Forage Fish

G. C. Matthiessen

QUEBEC-LABRADOR FOUNDATION
Atlantic Center for the Environment

Cover photograph by Greig Cranna
St. Mary's Island, Quebec North Shore

Forage Fish

G. C. Matthiessen

QUEBEC-LABRADOR FOUNDATION
Atlantic Center for the Environment

About the Author

George C. Matthiessen is a marine biologist and previous owner of Ocean Pond Corporation, an oyster farm on Fishers Island, New York. He served as Chairman of the Board of Directors of The Sounds Conservancy and lives in Lyme, Connecticut.

Acknowledgements

The photographs and information on the menhaden industry provided by Dan Horton and Captain Kenneth Payne are gratefully acknowledged.

Forage Fish is made possible with a generous grant from The Norcross Wildlife Foundation with additional support from the Quebec-Labrador Foundation/ Atlantic Center for the Environment.

Dedication

This publication was inspired by the late Christopher Percy, an ardent sportfisherman and environmentalist with deep concerns for the health of the marine ecosystem. After serving as Executive Director of the Connecticut River Watershed Council for 15 years, Percy founded and became President of The Sounds Conservancy in 1984, designed to protect the estuaries and coastal waters of southern New England. In 1988, he was appointed to the New England Fishery Management Council. He retired in 1995 after arranging a merger of the Conservancy's assets with those of the Quebec-Labrador Foundation in Ipswich, Massachusetts.

Percy's experience on the New England Fishery Management Council convinced him of the deficiencies in current marine fishery regulations. Before his death, he became particularly concerned about the intensive harvesting of forage fish, such as menhaden and capelin, that are vital links in the marine food chain and he often expressed hope that the potential damage done by these "industrial fisheries" would become more widely recognized. It is hoped that this publication may help increase public awareness of these fisheries and their possible impact upon the marine ecosystem.

Contents

1 Introduction

2 Forage Fish

5 Atlantic menhaden (*Brevoortia tyrannus*)

13 Atlantic Herring (*Clupea harengus*)

16 Capelin (*Mallotus villosus*)

18 Atlantic Mackerel (*Scomber scombrus*)

21 Sand Eel (*Ammodytes americanus, A. dubius*)

23 River Herring (Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*)

25 Squid: Northern Shortfin Squid (*Illex illecebrosus*) and Longfin Squid (*Loligo pealei*)

27 Bay anchovy (*Anchoa mitchilli*) and Atlantic silverside (*Menidia menidia*)

29 Predator-Prey Relationships

33 The Industrial Fisheries

37 Aquaculture

38 Conclusion

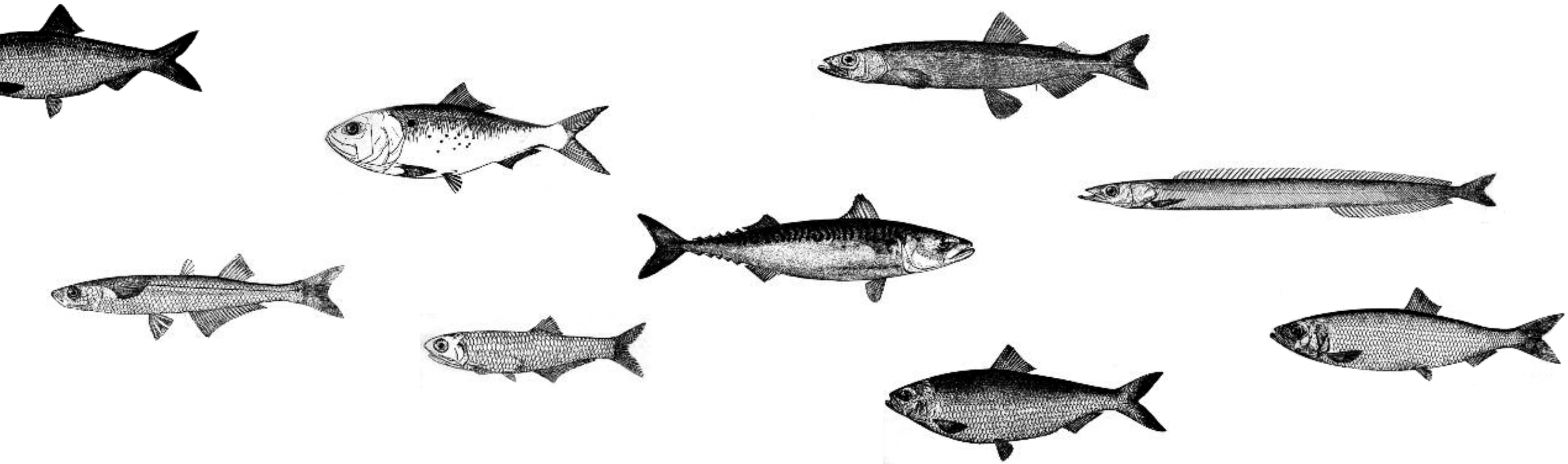
40 References

Introduction

There is little argument that many, if not most, of the oceans' commercial fish stocks are in serious trouble. According to the Food and Agriculture Organization of the United Nations, about 50% of these stocks are fully exploited, 15% are overfished and 6% are now depleted[1]. Although the annual catch during the past decade has remained fairly steady at about 90 Mt (90 million metric tons), there is serious doubt that this level can be sustained[2].

During the past 50 years, world landings have increased by roughly a factor of six[1]. The significant increase in fishing vessels, combined with the growing improvement and sophistication in fishing gear, has applied enormous pressure on the fish stocks, particularly as world demand for seafood has greatly increased. Landings from many parts of the ocean have declined under increasing fishing pressure. The result has been the collapse of certain important fisheries such as that for the Atlantic cod, which has been exploited to virtual extinction in the northwest Atlantic, and there is evidence that, in the absence of larger, more desirable species, the industry has come to depend more and more upon the harvest of smaller fish[3,4].

Certain of these, referred to as forage fish, are an extremely important link in the marine food chain, providing the essential food for large carnivores, including several species of whales and birds as well as finfish. As the ocean becomes depleted, these so-called "trash fish" and their role in the ocean's ecosystem are of increasing significance.



Forage Fish

A simplified marine food chain begins at the bottom with the tiny microscopic plants known as phytoplankton. These provide the food for zooplankton, which consists largely of small invertebrates, such as copepods, as well as fish eggs and larvae. At the third link in the chain are relatively small finfish, many of which—with some important exceptions — are too small to be directly utilized by man. Finally, at the top of the food chain are the large carnivorous finfish, many of which are valued for direct human consumption, as well as marine mammals and seabirds.

Forage fish for the most part represent the third link in the chain, providing the bulk of the diet of the larger and economically more important marine carnivores. Most forage species are relatively small, occur in large schools, and generally are pelagic in habitat, spending most of their lives at or near the ocean surface. (Although squid are mollusks, certain species are often included in the forage fish group, since they are an important source of food for larger predators).

