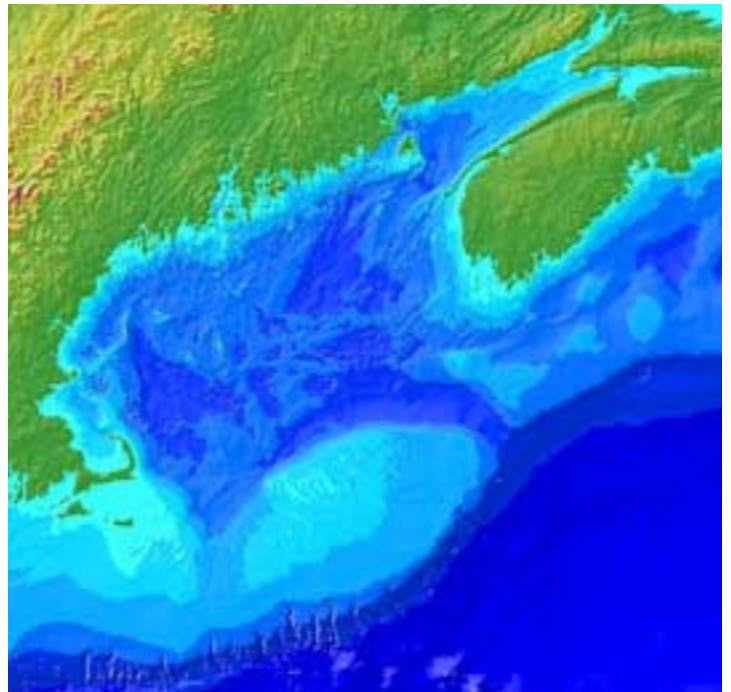


# Ecosystem Relationships in the Gulf of Maine

*Combined Expert Knowledge of Fishermen and Scientists*

*Fishermen and scientists have merged their expert knowledge about the Gulf of Maine to create a better understanding of fish, habitat, species interactions, and spatial and temporal dynamics.*

*The resulting diagrams, charts, and text presented here enable more sophisticated ecosystem-based decision making and relevant scientific work.*



Results of a collaborative project of the Northwest Atlantic Marine Alliance (NAMA), the Coastal Ocean Observing Center at the University of New Hampshire (COOA), and the Gulf of Maine Ocean Observing System (GoMOOS).

NAMA Collaborative Report 1  
August, 2006

## A Fresh Look at Ecosystems

Ecosystem-based management (EBM) is increasingly touted as the most appropriate and effective way to manage fisheries. Yet, to make EBM more than just a buzz-term, managers need to have a much more complete understanding of complex marine systems. This document represents the combined knowledge of fishermen and researchers to identify some of the Gulf of Maine’s ecosystem characteristics.

A simple definition of an ecosystem is “An ecological community together with its environment, functioning as a unit.” The fundamental components of an ecosystem are the physical and biological factors.

In the Gulf of Maine, this community includes commercially-important species of finfish (e.g., cod, flounder, monkfish) and crustaceans (e.g., lobster, shrimp), and their prey (e.g., planktonic copepods and euphausids) and predators (e.g., tuna, whales, humans). It also includes water temperature and salinity, as well as weather and currents. All of these aspects together form an intricately-entwined ecosystem.

The study of the Gulf of Maine is just as intricate. In addition to fisheries biologists who study individual fish species, physical oceanographers investigate the water and currents, chemists and toxicologists examine the nutrients and roles of river inflows, and biological oceanographers research the functions of different types of plankton, including larval fish.

While much research has focused on individual characteristics or parts of this system, very little has been done to connect the pieces to form a picture of the whole. This project brought researchers studying various aspects of the Gulf of Maine together to compare information and discuss relationships. Critically, these discussions also included commercial fishermen who offer a lifetime of observations and expertise from their intimate interactions with the ocean and its bounty. Their unparalleled three-dimensional view of the ocean enables complex relationships to surface.

This project and its outcomes are pioneering in two ways. First, the content itself shows relationships among numerous aspects of the Gulf of Maine ecosystem and variability over time and space. Second, the process of bringing fishermen and researchers together for in-depth full-day conversations is an exciting and effective approach to putting the pieces of an elaborate ecosystem puzzle together.

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## Project Background

The Northwest Atlantic Marine Alliance (NAMA) partnered with the Coastal Ocean Observing Center at the University of New Hampshire (COOA), and the Gulf of Maine Ocean Observing System (GoMOOS) in early 2005 to build closer ties between fishermen and researchers. The purpose was to document their shared understanding and questions related to the interannual variability of the Gulf of Maine fisheries and ecosystems, and possible relationships to the North Atlantic Oscillation and other sources of climate variability.

The project's design was motivated by key questions:

- What do the ecosystems in the Gulf of Maine look like?
- Which components of the ecosystem – species, environmental factors, relationships between them – should be a part of ecosystem-based approaches to fisheries management?
- Which types of oceanographic information are relevant to fisheries – for both fisheries businesses and management?
- How do seasonal, interannual and long-term variability in the ocean affect various species?
- How does the North Atlantic Oscillation affect Gulf of Maine fisheries?
- How can a regional observing system support fishery decision-making, management, and fishermen?

Each project included intensive, day-long meetings which brought fishermen and scientists together to share their knowledge. Discussions focused on 15 different commercial species (lobster, shrimp, and 13 fish species), and participants outlined basic biological and ecological characteristics (use of habitat, distribution and migrations, feeding relationships, changes in abundance over time).

Through broader discussions about seasonal patterns, interannual variability, and known or suspected biological-physical interactions, partici-

pants generated ideas about ocean-fishery relationships.

The diagrams, maps, and text in this document contribute to a clearer understanding of what is known and unknown about the marine ecosystems that surround and support the commercial species in the Gulf of Maine. These products will move the community closer to understanding this ocean region and its fisheries as an integrated system.

The materials resulting from this project – the ecosystem illustrations and accompanying text – are ground-breaking in that they integrate basic biological information across a number of commercial species from sources within the scientific and fishing communities. They represent concrete links between multiple species together with their habitats in the Gulf of Maine. Further efforts will be needed to flesh out the connections between species and the broader ocean environment in which they live.

