a number of new management actions starting in 1994, some stocks have started to improve. These actions included the establishment of large-scale closed areas, restrictions on the days-at-sea allowed for each vessel, and gear regulations such as increased mesh-size. Small pelagic fishes, notably herring and mackerel, also declined in the region under intensive exploitation by the distant water fleets in the 1960s. These species have since undergone a tremendous increase in abundance. During the period of decline for groundfish, a large-scale increase in abundance of certain elasmobranchs (dogfish and some skates) was observed.

Although the exact mechanisms underlying this increase have not been determined, one suggestion is that overall declines in abundance in certain parts of the ecosystem have resulted in the release of food and/or space that the dogfish and skates could then use. These small elasmobranchs began to decline starting in the mid- to late 1980s as fishing pressure on these species increased. Because elasmobranchs produce many fewer young than most other fish, and they tend to become mature at older ages, they are vulnerable to overexploitation. These changes in the composition of the fish communities and the relative importance of different species groups raise questions about whether the changes are reversible if we reduce overall fishing pressure or whether more direct manipulations might be needed. In some cases, the shifting patterns of fishing pressure on different groups over time may have strongly influenced patterns of decline and recovery.



Average species richness per ten-minute square from NEFSC spring and fall bottom trawl survey data, 1984-2005.

The average number of species caught in NEFSC bottom trawl stations averaged over all seasons indicates some distinctive patterns indicating higher species richness along depth gradients and other features

Why Does it Matter? - Fish Scales

When we look at things from an ecosystem perspective, different types of scales are important relative to a view that focuses on one species at a time. For example, the spatial scales of relevance may become the areas where identifiable groups (or assemblages) of species occur rather than the distribution patterns of an individual species. Or areas that have particularly high numbers of species may be of special interest. At another level, we tend to see that the overall abundance of whole groups of fish species tends to be much more stable than any one of the species making up the group. Some aspects of ecosystem-based fishery management will tend to focus on these different levels of organization and different scales.