Up to one-third by weight of the total annual ocean harvest—excluding aquaculture—are essentially forage fish[5], the majority of which are targeted for eventual reduction to fish meal and fish oil. Presently the major contributor to this industry is the Peruvian anchovy, or anchoveta (*Engraulis ringens*), which alone may provide one-quarter of the total world landings by capture fisheries in certain years[1].

Forage fish may be found in all of the oceans, but the major areas of productivity are those where very significant upwelling occurs, i.e., the California Current off the coast of Southern California; the Peruvian Current off the west coast of South America; and the Canary and Benguela Currents off the west coast of Africa[6]. At these locations may be found immense concentrations of small finfish such as anchovies and sardines as well as the larger predatory species including herring, mackerel and tuna. Upwelling areas are characterized by a) a narrow continental shelf; b) proximity of deep, cool nutrient-rich water; and c) prevailing offshore winds that allow this water to rise to the surface.

Historically, the most productive of these Eastern Boundary currents is the Peru-Chile Current System. During the 1960s, annual catches of anchoveta (*Engraulis ringens*) in this area exceeded 10 Mt. This period was followed by a sharp decline in anchovy abundance, resulting from the intrusion of the warm water mass known as El Nino, and the fishery shifted to sardines (primarily *Sardinops sagax*). The history of *E. ringens* is one of great scarcity followed by incredible abundance; production has increased from a low of 94,000 t (metric tons) in 1984 to over 10 Mt during the 1990s[7].

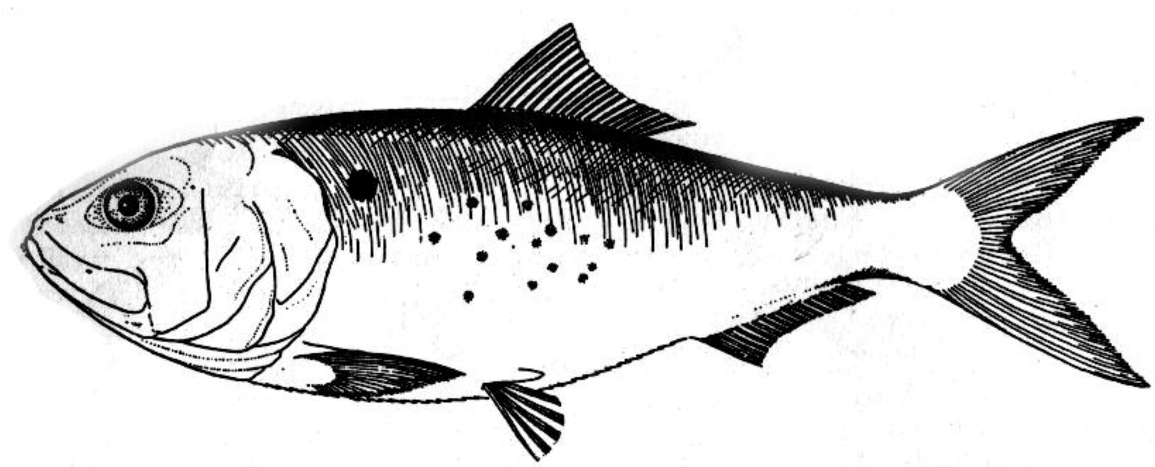
In the absence of anchovies, the fisheries along this coast may shift to the capture of sardines (*Sardinops sagax*), the next most abundant species in the Peru-Chile Current System. This species is also processed for the production of fish meal and oil. Although the annual harvest of sardines is generally less than that of anchoveta, it has nevertheless exceeded 1 Mt in certain years during the past decade.

The California pilchard, or sardine, was at one time the major fishery in the California Current System. This species (*Sardinops sagax caerulea*), considered by some to be a subspecies of *S. sagax*[8], was the basis of an important fishmeal and canning operation in southern California until the 1940s, when it virtually disappeared. The sardine population began to reappear in the Gulf of California in the 1970s, but it was not until the 1980s that this stock showed significant signs of recovery off the California coast. (During the past few years, annual landings have averaged around 60,000 t). Fluctuations in the abundance of this species, as in the case of the Peruvian anchoveta, appear to be governed by climate change, although intensive fishing pressure may be involved as well[6].

The pelagic fish populations off the west coast of Africa, in the Benguela and Canary Current Systems, are also dominated by anchovies (*Engraulis capensis* and *E. encrasicholus*) and sardines (*Sardinops ocellatus* and *S. pilchardus*), which may account for nearly 50% of the total fish catch in these two areas[9,10]. As in the case of the California and Peru-Chile Current Systems, the stocks of anchovies and sardines in these two areas are also unstable, going through severe cycles of abundance followed by scarcity.

Areas of upwelling of the magnitude of those cited above do not occur in the north Atlantic. Nevertheless, there are several species of relatively small fish found along the coast of North America that usually occur in large schools and are highly important links in the marine food chain. Most of these species are primarily oceanic, rather than estuarine, in habitat and include the Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*), capelin (*Mallotus villosus*), Atlantic menhaden (*Brevoortia tyrannus*), sandeel (*Ammodytes americanus*), and two species of squid (*Loligo pealeii* and *Illex illecebrosus*). Two anadromous species, the alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), migrate offshore and also provide forage for the larger carnivores. Because of their schooling behavior and resulting ease of capture in large volume, all of these species have frequently been targeted by the industrial fisheries.

There are several other important forage species found along our coast that are primarily estuarine. Because of their small size, they are of little commercial significance other than their use for bait. These include the silverside (*Menidia menidia*) and bay anchovy (*Anchoa mitchilli*).



Atlantic menhaden *(Brevoortia tyrannus)*

Of all the forage fish along the Atlantic coast, the menhaden is perhaps the most important. Because of its abundance and economic value, the menhaden was considered "King" of the United States fishing industry for many years[11]. Even today, menhaden annual landings are second only to those of the Alaska (or walleye) pollock (*Theragra chalcrogramma*), a Pacific Ocean species. (Currently, menhaden and Alaska pollock together account for about 50% of total fish landings in the U.S.) Because of the direct economic value of the menhaden ($30-40 million/year) and its critical role in the marine food chain, it has been referred to as "the most important fish in the sea"[12].

The menhaden is a member of the herring family—the Clupeids—and therefore is closely related to the Atlantic herring and the river herrings (alewife and blueback) as well as the American shad (*Alosa sapidissima*). Along the Atlantic coast it is known by various regional names: "pogy" (Massachusetts and Maine), "bony fish" (Connecticut), "bunker" (New York and New

Jersey), and "fatback" (North Carolina). The name "menhaden" derived from the Native American Indian name "munnawhatteaug," meaning "that which manures," referring to its value as a fertilizer[13]. There are two slightly different species of commercial importance: the Atlantic menhaden (*B. tyrannus*) found only along the Atlantic coast from Florida to Maine and occasionally Nova Scotia, and the Gulf menhaden (*B. patronus*), which occurs along the coast of the Gulf of Mexico between Florida and the Yucatan peninsula. The annual landings of the two species combined have averaged 850,000 t during the past ten years, with the Gulf menhaden accounting for about three-quarters of the total catch.