### **For additional copies of this document, for more information, or to comment, please contact**

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### **This material is also available on the NAMA, COOA, and GoMOOS web sites**

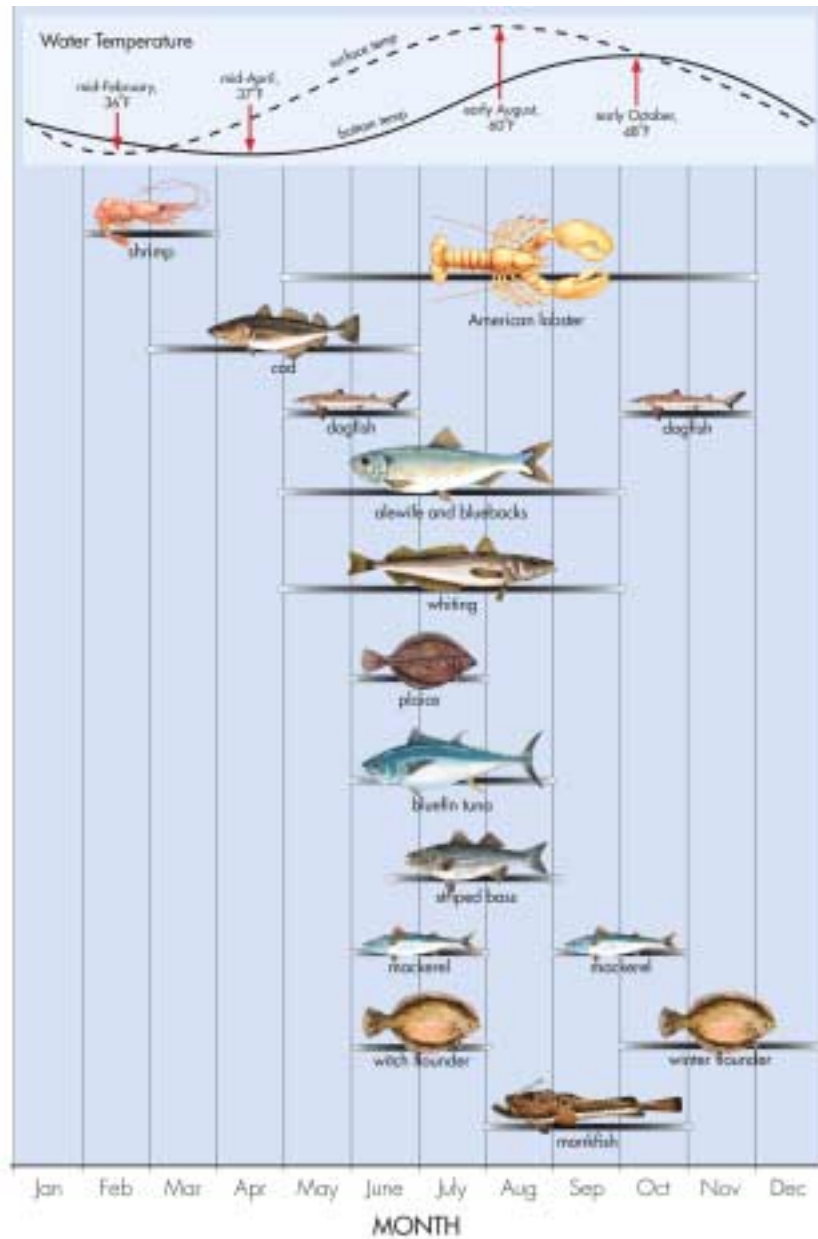
([www.namanet.org](http://www.namanet.org), [www.cooa.unh.edu](http://www.cooa.unh.edu), [www.gomoos.org](http://www.gomoos.org)).

## Seasonal Cycles of Fished Species in Southern Maine

Commercial species on the coastal shelf (0-100m, 0-50 fathoms) of southern Maine have varying seasonal migratory patterns. *Figure 1* captures the periods fishermen and researchers collaboratively identified as the highest in-shore abundance during a typical year. Species undertake these annual journeys for multiple reasons, including staying within hospitable water temperatures and finding food. Species also vary their behavior year to year. The North Atlantic Oscillation and other inter-annual climate variability likely impact species directly and indirectly through changes in water temperatures, prey availability, predator abundance and other factors.

**Winter** is a quiet time for near-shore fisheries in the Gulf of Maine as storms rage offshore, temperatures drop and salinities rise. Few species remain in the area through the winter months. Most fish and lobsters have left for warmer waters to the south and in the deeper offshore basins. Large female shrimp arrive in abundance to drop their eggs between January and March and support an important winter fishery before returning to deeper basins for the summer.

(Seasonal Cycles continued on page 4)



**Figure 1: Seasonal Cycles of Fished Species in Southern Maine**

The water temperatures in the illustration represent a fitted-sine curve average over 2001-2005 from GoMOOS Buoys B and C at two different water depths: 1m (surface) and 50m (bottom). The remaining content of the figure, and accompanying text, is based on discussions at NAMA-GoMOOS Fishery-Ecosystem meetings.

Graphic content developed by Heather Deese, Adrian Jordaan, Curt Rice, Craig Pendleton, Neal Pettigrew, Sally Sherman, Steve Train, and Dan Schick. Fish images courtesy of the Maine Department of Marine Resources Recreational Fisheries Program and the Maine Outdoor Heritage Fund, and NOAA. Concept by Tom Shyka and Heather Deese. Graphic by Ethan Nedreau.

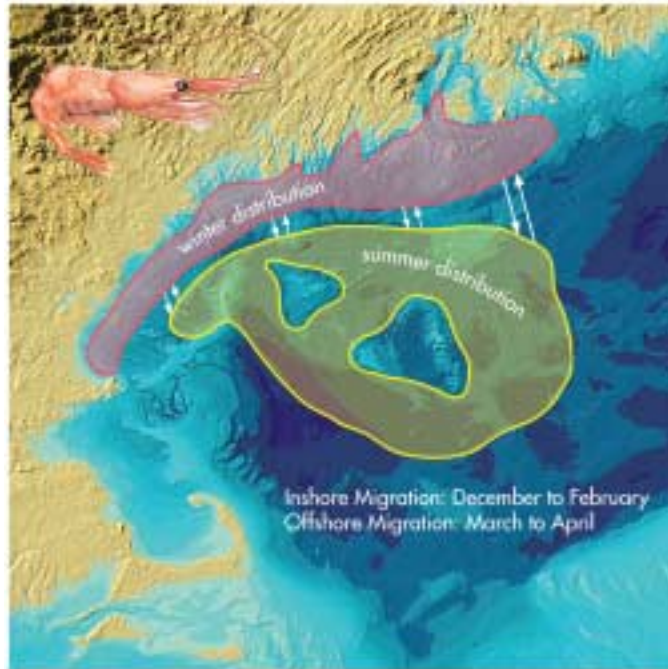
## Distribution of Adult Female Northern Shrimp

### Ecological Notes of Interest

Northern shrimp (*Pandalus borealis*) exist in places throughout the North Atlantic, North Pacific and Arctic Oceans. In the Gulf of Maine, northern shrimp are at the southern end of their range.