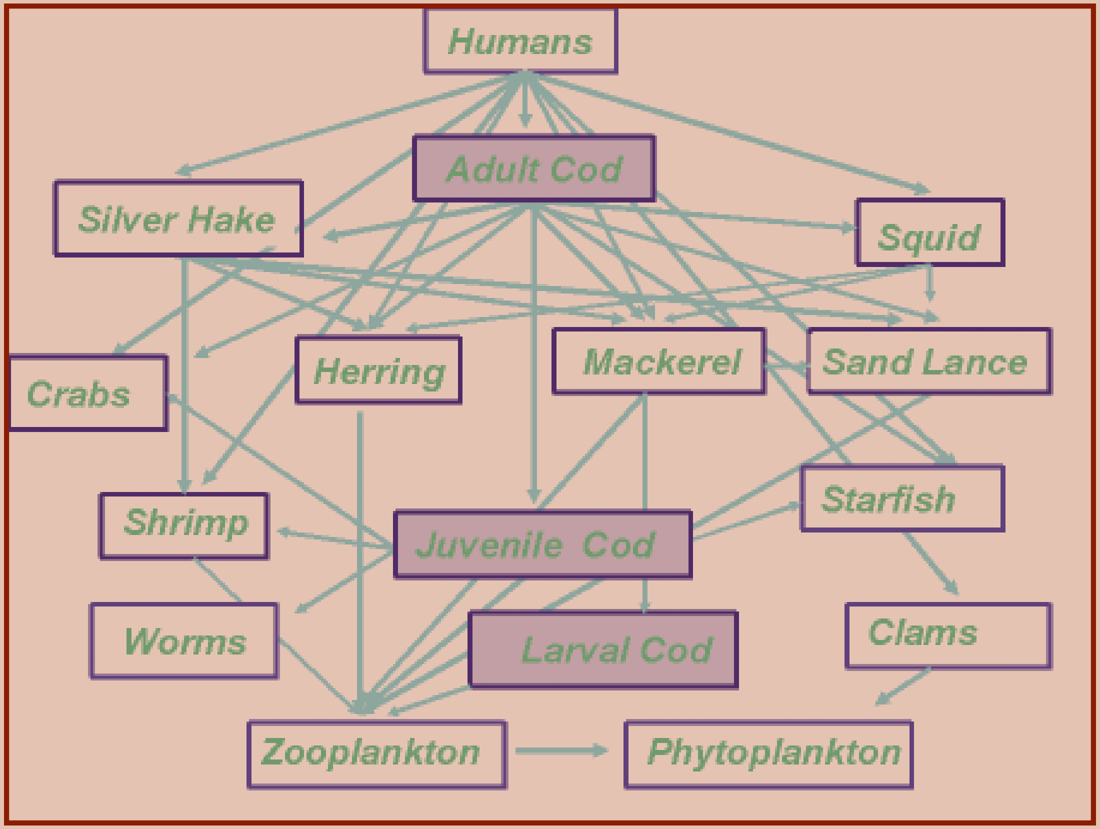
food habits


Cod preying on forage fish

Predator-prey interactions are an essential component of ecosystem structure and function. The flow of energy through an ecosystem depends on the interaction between predators and their prey. Preserving a balance between these ecosystem components is therefore essential.

Who Eats Whom?

Looking at the diets of fish reveals a complex web of interactions among many parts of the system. Even examining a small part of the food web illustrates the large number of linkages possible. For fish, which grow in size over a thousandfold over their lifetime, the progression in the food items they consume is remarkable. As they grow, their diets shift dramatically, so that over the lifespan, a large network of interactions develops. For example, cod begin feeding on zooplankton as larvae and then as juveniles feed on an assortment of larger zooplankton species as well as benthic animals. As adults, they feed on these food items but also become increasingly dependent on fish and squid in their diet. Among these prey are many commercially important species including hakes, herring, and mackerel among others. We see that throughout the lifespan of cod, connections are forged with the planktonic and benthic ecosystems both, highlighting the need to understand the system as a whole as we consider the factors affecting cod.



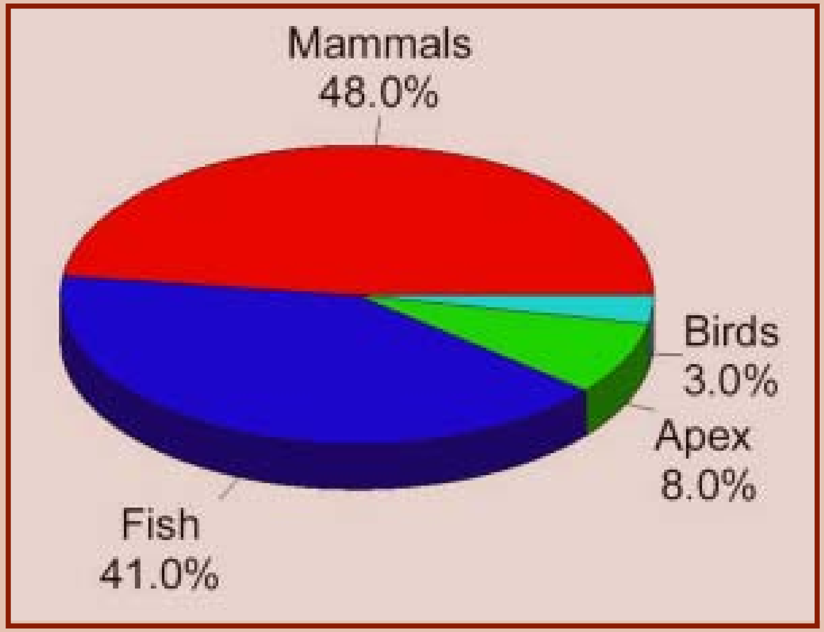
The food web involving cod on the Northeast continental shelf. Cod prey on a wide variety of benthic and pelagic animals, including many that are commercially important