The Atlantic menhaden fishery has existed for about 200 years and is reportedly the first established industry in North America[14]. Following the advice of the Native American Indians, the early New England colonists first used menhaden as fertilizer, planting the whole fish with their crops. (Because menhaden have very oily flesh and are exceedingly bony, they were seldom eaten in any quantity). It was soon found, however, that the menhaden oil permeated the soil and ruined its suitability for crops, and the fish were used primarily for animal food and bait[13].

The first industrial project for extracting the oil was started in Portsmouth, Rhode Island, in 1811, where the fish were boiled in large pots of water and then pressed under wooden boards weighted with rocks[15]. The oil was then skimmed from the surface and shipped to New York. The flesh and scraps were dried and sold as fertilizer. This marked the beginning of the menhaden fishery as an established industry. As the whaling industry declined during the mid to late 1800s, menhaden oil gradually became a substitute for whale oil.

The menhaden fishery was initially centered in New England, and many of the early menhaden fishermen were farmers as well. The industry expanded rapidly, and the volume of menhaden oil produced soon exceeded the amount extracted from whales. By 1877 there were 53 menhaden oil factories operating in New England, and the industry had begun to spread south along the Atlantic coast[13]. By the early 1900s, menhaden were being processed not only for oil but were being ground up into fishmeal, an excellent source


Kenneth Payne

Menhaden steamers, or "Bunker" boats, Greenport, New York

of food for livestock.

Initially, menhaden were captured mostly by small beach seines. Rowboats launched from shore were used to encircle the schools with a net, which was then dragged to shore and the fish deposited on the beach. As the industry grew, the fishing vessels increased in size and power and moved further offshore. Rowboats were replaced by sailing craft, which in turn were superseded by steam-powered vessels in the late 1800s. The steamers ranged in size from 90 to 150 feet in length, carried a crew of 20 or more, and captured

Pete Stevens

Menhaden seine boats setting out from the mother ship the fish in large purse seines[16].

By the mid 1900s, when the menhaden fishery had reached its peak, the menhaden fleet had converted to diesel engines and was deploying purse seines—up to a quarter of a mile in circumference and about 100 feet deep—that could contain a half-million fish or more in one set. The set was made by a pair of high-powered "purse" boats, around 30 feet in length and carrying up to a dozen men each, that set out from the mother ship in opposite semi-circles, paying out the seine as they encircled the menhaden school. When the two boats converged, a large weight—called a "tom"—was dropped from one of the purse boats to close the bottom of the net's purse and prevent the fish from escaping. The net was then pulled back into the purse boats by hand, gradually compressing the captured fish into a tighter and tighter triangle formed by the two purse boats and the mother ship. The fish were transferred to a hold in the mother ship by means of a bailing net[11].

In addition to the use of larger and better equipped vessels, the efficiency of the menhaden fishery has improved in other respects. Perhaps the most significant changes have been the adoption of spotter planes to locate schools of fish and radio their location to the fishing vessels; the use of the power block to hoist the nets faster and reduce the manpower required; refrigeration on board the mother ship to minimize spoilage; the use of nylon nets instead of cotton twine; and large-volume pumps to transfer the fish from the net to the mother ship[16].

The process of reducing menhaden to fish meal and oil on shore has also been improved. In a typical reduction plant, the fish are transferred to a storage box at the dock and then to a live steam cooker. When the fish are cooked, they are transferred to screw presses where the liquid is removed. The liquid, known as "press liquor," is centrifuged to recover the oil. The solid material from the press, known as "press cake," is made into fish meal in a dryer. Menhaden oil is an ingredient in many enriched foods. It is also found in certain industrial substances such as plasticizers, marine lubricants, resins and paints. The fish meal is valued for its importance as a component in agricultural (chickens and other livestock) and aquacultural (primarily salmon, trout and shrimp) feeds[17].

The Atlantic menhaden's range extends from

Crew hauling in the purse seine by power block

Florida to Maine[18]. It prefers warm water—above 50°F—and moves northward along the coast in the spring in large schools, migrating southward in the fall. Its migrations often bring it close to shore, and it frequently appears in the larger bays and estuaries along the coast, particularly the Chesapeake Bay.

Menhaden are considered to be primarily offshore spawners, but they may enter estuarine areas to spawn as well. Off the coast of southern New England spawning usually occurs from early to late summer. The eggs are buoyant and hatch within a few days after fertilization. The larvae are carried by currents into estuaries, where they find plentiful food in the way of planktonic microorganisms. (Menhaden are filter feeders, swimming with open mouths and entrapping food particles, primarily phytoplankton and organic detritus, on gill-rakers as the water flows through the gills). By fall, the juvenile fish, now several inches in length, have formed schools and begin to move out of the estuaries. Once in the sea they begin their migration southward, although their specific destination and wintering area has not been established. In spring, this cycle is repeated. When three years old, the menhaden is about nine to ten inches long, about a half-pound in weight, and has reached sexual maturity. Occasional fish may reach 18 inches in length.

Since the early 1950s, the Atlantic menhaden industry has shrunk substantially. Annual landings during the period 1997-2001 have averaged only 249,000 t, down 60% from the five-year average of 584,000 t in the period 1952-1956, when the

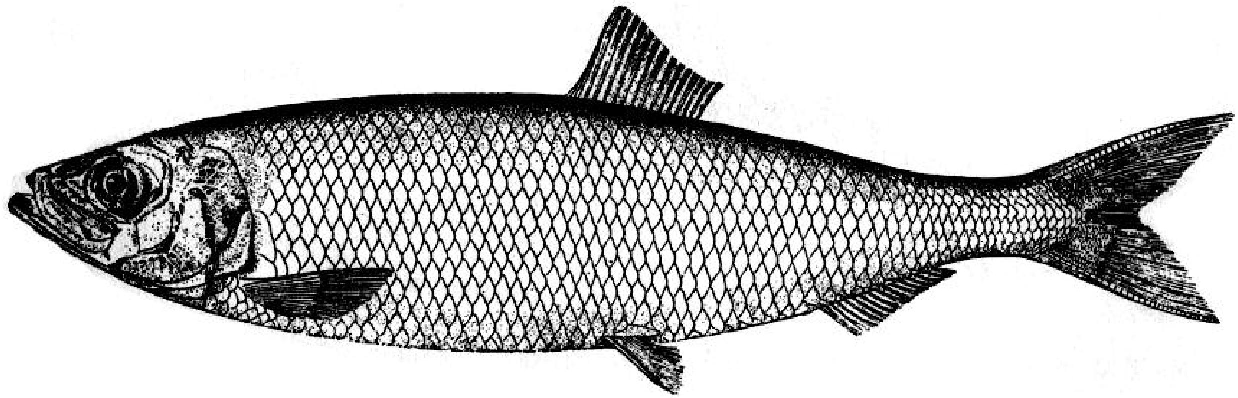
Hauling the purse seine

Kenneth Payne

industry was at its peak. In 2001, only one reduction plant operated along the Atlantic Coast, compared with 23 in 1955[19]. Presently there are three plants in operation in the Gulf of Mexico, one in Mississippi and two in Louisiana.