Seasonal changes in bottom temperature are thought to trigger adult female movement inshore for spawning (see *Figure 2*). Interannual changes in bottom temperature, salinity and nutrients might affect overall abundance and distributions of shrimp within Gulf of Maine. Shrimp migrate up into the water column at night and spend their days on bottom. The commercial fishery targets adult females while they are inshore to release eggs (in the winter and early spring). Vessels trawl with 2-inch mesh and the Nordmore grate across the front of the net to reduce by-catch.

(Shrimp continued on page 5)



**Figure 2: Distribution of Adult Female Northern Shrimp**

Graphic content developed by Adrian Jordaan, Curt Rice, Craig Pendleton, Sally Sherman, Steve Train, and Dan Schick. Shrimp from [www.hafra.is](http://www.hafra.is). Concept by Heather Deese. Graphic by Ethan Nedeau.

(Seasonal Cycles continued from page 3)

**Spring** is a season of intense activity for marine species and fishermen. Temperature warms, salinities drop, and daylight lengthens. The combined environmental conditions trigger intense plankton blooms, which provide abundant food for fish larvae and many other small marine species. Larger commercial species arrive to feed or breed. Cod and dogfish arrive in early spring, followed by lobsters and the smaller fishes such as whiting, alewife and blue-back herring.

**Summer** is a time of abundance and diversity. Commercial species arrive in-shore in waves throughout the season, staying for weeks or months before moving on. Species such as dogfish, mackerel, cod, plaice, witch flounder, tuna, and striped bass are likely coming from the south in coastal migrations. Mackerel and dogfish come through the area twice each year, much like migrating birds – once on their way north and east in spring, and again on their way south and west in fall. Other species migrate inshore from deeper, offshore basins including lobsters, whiting, white hake, red hake, and monkfish. Marine mammals and birds also migrate through the area, although some, including the harbor seals, are thought to be year-round residents.

**Fall** is a time of shifting fishing activity as lobstering intensifies while many other commercial species have left for the year. A fall plankton bloom and maximum annual temperatures are followed by cooling and shortening daylight. Some fish species may gather for local spawning events (herring and possibly monkfish and cod), while others return to the area on southerly fall migrations, such as dogfish and mackerel. Lobsters are the major commercial species in fall. Fishing drops off steadily in late fall as many lobsters move to deeper water or leave for longer migrations.

## Depth Distributions and Habitat Types for Gulf of Maine Commercial Species

Figure 3 on page 6 presents the depth zones and broad habitat types where fishermen and researchers expect to most commonly find a range of commercial species. Most species move through various habitats during different life stages, and may occupy different depth zones depending on where they are within the Gulf of Maine.

The depths indicated for each broad habitat type overlap, indicating the variation in the seafloor throughout the region. Many species move seasonally as well, but this graphic portrays the type of area where you would most commonly find adults of each species along the north-

western coast of the Gulf of Maine.

### **Near-shore (0-50 fathoms / 0-100m)**

Geologically, the inner portion of the near-shore coastal shelf was exposed to dry land as the glaciers retreated from the last ice age, leaving a rockier seafloor today down to 55-65m depth due to tide and wave action at lower sea levels.

The coastal shelf rims the Gulf of Maine, and the shallowest section of the shelf comprises a mixture of bottom types from mud to hard-bottom (rocky or gravel areas). Juveniles of many commercial species occupy these areas, including cod, haddock, pollock, and winter

(Depth Distribution continued on page 6)

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(Shrimp continued from page 4)

### **Life History**

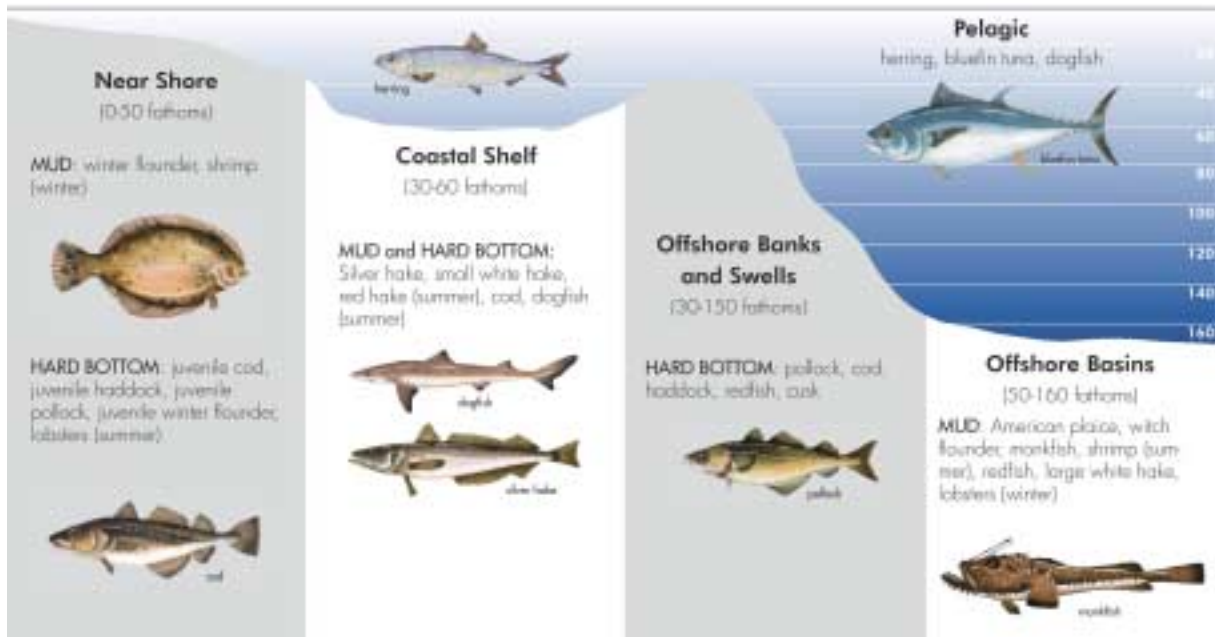
There is little known about the pelagic larval stage of northern shrimp, but they are believed to spend approximately four weeks in this stage. After the first four weeks, juveniles are thought to settle within 10 miles of the coast and remain there for 12 to 20 months before they start moving offshore as males. Shrimp spawn for the first time as males during their 3<sup>rd</sup> summer (2.5 years old), and then become females during following year. Very few survive beyond 5 years old. They are believed to spawn in late summer, and develop eggs which females carry on their pleopods (swimmerets) for a few months.

### **Spawning Migration**

Adult females arrive in near-shore waters sometime between January and early March (earlier in the west, progresses east) to release live larvae from their eggs. They tend to gather in 10-30 fathoms on muddy bottom near some harder, structured bottom, often 'downstream' or lee-side of ridges or islands which may provide some protection from strong currents. Some aggregations occur near river mouths, even up into some rivers. They may move inshore along canyons leading up to the shallow areas from the deeper basins. They remain in the shallow areas for 1-2 weeks after they release larvae and egg cases before starting the journey back to deeper basins for the summer, molting along the way.