Forage Fish: The Herring Example

Fish that are consumed by a broad spectrum of predators are called “forage” fish. Natural predators such as other fish, marine mammals and seabirds often eat more forage fish than humans catch. For forage species such as Atlantic herring, the amount consumed by predators is now substantially higher than the harvest itself. The amount of herring consumed by natural predators has increased as the abundance of this species has increased. Many predators are

Why it Matters –
It's a Fish Eat Fish World

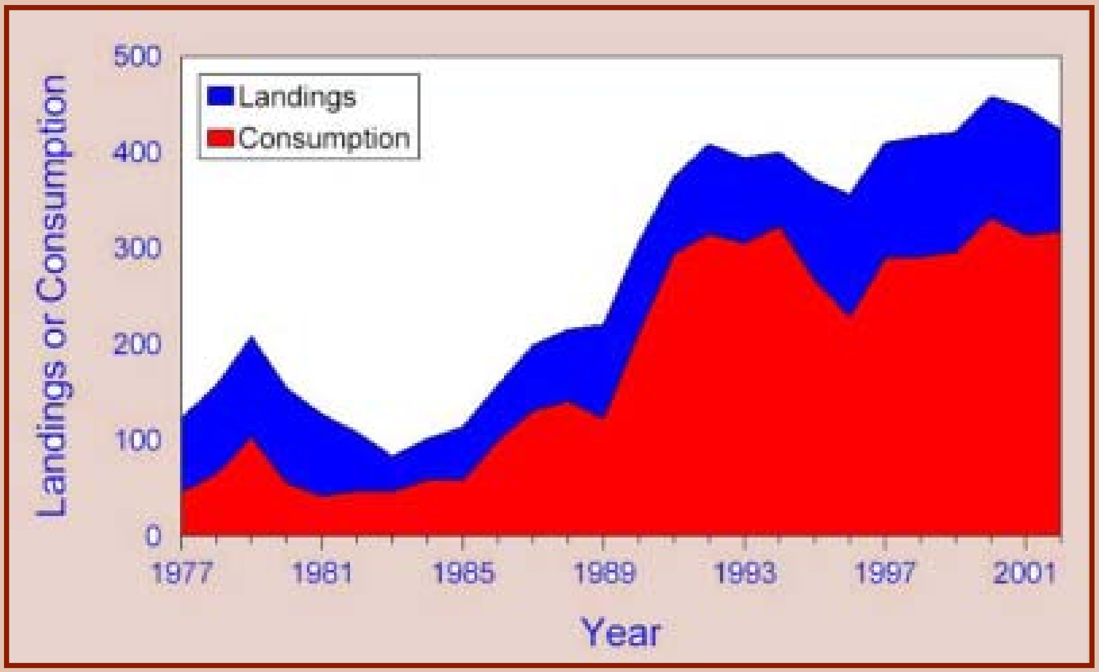
Recognition of the importance of predator-prey interactions among exploited populations will require tradeoffs in management strategies in an ecosystem context. Depending on the strength of the predator-prey interaction, management actions that affect the predator may have indirect effects on the prey and vice versa. Therefore ecosystem-based fishery management will require an additional set of considerations in establishing objectives for management. For species linked by predator-prey interactions, it will not be possible to have all at high levels of abundance.



Fish and marine mammals consume the highest proportions of sea herring with lesser amounts taken by apex predators (sharks and billfish) and seabirds

opportunistic and will feed on the most abundant prey items they encounter. In recent years, marine mammals and fish consumed roughly equal amounts of herring, with far lower consumption by seabirds and apex predators such as tunas and billfish. We have also seen the relative importance of different predator groups change with time. For example, in the early 1990s, the dominant natural predators of herring were other fish, accounting for 70% of the natural predation and consuming nearly three times the herring eaten by marine mammals.

Because forage species such as herring are so important as prey, consideration of ecosystem approaches to fishery management will entail an evaluation of the food requirements of these predators to maintain a balanced ecosystem.