The decline of the Atlantic menhaden fishery is probably due to a number of reasons. Larval survival and recruitment during the past decade has been poor. This has been attributed in part to adverse environmental conditions in the Chesapeake Bay — much the most important menhaden nursery along the Atlantic coast—which have included periodic anoxic conditions in parts of the bay; an increase in the numbers of ctenophores, a type of jellyfish that preys upon fish larvae; a decline in water clarity; and a reduction in the abundance of phyto- and zooplankton upon which the menhaden subsist[20].

Many recreational fishermen attribute the menhaden's decline largely to overfishing, particularly by commercial vessels purse seining in the lower part of the bay. The reduction fleet is accused primarily of employing too small a mesh in their nets, thereby preventing juvenile fish from escaping and hastening the depletion of the stocks of the important forage-size fish. Spokesmen for the industry, on the other hand, claim that at least part of the reasons for decline is the tremendous increase in numbers of striped bass, a major predator of menhaden, in the bay and along the Atlantic coast[21].



Atlantic Herring *(Clupea harengus)*

The Atlantic herring prefers colder water than does the Atlantic menhaden. In the northwest Atlantic, its range extends from the Carolinas north to the Gulf of Maine, the coast of Labrador and west coast of Greenland. On the other side of the Atlantic, it is found along the entire European coast from the Bay of Biscayne to Scandinavia and northern Russia[18]. The great majority of Atlantic herring—perhaps 80-90%—are landed in Europe, primarily Norway and Iceland, while the remainder are landed in Canada and New England.

The herring fishery, like that of the cod, has played an important part in the economies of countries on both sides of the Atlantic for several centuries, and it has been asserted that more has been written about it than any other species of fish[22]. Unlike the menhaden, which is sought almost exclusively for industrial uses, the herring is a valued food fish, particularly in Europe, where the larger fish are sold smoked, salted, dried or pickled. Smoked "kippered" herring are especially favored in Great Britain. The smaller herring, about two years old, 5-7 inches in length, and referred to as sardines, were the basis of a thriving canning industry in Maine for over one hundred years[23]. At one time, nearly 50 canneries were operating in Maine; depletion of the herring stocks has reduced this number to six today.

In North America, where virtually all Atlantic herring are landed in the New England states (mostly Maine), the herring fishery was originally pursued by "fixed" gear in the way of weirs, or traps. In the 1940s, these were supplemented by stop seines, whereby gill nets were stretched across the mouths of coves into which herring had entered. Since 1960, and as inshore herring populations became scarcer, shore-based methods have given way for the most part to mobile gear suitable for deeper water, i.e., purse seines and mid-water trawls[24].

National Marine Fisheries Service

Menhaden aboard the mother ship

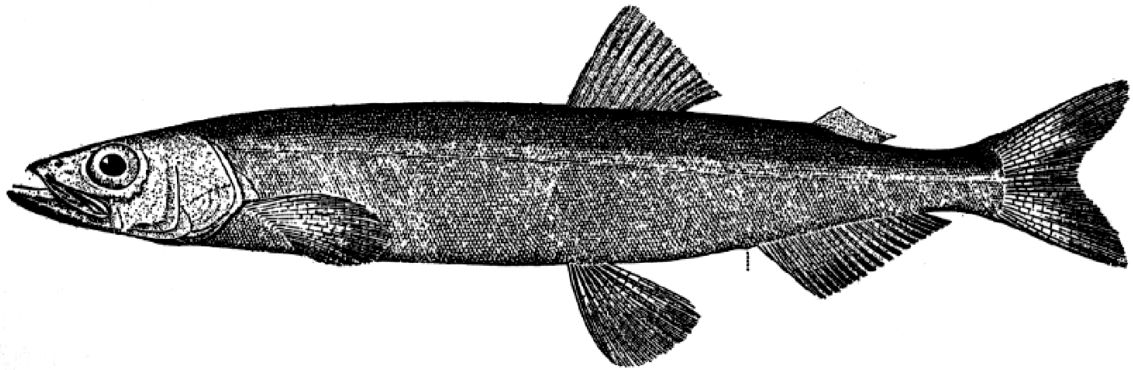
The Atlantic herring becomes sexually mature when four years of age. Unlike the Atlantic menhaden, which releases buoyant eggs, the female herring deposits her eggs on rocky or gravelly bottom, often quite close to shore. In about ten days the eggs hatch and the larval herring drifts about in the ocean currents during the remainder of the fall and winter, feeding largely upon tiny planktonic crustaceans and other invertebrates. (Unlike the menhaden, it is not a filter feeder.) In the spring the juveniles begin to form schools and undertake movements into deeper water. By the following spring some may exceed five inches in length and qualify as sardines. At this stage, the herring seek out and move with their planktonic food, the most important of which are copepods. However, the majority do not become sexually mature until their fourth season. During their migrations, they pro-


National Marine Fisheries Service

Seining herring, Maine

vide a major source of food for a variety of predators — cod, silver hake, pollock, mackerel, tuna, salmon, striped bass, squid, various seabirds and whales — and mortality rate is extremely high[25].

In the United States, the adult herring is valued principally as bait, particularly for the lobster industry. In Iceland and Europe, as much as half the annual catch may be processed to fishmeal and oil. During the 1990s, landings in New England nearly doubled, from about 48,000 thousand metric tons in 1991 to over 95,000 t in 1997, only to drop back to 70,000 t by the year 2000.



Capelin *(Mallotus villosus)*

The capelin, a close relative of the rainbow smelt, is a small pelagic species inhabiting the cold waters of the North Atlantic and North Pacific. In the northwest Atlantic it is abundant chiefly in the Gulf of St. Lawrence, off the coasts of Newfoundland and Labrador, and the Grand Banks. It is also found off the coasts of Greenland, Iceland and Norway and in the Barents Sea[26]. It is broadly distributed in the most northerly regions of the Pacific as well.