### **Threats to Habitat**

There are a combination of human and natural threats to shrimp habitat. Anthropogenic activities include coastal development, pollutant run-off, and harbor dredging. Additionally, changes in the oceanographic conditions due to the North Atlantic Oscillation or other natural factors may cause warm water to intrude into some of the deep basins in the Gulf of Maine, thereby disturbing natural cues. Some mobile fishing gear in critical habitats (e.g., trawls used to harvest groundfish) may be a threat to the bottom. However new gear technologies and cooperative research efforts continue to find ways to mitigate these impacts.



**Figure 3: Depth Distributions and Habitat Types for Gulf of Maine Commercial Species**

Graphic content developed by Adrian Jordaan, Curt Rice, Craig Pendleton, Neal Pettigrew, Sally Sherman, Steve Train, and Dan Schick. Fish images courtesy of the Maine Department of Marine Resources Recreational Fisheries Program and the Maine Outdoor Heritage Fund, and NOAA. Concept by Heather Deese. Graphic by Ethan Nedeau.

(Depth Distribution continued from page 5)

flounder. Winter flounder are one of the few adult commercial species found in this zone, although northern shrimp migrate into shallow muddy areas in late winter to release their eggs.

Oceanographically, the near-shore is an extremely variable environment. Temperatures can range from near-freezing in the winter to over 70 degrees fahrenheit in summer. Salinities are often lower in this zone than further off-shore due to river inflow. Tidal currents can be intense and storm waves regularly reshape the bottom in some areas. During fall and winter, the sea water mixes top-to-bottom in this zone, bringing cold water and nutrients to the surface.

The near shore areas have also been subject to a range of impacts from humans, due to land-based sources of pollution and nitrification, and habitat alteration due to shoreside development.

### Coastal Shelf (30-60 fathoms / 60-120m)

The outer coastal shelf has a different character because it remained submerged after the last ice age and therefore is mostly muddy bottom inter-

persed with rock and gravel areas. This zone also hosts the core flow of the Gulf of Maine Coastal Current, which flows counterclockwise around the Gulf from Nova Scotia to Cape Cod.

Many important commercial species are found in abundance, including cod, whiting (silver hake), red hake near the seafloor, and dogfish and herring in the water column above. Young adult white hake are also most commonly found in this area, while progressively larger white hake are found in deeper and deeper waters.

The transition region from the coastal shelf to the deeper areas of the Gulf is often characterized by changes in water temperature, salinity, nutrients, dissolved oxygen, and other characteristics. This is what oceanographers call a 'frontal region,' which is usually associated with high plankton growth and good feeding conditions for fish. The strength and position of fronts and the coastal current varies with season and year, depending on the different mix of waters in the Gulf, weather conditions, and other factors. Some species, including dogfish, herring, and

(Depth Distribution continued on page 7)

## Feeding Relationships in Off-shore Basin Species

Marine food-webs are incredibly complex, with direct and indirect species relationships and prey-switching behaviors. Many questions remain about how much feeding behavior is shaped by preference for specific prey versus availability, and how these dynamics change with seasons and areas within the Gulf.

For example, fishermen have ‘clean’ shrimp catches for part of the season, meaning shrimp are not mixed with other species. Then their catches are completely mixed with shrimp and herring for a different period of time. Why is this? Are the herring feeding on shrimp eggs? Are they both occupying the same habitat for some reason unrelated to each other?

*Figure 4* on page 8 provides a simplified image of some food web interactions. This illustration focuses on monkfish as an important predator, and shrimp as important prey for many commercially

(Feeding Relationships continued on page 8)

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(Depth Distribution continued from page 6)

whiting, occupy the coastal shelf throughout the year, but move north and south along the shelf on annual migrations chasing their prey and staying within hospitable temperatures.

### **Offshore Banks and Swells (30-150 fathoms / 60-300m)**

The rough undersea topography of the Gulf was shaped by glaciers which covered what is now the seafloor 10,000 years ago. Today the result is a series of spires, ledges, and other shoal areas rising from the deep which traditionally have been named ‘banks’ or ‘swells’. Currents and mixing are often accelerated by complex interactions between the steep topography, wind, tides, and water masses surrounding these shallower areas. Many host a rich diversity of marine life and productive fisheries. The seafloor is relatively hard rock and gravel, with patches of sand, particularly on the larger banks (Stellwagen Bank east of Cape Ann is a good example).

Pollock, cod, haddock, cusk, and redfish are found near the seafloor and many other fish, including bluefin tuna, dogfish, and herring use the water column above. Large whales often visit these areas to feed on zooplankton or small fish. This is the depth of the Gulf of Maine intermediate water, which forms each winter when strong winds and cold temperatures cause surface waters to mix with deep water below, bringing up nutrients which feed the next spring bloom.

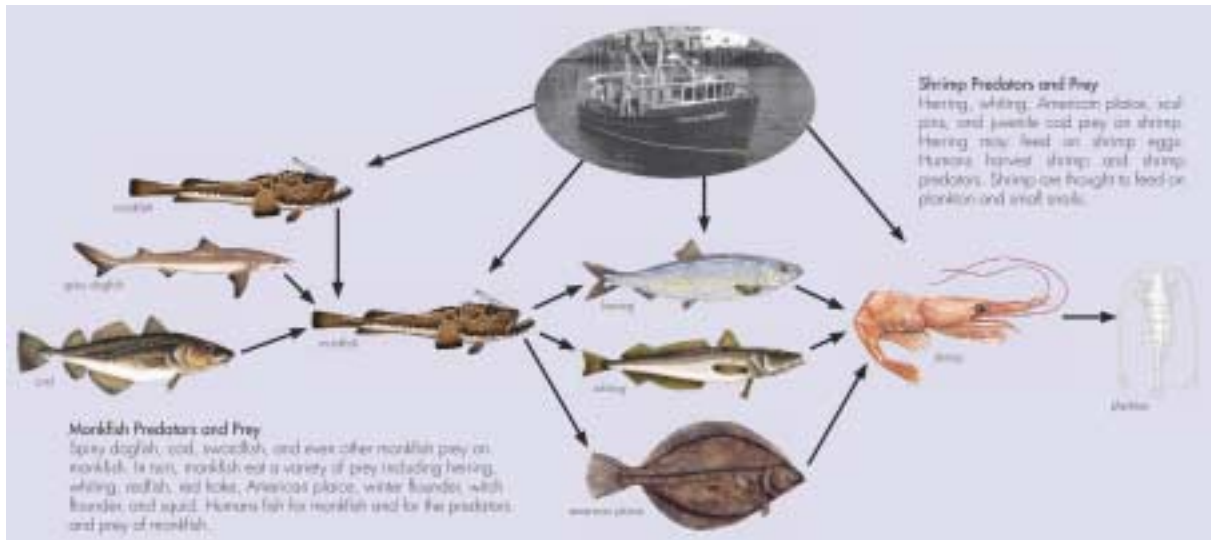
### **Offshore Basins (50-160 fathoms /100-320m)**

The deepest areas of the Gulf host a surprisingly rich mix of fished species, including American Plaice (dabs), witch flounder (grey sole), monkfish, shrimp, lobster, large white hake, and redfish. These deep basins, which lie between the offshore banks and swells, tend to be covered in mud, which has accumulated from years of deposition. The water at the bottom of these basins is warmer and saltier than the intermediate depth waters, and stays a more constant temperature throughout the year.