Atlantic herring are important prey for a large number of fish, marine mammal, and seabird species. The amount of herring consumed by these predators has increased as the abundance of herring has increased and it is now larger than the amount taken by the commercial fishery

protected resources

Special considerations are required for species that are threatened or endangered by human activities. Legal mandates and authorities for protection of these species fall primarily under the Marine Mammal Protection Act, the Endangered Species Act, and other pieces of legislation including the Magnuson-Stevens Fishery Conservation and Management Act.

Marine Mammals

Marine mammal species listed as endangered that occur on the Northeast Shelf include the blue, humpback, north Atlantic right, fin, sei and sperm whales. The status of the western North Atlantic right whale is of particular concern. This population is thought to number only about 300 individuals. They are highly susceptible to both collisions with ships and entanglement in fixed fishing gear, resulting in serious injuries and deaths. Current efforts to reduce these risks include sighting surveys for whales during times when they are congregated, wide dissemination of whale locations to mariners, seasonal closure of areas to some fishing gear, deployment of disentanglement teams, and support for researchers working on new gear and sensing technologies that could further reduce these risks.

North Atlantic right whales are critically endangered

Other marine mammal species have increased markedly. For example, harbor seals increased dramatically over the last decade with potentially important implications for the ecosystem. Harbor seals prey on fish species and in some areas, conflict has arisen over the predation by seals on commercially important fish species.

Sea Turtles

Five species of threatened or endangered sea turtles can be found on the Northeast Continental shelf including green, hawksbill, Kemp's ridley, leatherback, and loggerhead turtles. Threats to sea turtles include disruption of nesting sites, incidental capture in fishing gear, and ship collisions. The latter two impacts are of concern for species occurring on the Northeast Continental Shelf.

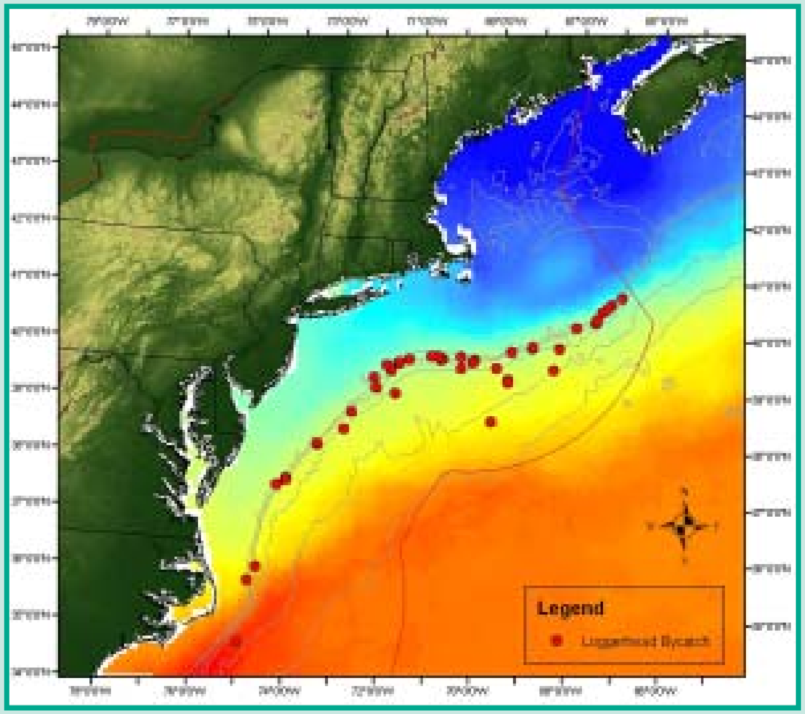
The distribution of sea turtles follows well-defined oceanographic features, namely fronts associated with the Gulf Stream. These fronts are also important habitat for large pelagic fishes, and there are consistent spatial patterns of incidental takes of sea turtles in the longline fishery off the edge of the shelf. These takes have been substantially reduced both through closures and development of modified hooks.