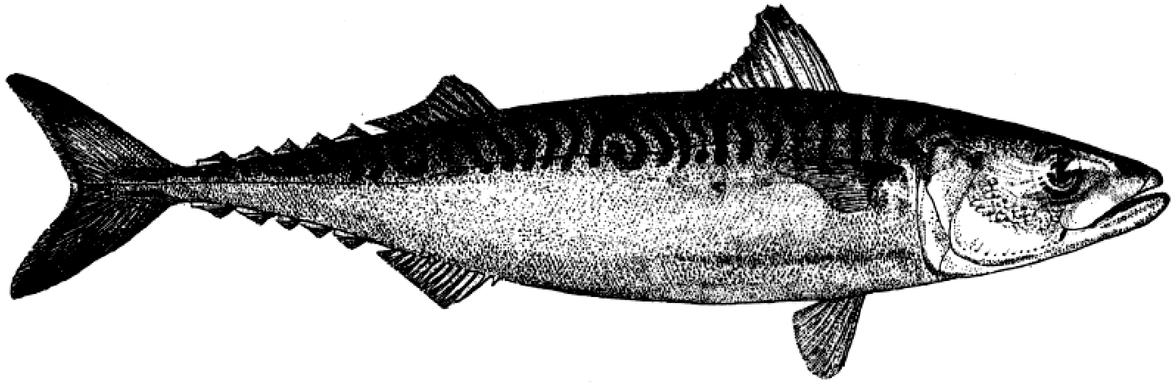
The capelin is considered to be one of the most important forage fish in the North Atlantic. On the western side of the Atlantic, the capelin fishery is quite small in comparison with the Atlantic menhaden and Atlantic herring fisheries, and the majority of the world catch is landed in Iceland, Norway and Russia. This species plays an extremely important role in the Arctic and sub-Arctic ecosystems, providing a primary source of food for larger finfish, marine mammals and seabirds[27,28].

Although the capelin spends most of its life offshore, the majority move into shore in early or mid summer to spawn, usually at an age of three or four years. At this time, the males and females have usually formed separate schools, and the females generally follow the males into shore. The eggs are deposited in shallow water and adhere to the sand and gravel, and many are buried by the surf. A large percentage of the adult fish die after spawning.

The incubation period for the eggs may be 15-20 days depending upon temperature. After hatching the larvae may remain buried in the gravel until washed out to sea by wave action. By the end of the summer, the juvenile fish are pelagic, feeding near the surface on tiny planktonic invertebrates. By winter, they have reached one to two inches in length[26].

In the northwest Atlantic, most of the capelin were initially harvested—by means of traps and weirs—from the waters close to shore around Newfoundland. These fish were used for fertilizer and bait as well as human consumption. A directed offshore commercial fishery for capelin began in the early 1970s, largely on the Grand Banks. As this fishery declined in the late 1970s, a new market for capelin roe developed in Japan. Presently the great majority of capelin captured in Canadian waters are caught near shore during or immediately before the spawning season and are destined for this market. The male capelin captured in the nets are often discarded. In recent years, a large percentage of the Canadian catch has been made by purse seine along Newfoundland's west coast[26].

Annual landings of capelin in the northeast Atlantic, where Iceland and Norway are the chief participants in the capelin fishery, are considerably larger than those in Canada. During the past ten years, annual landings in Canada (primarily Newfoundland) averaged about 24,000 t, as compared with 697,000 t for Iceland and 288,000 t for Norway. Most of the European catch is harvested from the Barents Sea, and a significant percentage of the catch is converted into fishmeal.



Atlantic Mackerel *(Scomber scombrus)*

The Atlantic mackerel, a member of the Family Scombridae, is closely related to the tunas. It differs from its relatives, however, in that it lacks a swim bladder and must swim continuously in order to satisfy its oxygen requirements[18]. It is a fast-swimming fish and, like other important forage fish, occurs in dense schools. The mackerel's range on the west side of the Atlantic extends from North Carolina to the Gulf of St. Lawrence, the east coast of Newfoundland and south coast of Labrador. On the east side of the Atlantic, it occurs all along the coast of western Europe, from the Baltic Sea south to the Mediterranean and Black Seas.

In the northwest Atlantic, there are considered to be two mackerel stocks. The southern stock spawns during March and April of the coast between New Jersey and Long Island, New York. The northern stock spawns mainly in the Gulf of St. Lawrence and to a lesser extent along the coast of Nova Scotia and off the Grand Banks[29].

Mackerel usually overwinter in deep offshore waters and move closer to shore in the spring to spawn. The eggs are pelagic and drift about in the ocean currents for a period of five to seven days before hatching. By the end of the summer, the juvenile fish may have reached two inches in length and have formed schools. Growth proceeds rapidly, and by completion of its first year the young mackerel may have reached 10 inches in length. Growth rate declines after this; sexually mature fish three years of age are about 14 inches in length and weigh about a pound. Some mackerel may live 12 years and may reach 22 inches in weight[18].

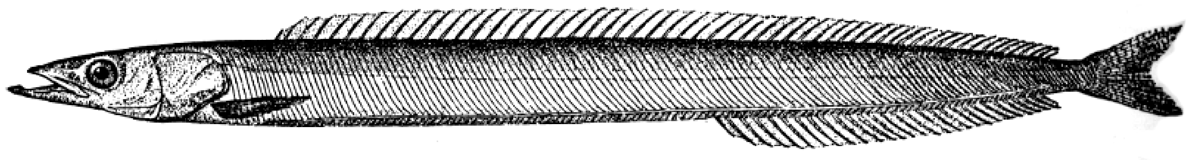
The food of the mackerel varies with its size. Juvenile fish feed primarily upon zooplankton, particularly copepods and other planktonic crustacea. As the mackerel become larger, a variety of small finfish, such as young herring, launce (sand eels) and even smaller mackerel, as well as squid, are included in its diet.

During the 1800s, many of the fishing communities in New England relied upon mackerel nearly as much as cod, and the fishing fleet often followed the mackerel schools along the coast from Virginia northward[30]. For many years, jigging by hand was the usual method for catching mackerel offshore, but eventually the purse seine came into use in the 1850s. Mackerel are also captured in traps and gillnets near shore.

The history of the Atlantic mackerel fishery is one of feast or famine, with periods of extraordinary abundance alternating with sudden scarcity and, in some areas of the North Atlantic, virtual disappearance[18]. It is generally believed that abundance is determined primarily by natural factors during reproduction, such as favorable water temperatures and/or abundance of food during the early life stages.

Only about 10% of the annual Atlantic mackerel catch is landed on the west side of the Atlantic; the great majority (about 90%) of the landings are along the coast of Europe.