The combination of quiescent, muddy bottom with a nearly constant temperature makes these basins quite different than the more active coastal shelf and shoal banks and swells. Some species such as monkfish and shrimp are thought to remain in this stable environment most of the year, journeying inshore only for a short seasonal trip to reproduce, leaving eggs and larvae in the shallower environments.

These deepest environments in the Gulf of Maine vary in character year to year as the waters entering the Gulf from the north and east change. The North Atlantic Oscillation can usher in warmer, saltier, high-nutrient waters from north of the Gulf Stream or colder, fresher, lower nutrient waters from the Labrador Sea. Scientists are just beginning to study how differing conditions impact commercial species in the Gulf.





**Figure 4: Highlighting Feeding Relationships in Off-shore Basin Species**

Graphic content developed by Heather Deese, Adrian Jordaan, Curt Rice, Craig Pendleton, Neal Pettigrew, Sally Sherman, Steve Train, and Dan Schick. Additional source: Bigelow and Schroeder, *Fishes of the Gulf of Maine*, Bruce Collette and Grace Klein-McPhee, eds. 3<sup>rd</sup> edition. 2002. Smithsonian Institution Press, Washington D.C. Fish images courtesy of Maine Department of Marine Resources Recreational Fisheries Program Maine Outdoor Heritage Fund. Shrimp from [www.hafra.is](http://www.hafra.is). Concept by Heather Deese. Graphic by Ethan Nedeau.

(Feeding Relationships continued from page 7)

harvested species. Notice the fishing vessel *Susan and Caitlyn* at the top of the diagram, indicating human influences at various levels of the system.

### Monkfish Feeding Habits

Monkfish feed on many species, including many fished species such as herring, whiting, redfish, squid, American plaice (dabs), red hake, winter flounder (blackbacks), and witch flounder (grey sole).

Monkfish lay on the mud and dangle a bait in front of their mouth. When something comes along for that worm, the monkfish eats it. Monkfish will feed heavily on whiting when whiting are abundant, including ‘cigarette whiting’, small whiting the size of cigarettes. In particular, monkfish will be full of whiting in January and February some years.

It’s estimated that 80-90% of the Monkfish harvested have redfish in their stomachs. However, observations suggest that very seldom are the redfish digested. So, there is some question as to whether they are a preferred prey for monkfish.

### Shrimp Feeding Habits

Shrimp prefer live prey including smaller snails and zooplankton. They are seen migrating higher in the water column at night. Scientists have assumed this is to feed. However, some studies have shown highest stomach fullness in mid afternoon, which would indicate they are feeding on the bottom during the day.

## Geography of Atlantic Cod Reproduction in the Western Gulf of Maine

### Why do cod spawn where and when they do?

Figure 5 on page 10 presents cod spawning grounds, including seasonal variability. Once spawning occurs, local currents control the distribution of eggs and larvae as they develop. Yet, many questions remain about what impacts their survivability.

Must eggs and larvae end up in just the right places and at the right time for juveniles to survive and later become members of the spawning population? What is the role of the availability of food for larvae (e.g. timing in relation to plankton production cycles)?

There must be enough planktonic food in the water for larvae to feed and grow out of the vulnerable early life stages. Along with food supply, temperature affects the larval growth rate. The higher the temperature, the faster the larvae can grow, given a sufficient food supply.

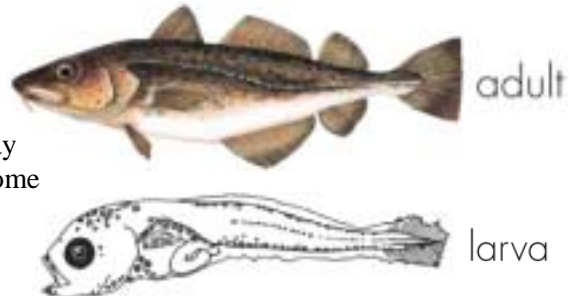
The timing and distribution of predators also affect cod recruitment (the survivability of cod to breeding age). Cod eggs and larvae are especially vulnerable to predation by other fish (for example, herring), jellyfish and even planktonic copepods.

Each of these factors varies in space and time. This variability may fluctuate around some average condition over a period of many years or the average itself may be changing over time. Hence there is a broad potential for variability in recruitment from year to year and over longer time scales.

### The early life cycle of cod

Individual female cod produce on average about 1 million eggs per season in the Gulf of Maine, which progress through larval stages until they settle at the bottom as juveniles. Eggs are released into the water column and may be broadly distributed over depth, although the vertical distribution of cod eggs in the Gulf of Maine is not well known. Larvae tend to be deeper in the water column as they grow older. On average the larvae settle to the bottom as juveniles at a size of about 40mm, and the entire larval stage lasts approximately 100 days.

Juvenile nursery habitats are thought to be in relatively shallow depths near shore, with concentrations in Ipswich Bay



Atlantic cod images courtesy of the Maine Department of Marine Resources Recreational Fisheries Program, the Maine Outdoor Heritage Fund, and Colton & Marek 1969.

and Massachusetts Bay. Juveniles may also migrate out from the nearshore onto nursery habitats on Jeffreys Ledge.

### Predicting larval transport and environmental conditions for recruitment success

Scientists have developed computer-based circulation models to predict transport of eggs and larvae. The circulation models can be run with particles representing eggs and larvae of cod for various sets of environmental conditions. For example, a simple model can simulate transport of cod early life stages from the spawning sites using the actual winds to modify the coastal circulation.