Observations of incidental takes of non-target and protected resource species in commercial fisheries in 2002 showed that sea birds composed the largest fraction of captures in terms of numbers, followed by sea turtles and dolphins. Whales accounted for the smallest fraction. Strategies for reducing incidental capture of each of these groups remains a principal focus of research at the interface between fisheries and conservation biology of protected species.

Why it Matters - More than Warm and Fuzzy

Threatened and endangered species are important in their own right. However, they also play an important role in ecosystem structure and function. We have seen that these species play a wide range of roles in the ecosystem. Because of the large-scale reduction in many of these species, disruption of the balance in the hierarchical ecosystem structure is a primary source of concern. Even if these species are not top level predators, they exert other forms of influence on the ecosystems. For example, many travel extensive distances in the course of their annual migration and movement cycles and they can bridge a number of ecosystems or ecosystem subareas.

Sea turtles that occur on the Northeast Continental Shelf are also threatened or endangered

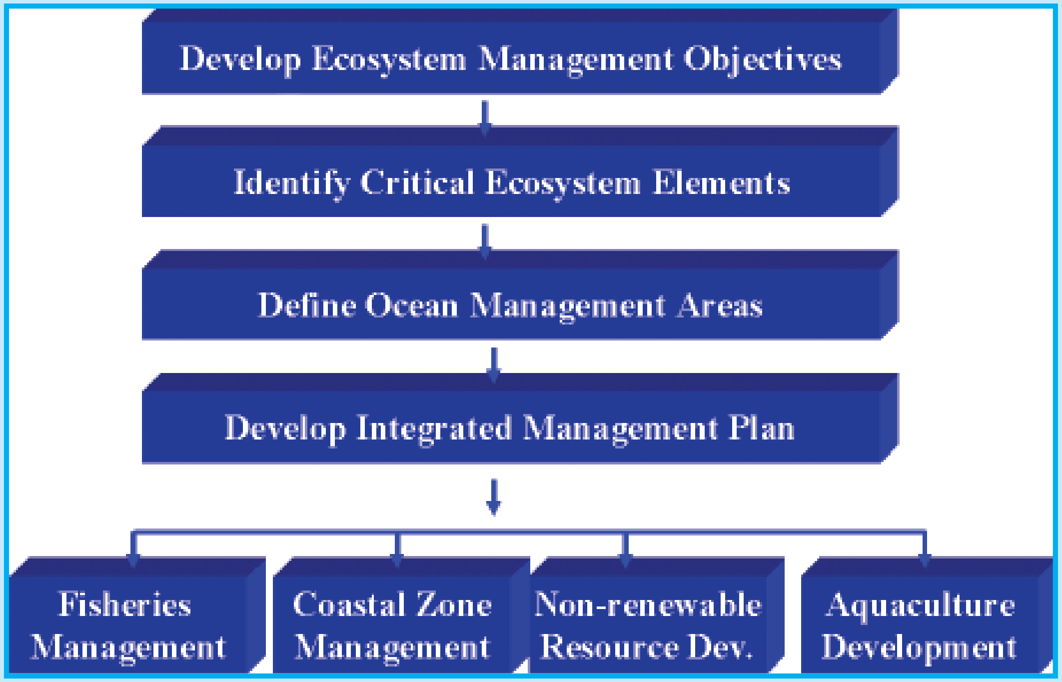


Sea turtles that are incidentally taken in longline sets along the edge of the continental shelf in association with distinctive oceanographic features

the steps ahead

The development of an ecosystem approach to fisheries management, as one component of an overall ecosystem-based management strategy, will entail a collaborative effort among different stakeholder groups. Progress will be substantially enhanced through the development of Fishery Ecosystem Plans (FEPs). A FEP provides background information on the ecology of the system to guide the development of management strategies. As suggested by the NMFS Ecosystem Principles Advisory Panel, constructing an FEP involves the following actions:

- Delineate the geographical extent of the ecosystems(s) that occur(s) within Council authority, including characterization of the biological, chemical, and physical dynamics of those ecosystems, and 'zone' the area for alternative uses
- Develop a conceptual model of the food web
- Describe the habitat needs of different life history stages for all plants and animals that represent the 'significant food web' and how they are considered in conservation and management measures
- Calculate total removals – including incidental mortality – and show how they relate to standing biomass, production, optimum yields, natural mortality, and trophic structure
- Assess how uncertainty is characterized and what kind of buffers are included in conservation and management actions
- Develop indices of ecosystem health as targets for management
- Describe available long term monitoring data and how they are used



Steps in developing an Ecosystem-Based Management Program

- Assess the ecological, human and institutional elements of the ecosystem which most significantly affect fisheries and are outside Council/Department of Commerce authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives

We have touched on a number of these elements as a prelude to the dialogue to follow. An extensive information base on the ecology of the Northeast Shelf is available. This, coupled with the ecosystem knowledge of fish harvesters and others, provides an important stepping-stone to developing an ecosystem-based management strategy. It will also be necessary to integrate information for the continental shelf with that for the immediate coastal and estuarine areas, to develop a fuller picture of ecosystem influences from the watershed to the edge of the shelf.

Eight Ecosystems Principles

The National Marine Fisheries Service Ecosystem Principles Advisory Panel developed the following list of dominant ecosystem characteristics:

1. **The ability to predict ecosystem behavior is limited**
2. **Ecosystems have real thresholds and limits which, when exceeded, can effect major ecosystem restructuring**
3. **Once thresholds and limits have been exceeded, changes can be irreversible**
4. **Diversity is important to ecosystem functioning**
5. **Multiple scales interact within and among ecosystems**
6. **Components of ecosystems are linked**
7. **Ecosystem boundaries are open**
8. **Ecosystems change over time**

CREDITS

Written and produced by Michael J. Fogarty, NMFS, NEFSC
Design and layout by Marla Trollan NMFS, NERO
Cover photos, NOAA's Maritime Heritage Program/Tane Casserley
Page 2, Illustration by Michael Fogarty NMFS, NEFSC, and Jack Cook WHOI
Page 4, Map by Timothy Haverland NOAA, NOS
Page 5, Illustration by William Michaels NMFS, NEFSC
Page 6, Illustration by Michael Fogarty NMFS, NEFSC, and Jack Cook WHOI
Page 7, Map by Charles Green and Andrew Pershing Cornell University
Page 8, Circulation map by Michael Fogarty NMFS, NEFSC, Peter Wiebe WHOI
Page 8, Satellite map by Jay O'Reilly NMFS, NEFSC
Page 9, Stratification map by Jay O'Reilly NMFS, NEFSC
Page 10, Primary Production and Chlorophyll; Maps by Jay O'Reilly NMFS, NEFSC
Page 11, Energy pyramid by Michael Fogarty NMFS, NEFSC
Page 12, Fish habitat photo courtesy of NOAA's Maritime Heritage Program/Tane Casserley
Page 12, Bottom habitat photo by Dann Blackman and Page Valentine USGS
Page 13, Coral habitat photo courtesy of National Undersea Research Center
Page 14, Zooplankton map by Joseph Kane NMFS, NEFSC
Page 15, Illustration by Gregory Lough NMFS, NEFSC, and Paul Oberlander WHOI; Tuna photo by Greg Skomal, MADMF
Page 16, Map by Chad Keith NMFS, NEFSC
Page 17, Map by Chad Keith NMFS, NEFSC
Page 18, Cod illustration courtesy of GLOBEC International Program Office, Artist Glynn Gorick (Glynn@Gorick.co.uk)
Page 20, Large right whale photo, NOAA
Page 21, Sea turtle bycatch map by Christopher Orphaneides NMFS, NEFSC
Page 21, Whales tail and sea turtle photos, NOAA
Page 22, Fisherman photo, Marla Trollan, NMFS, NERO
Page 23, Mackerel photo, NOAA
Page 23, Fishing vessel photo, Marla Trollan, NMFS, NERO