Greig Cranna, *Blacks Harbour, New Brunswick*



Sand Eel *(Ammodytes americanus, A. dubius)*

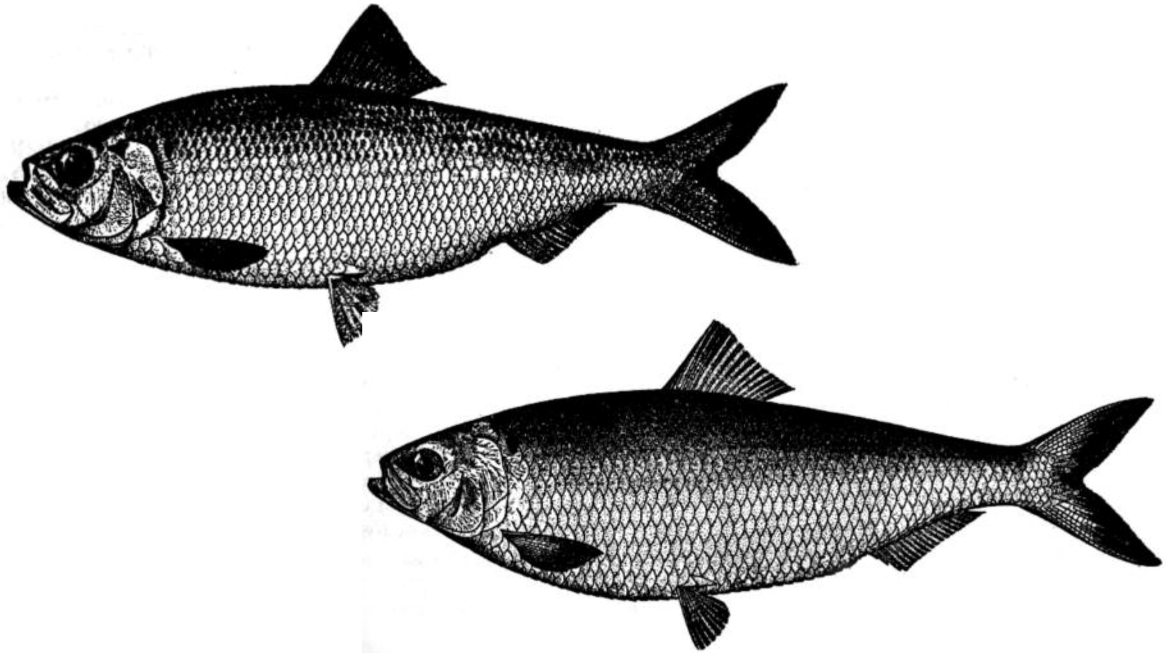
The sand eel (also known by the names of sand lance or launce) is a small, slender fish that rarely exceeds more than 10 inches or so in length. Equipped with a pointed snout, it is capable of burrowing rapidly into the bottom sediment to elude predators. There is some question as to whether members of the inshore populations of sand eels (*A. americanus* = American sand lance) are the same species as those found farther north and further offshore (*A. dubius* = northern sand lance), which is a smaller fish[31].

The range of the sand eel extends from Cape Hatteras to the Maritime Provinces of Canada and the west coast of Greenland. (A closely related species, *Ammodytes tobianus*, is common along the coasts of western Europe). Sand eels prefer relatively shallow water, are rarely found at depths greater than 300 feet, and tend to live close to the bottom over sand or light gravel. They form dense schools and often burrow into the sand between the tide-lines, emerging when the tide returns. As a result, they are often captured by clam-diggers working exposed flats during low tides, providing a source of bait[32].

Sand eels become sexually mature when two years of age. They generally spawn during winter, and their eggs adhere to sand particles on the bottom. After hatching, the larvae drift near the surface for a period of several weeks before returning to permanent residence near the bottom. Their chief source of food consists of small planktonic invertebrates, primarily copepods.

The American sand lance appears to migrate to some extent, moving close to shore and into estuaries during summer and returning to deeper water in the fall. After one year, they are about three inches in length. By the age of five years, they may exceed seven inches[18].

Other than providing a source of bait, the sand lance is of little direct economic value in the northwest Atlantic, but it is of tremendous value as food for a large variety of predators, including 5marine mammals and seabirds as well as many species of finfish. In Europe, similar species—*A. tobianus* and *A. marinus*—are harvested in large numbers, particularly from the North Sea, and contribute significantly to the fish meal industry.



River Herring (Alewife *(Alosa pseudoharengus)* and Blueback Herring *(Alosa aestivalis)*

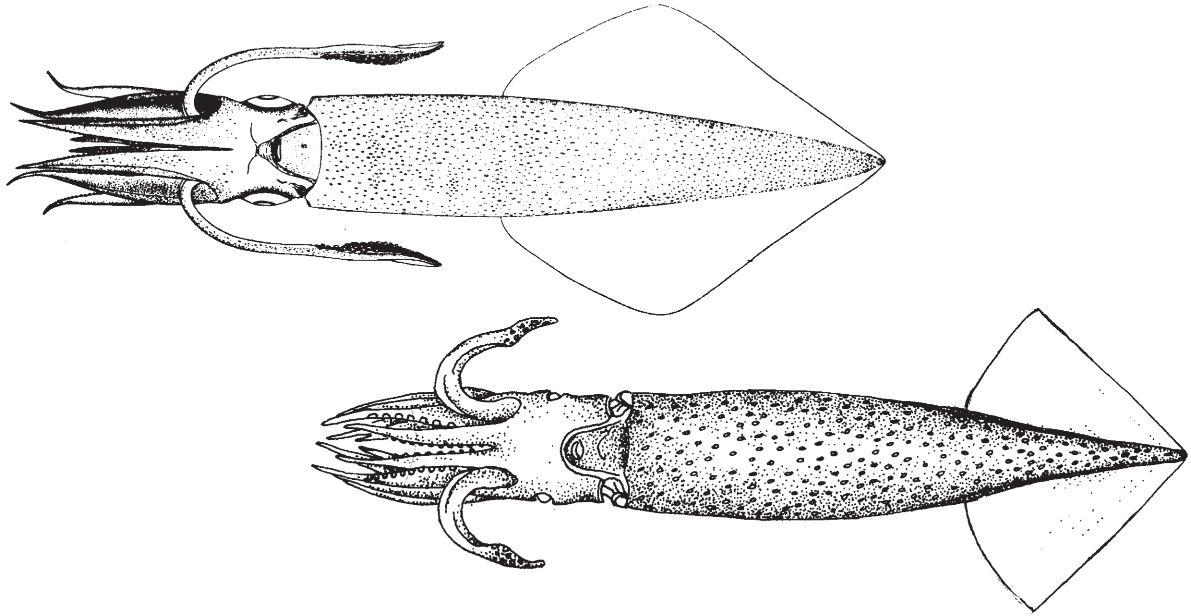
Alewife and blueback herring, both members of the family Clupeidae, are often referred to as "river herring." These two fish, like their close relative the shad, are anadromous, migrating from the ocean into fresh or nearly fresh water to spawn. These are small schooling fish, rarely over 12 inches in length and quite similar both in appearance and general habits. The range of the alewife extends from South Carolina to Newfoundland, the blueback herring from Florida to Nova Scotia. Both species spend most of their lives at sea, wintering over the continental shelf fairly near the coast.

The reproductive habits of the two species differ in certain respects. Alewives are the first to enter the tributaries in the spring, usually arriving several weeks in advance of the blueback herring. While alewives may spawn in a variety of freshwater habitats, including small ponds, lakes and sluggish rivers, the blueback herring prefers more rapidly flowing water. The adult fish return downstream and into the ocean immediately after spawning[18].

The eggs of both species are deposited on the stream bottom and tend to adhere to bottom vegetation. Hatching generally occurs within several days after spawning, and the larval and juvenile stages remain near the spawning areas during much of the summer, gradually moving downstream and into the estuaries by fall. Their diet consists of zooplankton, primarily small crustaceans. By early winter, and now up to about five to six inches in length, they enter the ocean, not to return to their natal streams for several years.

There seems to be little known about the alewife and blueback herring between the time they first enter the ocean and their eventual return as adults three to four years of age and sexually mature. More than 99% of the eggs spawned fail to survive the early life stages, and the total annual mortality has been estimated at about 70%.