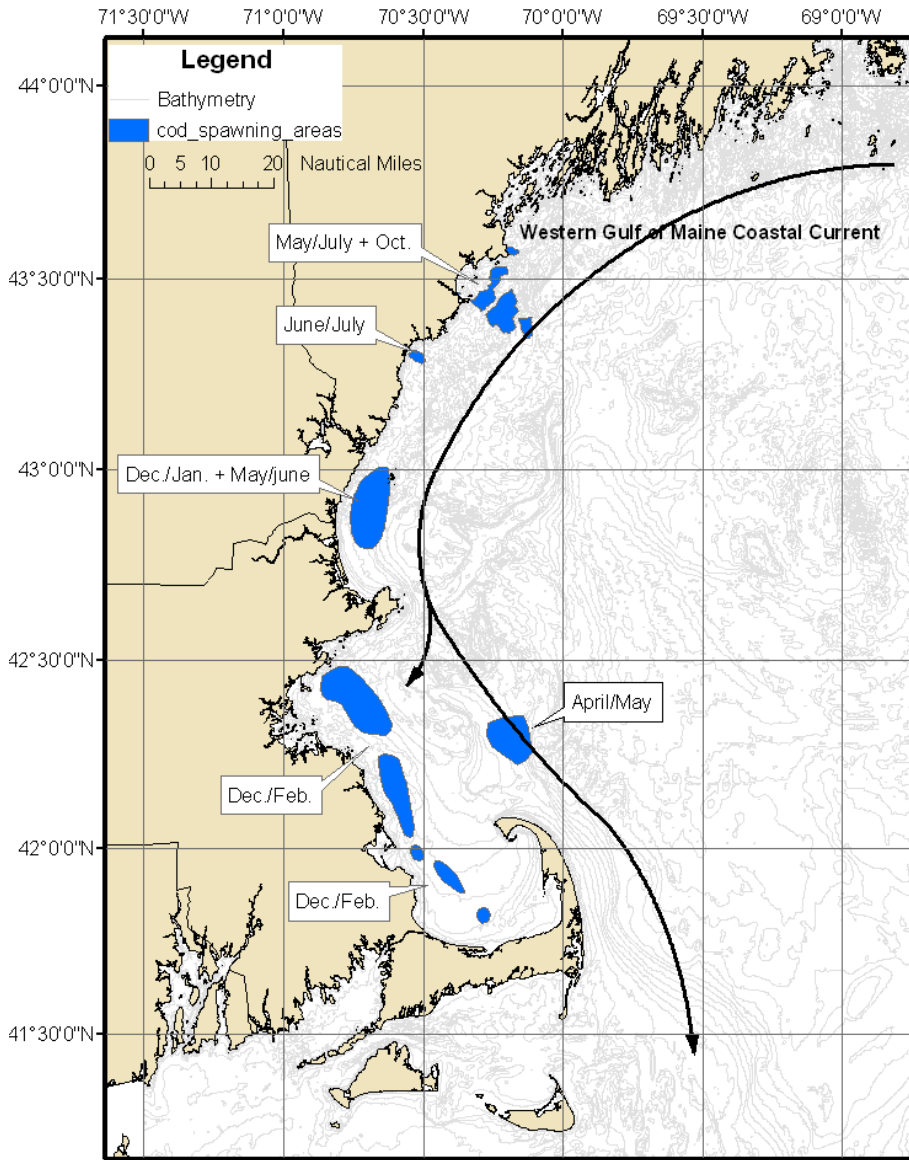
Larvae transported toward nearshore habitats and into Massachusetts Bay are thought to be retained in the Gulf of Maine. Larvae advected past Cape Cod or out into the cen-

(Cod continued on page 10)

(Cod continued from page 9)  
 tral Gulf of Maine are assumed to be lost to the local spawning stocks. These transport models provide insight into the fate and distribution of larvae and juveniles spawned from different groups of cod in the western Gulf.

In the future, models of greater complexity will also simulate larval swimming behavior as well as variability in temperature and in plankton production cycles (food conditions for larvae). It will be possible to simulate transport and survival of eggs and larvae from the

identified spawning sites using observations of wind and plankton conditions for a given year. Scientists are working to refine the observing data collection and predictive capabilities of the model to forecast environmental conditions for recruitment into the future.



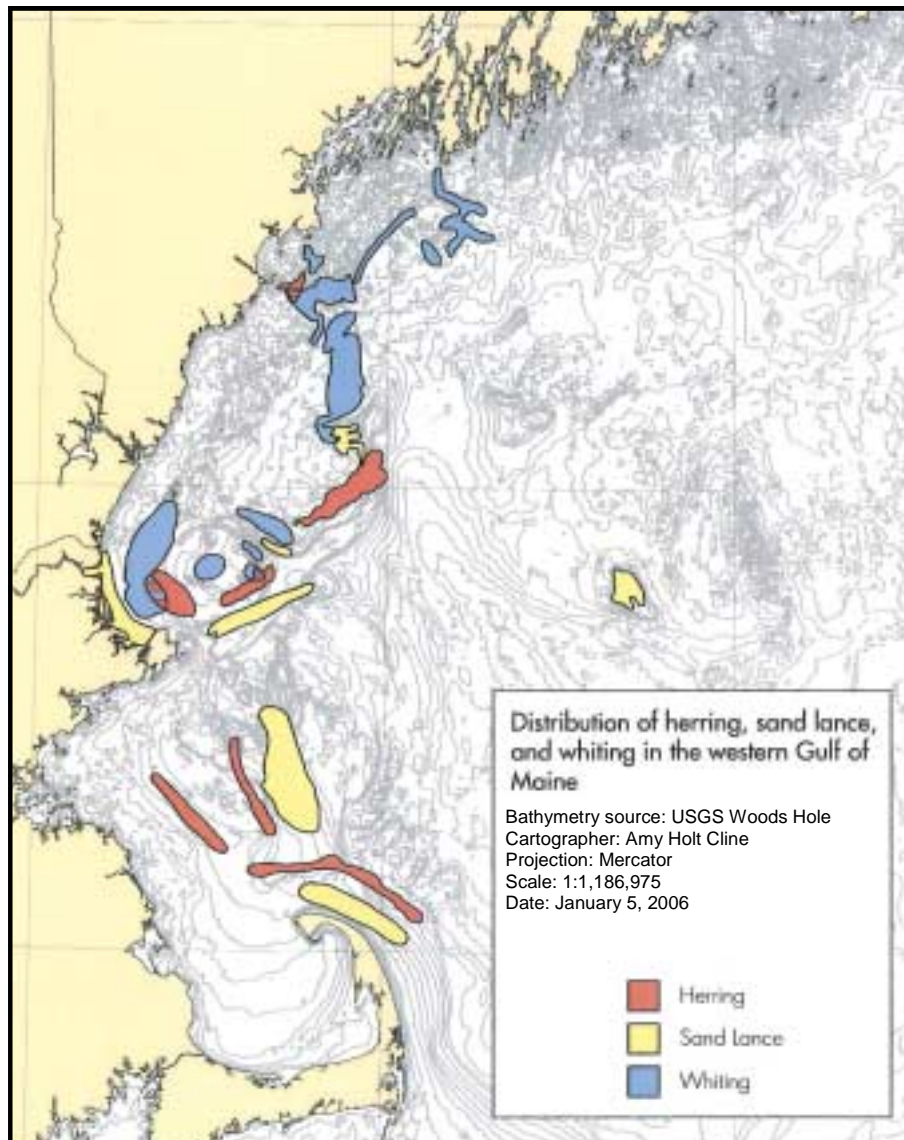
**Figure 5: Geography of Atlantic Cod (*Gadus morhua*) Reproduction in the Western Gulf of Maine**

Graphic content developed by Amy Cline, Heather Deese, Randy Gauron, David Goethel, Ellen Goethel, Lew Incze, Les Kaufman, George Littlefield, Frank Mirarchi, Craig Pendleton, Jeff Runge, Peter Stevick, Richard Taylor, Norman Vine, and with the assistance of the Massachusetts Fishermen’s Partnership. Concept by the NAMA/COOA project team. Graphic by Martin Huret.

## Three Key Prey Species in the Western Gulf of Maine: Herring, Whiting, and Sand Lance

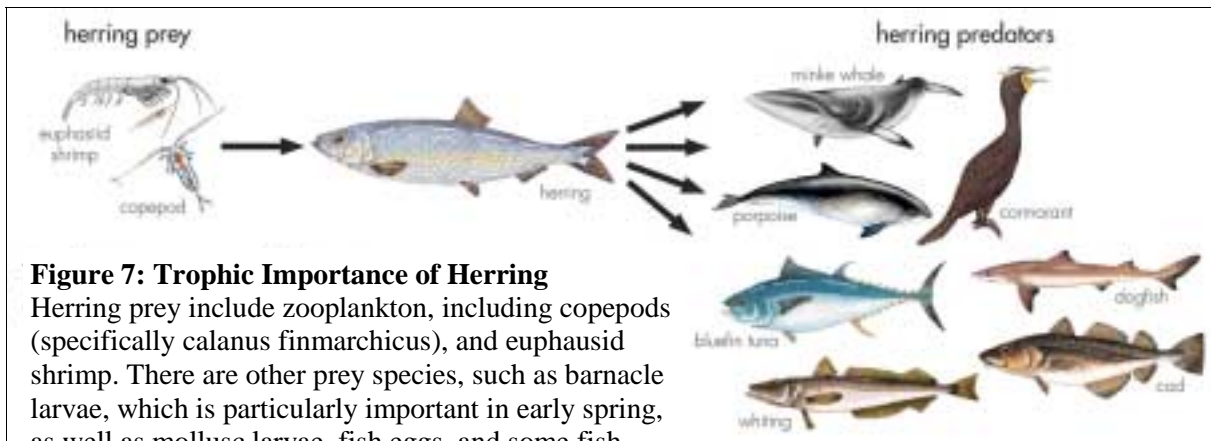
Feeding relationships among marine species are complicated and dynamic. They are analogous to a circuit board – not all channels carry energy at all times, but all are important at some times in some places. Regardless of what is being utilized in the moment, it’s vital to make sure no parts of the circuit go dead. While there are other prey for commercial species, including mackerel, squid, and

(Three Key Prey continued on page 13)



**Figure 6: Distribution of herring, sand lance, and whiting in the western Gulf of Maine**

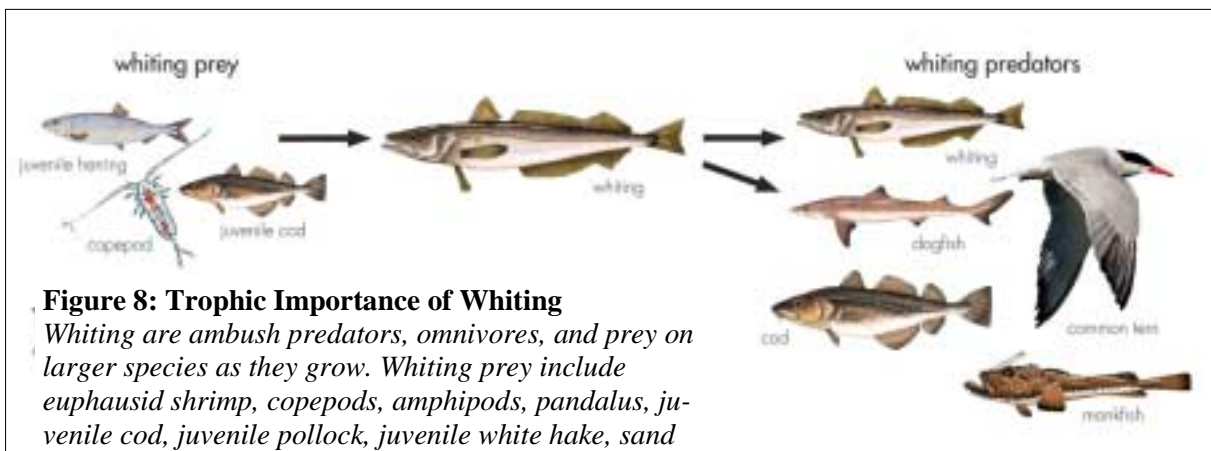
*Graphic content developed by Amy Cline, Heather Deese, Randy Gauron, David Goethel, Ellen Goethel, Lew Incze, Les Kaufman, George Littlefield, Frank Mirarchi, Craig Pendleton, Jeff Runge, Peter Stevick, Richard Taylor, Norman Vine. Fish images courtesy of the Maine Department of Marine Resources Recreational Fisheries Program, the Maine Outdoor Heritage Fund, and Colton & Marek 1969. Concept by the NAMA/COOA project team. Graphic by Ethan Nedeau.*



**Figure 7: Trophic Importance of Herring**

Herring prey include zooplankton, including copepods (specifically calanus finmarchicus), and euphausiid shrimp. There are other prey species, such as barnacle larvae, which is particularly important in early spring, as well as mollusc larvae, fish eggs, and some fish larvae. Juveniles may rely more on copepods and adults on euphausiid shrimp.

Herring predators include silver hake (whiting), cod, and spiny dogfish. Many other fishes (pelagic and demersal), marine mammals, and seabirds feed on herring. Herring also supports a substantial commercial fishery. Dense groups of monkfish feed on herring on the bottom during the day. Otherwise, they are dispersed and difficult to catch. Tuna have a higher quality flesh and are fatter when feeding on herring than sand lance or whiting.



**Figure 8: Trophic Importance of Whiting**

Whiting are ambush predators, omnivores, and prey on larger species as they grow. Whiting prey include euphausiid shrimp, copepods, amphipods, pandalus, juvenile cod, juvenile pollock, juvenile white hake, sand lance, herring, mackerel, and others. Predators include larger whiting, cod, dogfish, monkfish, seabirds (terns), tuna, squid, large white hake, skates, pollock, bluefish, harbor porpoise and humans.