For several centuries, the commercial river herring fishery was confined largely to the United States. This was one of the oldest fisheries in the country, involving the use of fish weirs, pound nets and gill nets. During the 1960s, however, foreign vessels began to harvest the river herring schools intensively offshore, and average landings declined from 25,000 t (1960-1969) to about 500 t (1994-1998). Overfishing, combined with reduction of suitable spawning habitat—such as adequate access to favorable spawning grounds—has virtually eliminated the fishery[33].



Squid: Northern Shortfin Squid *(Illex illecebrosus)* and Longfin Squid *(Loligo pealei)*

Although squid are mollusks (members of the class Cephalopoda), they are frequently grouped with forage fish because of their importance as a food source for many species of finfish, marine mammals, and seabirds, as well as man. Both the northern shortfin squid and the longfin squid have characteristics typical of forage fish; they are relatively small, are rapid swimmers and tend to occur in large schools and to undertake extensive seasonal migrations.

The northern shortfin squid is widely distributed in the western North Atlantic, ranging from

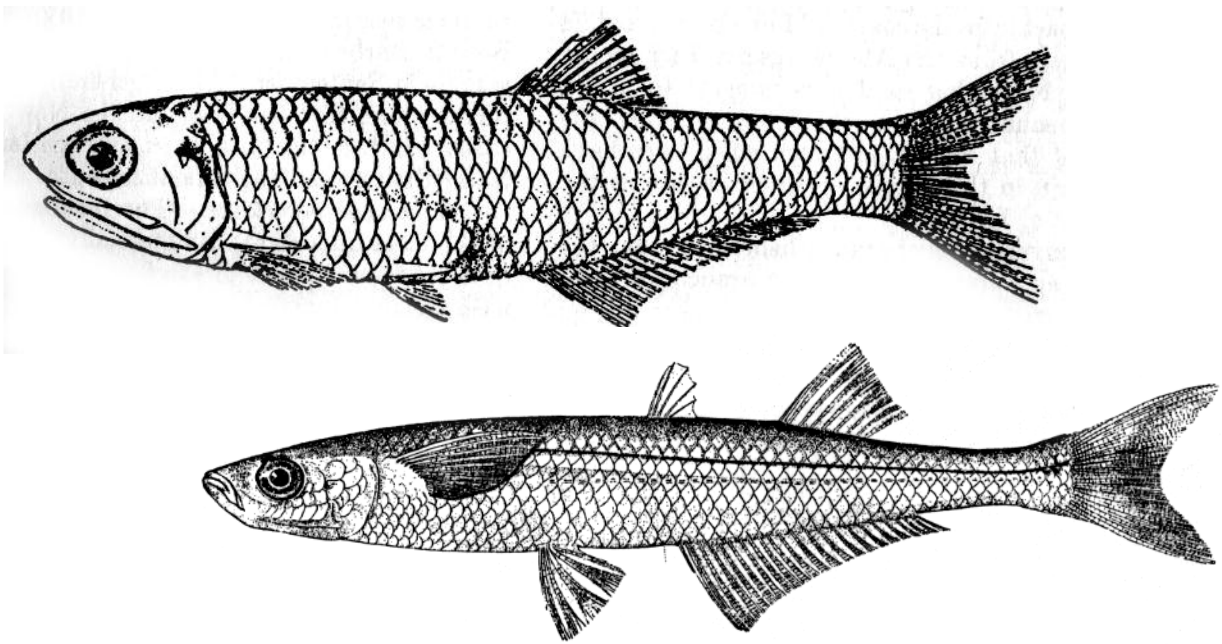
Florida to Labrador. It is generally found a considerable distance offshore, near the outer continental shelf, with chief concentrations north of Cape Hatteras[34]. The range of the longfin squid extends from Nova Scotia to South America, with heaviest concentrations between Cape Hatteras and Georges Bank. This species is more apt to occur in shallower water than the shortfin, often being captured in fish traps near shore during spring and early summer.

Both of these species are small, rarely exceeding 12 inches in length of the mantle. They are both fast-growing and short-lived, usually dying after spawning at the age of about one year. The majority of shortfin squid move south of Cape Hatteras during the fall and spawn during winter. The young stages—larvae and juveniles—drift north with the Gulf Stream and onto the continental shelf in the spring. Growth proceeds rapidly during the summer months and into the fall as the squid move back to their winter spawning grounds, thereby completing the cycle[35].

The longfin squid also undertake an inshore-offshore migration, wintering along the edge of the continental shelf and moving closer to shore in the spring. This species, however, may spawn year-round. As in the case of the shortfin squid, the eggs are enclosed in gelatinous capsules from which the larvae emerge after several weeks. The young squid are voracious, feeding on a variety of small fish and crustaceans as well as smaller squid.

Until the 1970s, squid were captured primarily for bait. They are now harvested for human consumption in many countries, particularly Japan. The majority are caught in small-mesh otter trawls[36].

Management of the squid fishery is made difficult because of the squid's short life span, rapid rate of growth, and sharp and unpredictable fluctuations in abundance.



Bay anchovy *(Anchoa mitchilli)* and Atlantic silverside *(Menidia menidia)*

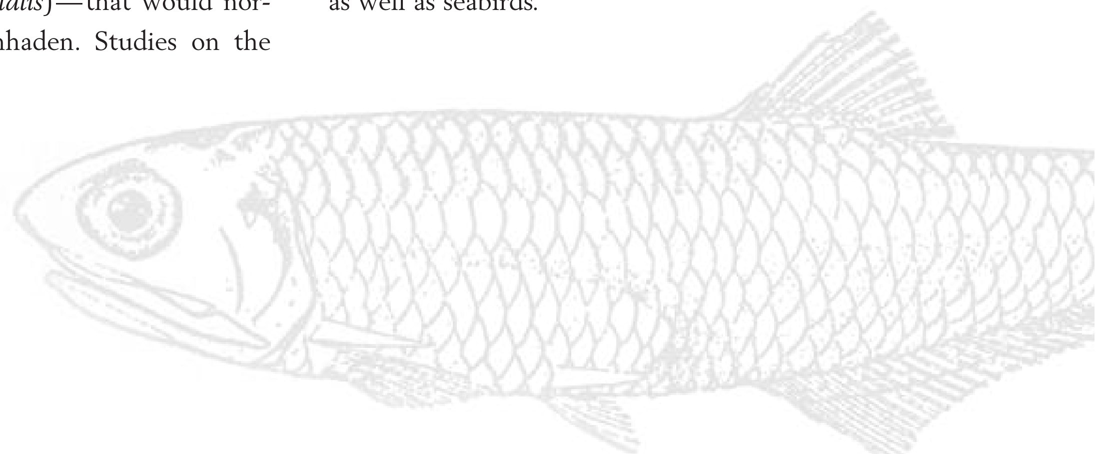
Both the bay anchovy and the Atlantic silverside are largely shallow-water species, tolerant of brackish water and frequenting estuaries and inshore areas. Both are small schooling species—rarely exceeding four to five inches in length—that generally move offshore in the fall and return in the spring[37,38].