Graphic content for figures 7, 8, and 9 developed by Amy Cline, Heather Deese, Randy Gauron, David Goethel, Ellen Goethel, Lew Incze, Les Kaufman, George Littlefield, Frank Mirarchi, Craig Pendleton, Jeff Runge, Peter Stevick, Richard Taylor, Norman Vine. Fish images courtesy of the Maine Department of Marine Resources Recreational Fisheries Program, the Maine Outdoor Heritage Fund, and Colton & Marek 1969. Additional source: Bigelow and Schroeder, *Fishes of the Gulf of Maine*. Concept by the NAMA/COOA project team. Graphic by Ethan Nedeau.

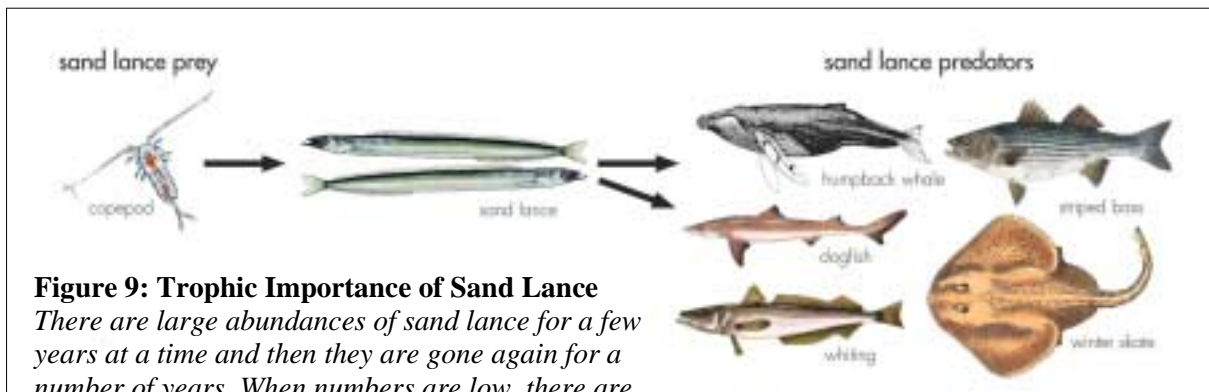
(Three Key Prey continued from page 11)

euphausiids, this section focuses on the particularly important herring, whiting, and sand lance. These species have different distributions, as shown in *Figure 6*, and their population sizes vary year to year.

Herring, whiting, and sand lance are key species that play important trophic roles in the overall ecosystem as food for commercial fish and many other species, and for their commercial value themselves. *Figures 7, 8, and 9* on pages 12 and 13 provide a snapshot of their food web roles.

When considering food web dynamics, it's important to remember that the number and mix of species change in time at all trophic levels. As changes occur in one population, there may be unexpected effects on others. This often results in the potential for trophic cascades, in which changes at one trophic level also have impacts on successive trophic levels, either up or down.

Many fish species have preferred food, but will feed on something else if their preference is unavailable. For example, the bluefin tuna prefers herring. Yet, tuna will feed on other species, such as whiting, when herring is not available. This feeding shift impacts the availability of whiting as prey for other species and for commercial harvest. This is an example of a cascading effect.



**Figure 9: Trophic Importance of Sand Lance**

*There are large abundances of sand lance for a few years at a time and then they are gone again for a number of years. When numbers are low, there are remnants in coastal sandy areas. They are found on Stellwagen Bank and all along the ocean shore of Cape Cod in high numbers, and extend to the middle of North Bank, almost to Thatchers; also occasionally along Plum Island. Schooling is important, and they school with herring post larvae. Sand lance burrow in sandy/pebbly bottoms. Prey include mysids, chaetognaths, animal eggs and larvae, fish fry, dinoflagelletes, diatoms, copepods, euphausiids, salps, urocordates, dinoflagelletes and diatoms. They are possibly filter feeding and selective feeding. Predators include porpoise, Atlantic harp seals, finback and humpback whales, haddock, red hake, silver hake (whiting), white hake, halibut, mackerel, striped bass, spiny dogfish, and winter skate.*

## People's Place in the Ecosystem

A discussion of ecosystems would not be complete without including people. Fishing is a top predatory activity that depends on and influences ecosystem dynamics. Additionally, land-based activities, such as shoreside development and run-off, as well as shipping, tourism, and other marine activities can markedly affect marine ecosystems.

Commercial fishing impacts stock populations in the Gulf of Maine, and a firm understanding of ecosystem relationships is key to maintaining balance. Fishermen do not want to remove so much from the system that it disrupts sustainability, and science-based limits help to avoid overfishing.

Spawning and recruitment success of commercially fished stocks reciprocally affect the viability of commercial fishing.

// Putting all of this information and knowledge together is critically important. We may never be able to nail down predictions on a month to month or year to year basis, but we may pinpoint indicators to help us determine positive or negative trends so fishermen and managers can prepare."

*Lew Incze  
University of  
Southern Maine*

Changes in current, water temperature, salinity, and weather have great bearing on the amount of a stock that can be sustainably harvested. In addition, movement patterns of fish greatly affect fishing behavior. Inshore boats are familiar with seasonal migrations of stocks and depend on the fish coming to them. In contrast, because they have greater mobility, offshore boats follow their targets' preferred depths and bottom types at various times of the year.

This knowledge of movement patterns and population trends is vital to a greater understanding of ecosystems. The illustrations throughout this document harness fishermen's deep understanding of predatory/prey relationships, seasonal variations, migratory behaviors, habitat preferences, and more. Through almost daily interaction with the ocean, fishermen develop a three-dimensional view of what occurs below the surface. These observations complement scientists' quantitative understanding of species, circulation, and ecosystem processes to paint a more complete picture of the ecosystem as a whole.

Historically, fishermen's observations have been termed anecdotal, and not considered along with traditional scientific information. Collaborative research has begun to change this scenario by more effectively incorporating fishermen's knowledge into scientific studies. Continued dialogues between fishermen and researchers will do much to link understandings of population dynamics, atmospheric conditions, currents, salinity, feeding and spawning patterns, temperature, and other aspects to form an understanding of the system as a whole.



*David Goethel is a commercial fisherman from New Hampshire and a member of the New England Fishery Management Council .*

// The multi-disciplinary approach to ocean studies is the way to go. It's done on a cooperative basis and this is a model I want to move forward. This is a way I've wanted to see things done—with a number of disciplines sitting down together having these discussions. This demonstrates that we have combined a number of different specialties sitting with fishermen."

*David Goethel  
Commercial Fisherman*

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