The range of the bay anchovy extends from Cape Cod to the Gulf of Mexico. Unlike the Atlantic silverside, the eggs of which cling to the bottom, bay anchovy eggs are buoyant and may often be the dominant member of the ichthyoplankton in the bays and estuaries during the summer months. This species feeds primarily upon copepods. It is most abundant along the mid-Atlantic coast and is considered to be one of the most important forage fish in Chesapeake Bay[39].

The decline of the bay anchovy population in the Bay since 1994 has been linked to the sharp increase in numbers of predators—primarily striped bass (*Morone saxatalis*)—that would normally be feeding on menhaden. Studies on the feeding habits of the bluefish (*Pomatomus saltatrix*) have indicated that the bay anchovy is a major component in the diet of this species[40].

The Atlantic silverside is common along the coast from Nova Scotia to Florida.

Like the bay anchovy, this species feeds on small crustaceans as well as worms, insects and algae. Atlantic silversides form dense schools and are preyed upon by many of the larger carnivorous species of finfish, such as striped bass and bluefish, as well as seabirds.



Predator-Prey Relationships

The forage fish discussed here are obviously of major importance to all the larger carnivores of the sea, which include aquatic mammals such as whales and seals and a variety of seabirds. However, the major consumers of the forage fish are other larger finfish[41], often of the same species. (Notable examples of cannibalistic fish are walleye pollock (*Theragra chalcogramma*)[42] and the Atlantic cod (*Gadus morhua*)[43].

Interactions between different fish populations have been described in which a decline of a prey species—as a result of intensive predation by a second species—has an impact upon a third. In the Bering Sea, Atlantic cod feed primarily upon capelin, and the herring feed upon capelin larvae. During the 1980s, the capelin stock collapsed as a result of heavy predation by herring, unfavorable conditions for capelin growth, and intensive fishing. This was soon followed by a decrease in the growth and fecundity of the cod and an increase in cod cannibalism[44].

As predators decline in numbers, populations of prey species would be expected to increase. This type of inverse relationship occurred on Georges Bank during the 1970s with the collapse of the herring and mackerel stocks. Both species prey heavily upon sand eels. As their numbers dwindled, the sand eel population exploded[45]. As the sand eel population then began to decline after 1981, the mackerel stocks were rapidly increasing.

The precise impact that a particular forage fish may have upon the abundance of a particular predator is difficult to determine. For example, the striped bass (*Morone saxatilis*) is one of the most important fish along the Atlantic coast, both from a recreational as well as a commercial standpoint. Although this species is found from Florida to the Gulf of St. Lawrence, the great majority are harvested from the mid-Atlantic bight (Cape Hatteras to Cape Cod). The striped bass is anadromous, and perhaps as much as 80% of the population derives from the rivers and tributaries of Chesapeake Bay.

Most striped bass remain in the rivers throughout their first year. When a year-old and about eight inches in size, they begin to move downstream into the estuaries. At this point, the young bass begin to feed heavily upon juvenile menhaden that entered the estuaries as larvae. When two to three years of age, striped bass begin to undertake the extensive coastal migrations characteristic of the species. These migrations coincide to some extent with those of menhaden moving north in the spring and returning south in the fall.

The menhaden, with a high concentration of lipids, are believed to be a critical source of nutrition for young and adult striped bass. In recent years, during which the menhaden populations along the Atlantic coast have declined, the quality of the striped bass—in terms of weight and condition—in different estuaries along the coast has reportedly declined as well. It is believed by some that the bass, deprived of the oily flesh of the menhaden, are undernourished and susceptible to parasites and disease. Menhaden also provide a significant portion of the diet of ospreys, and some biologists suspect that the relative scarcity of breeding ospreys in what once were prime nesting areas along the coast may well be due to the absence of menhaden[12].

A similar interaction has been described involving the Atlantic cod (*Gadus morhua*) and the capelin stocks in the western North Atlantic. As the capelin move onto their spawning grounds, they provide a major source of food for seabirds, whales, seals and groundfish, particularly the cod. According to some investigators, there is an important link between the availability of capelin, which declined significantly during the 1990s, and the growth, condition and fecundity of the cod. Like the menhaden, the capelin has a high oil content and therefore provides a diet that enhances the growth rate and fecundity of its predators[46].

Studies on the interactions between the forage fish and seabirds in several world marine ecosystems indicate that the impact of seabirds upon forage fish is relatively small, the annual consumption by the birds being about 2-5% of the prey population[41]. The inverse of the relationship, however, can be catastrophic for the birds. Some of the more dramatic disasters for seabirds occur off the coast of Peru in the Peruvian Current System. Here, literally millions of seabirds—primarily the Guanay cormorant, Peruvian booby and Peruvian pelican—as well as sea lions and fur seals feed heavily upon the anchoveta (*Engraulis ringens*) during their breeding season. During periods of El Nino, warmer surface water moves into the area, the nutrient-rich water is displaced, and the anchoveta move into deeper, colder water. When this occurs, a large percentage of the seabird population may die from starvation, and breeding of the mammals is severely reduced. During the El Nino event in 1957, perhaps as many as 18 million boobies, pelicans and cormorants starved. Similar bird mortalities occurred during the 1972 and 1982 El Nino events, when up to 85% of the bird population either starved or abandoned their nests[47].

A similar correlation is found between sardine (*Sardinops sagax*) abundance in the Benguela upwelling system and the breeding population of Cape cormorants, which feed heavily upon the sardine. During periods of sardine scarcity, reproductive success among the cormorant population decreases, and mortality among the adult birds may be severe[48].

In the Barents Sea, when the capelin stocks collapsed during the 1980s, large numbers of seabirds, particularly guillemots, starved to death, and arctic seals were forced to seek food along the Norwegian coast. About the same time, in the North Sea, a sharp decline in the puffin population coincided with the collapse of the Atlantic herring stocks[44].

The impact that marine mammals—the cetaceans (whales, dolphins and porpoises) and pinnipeds (seals, sea lions and walruses)—are believed to have upon the forage fish populations is considerably greater than that of the seabirds. On the basis of studies in several different ecosystems, the annual consumption of fish by the marine mammals worldwide has been estimated to be about 5-10% of the stocks upon which they are feeding[41]. Total yearly fish consumption by cetaceans in the North Atlantic has been estimated to be 15-25 million tons, or 87-144% of the yearly commercial fish catch in this area[49]. This would suggest that the cetaceans are significant competitors of the commercial fisheries for forage fish. In the Pacific, annual food consumption by marine mammals is estimated to be about three times the amount taken by the commercial fisheries[50].

In the North Atlantic, the larger fish-eaters among the whales include the fin whale, which preys upon capelin, sand lance, mackerel and herring; sei whales; humpback whales, that feed upon capelin and other small pelagics; and minke whales, which feed upon capelin, herring and sand eels[49].

Forage fish are essential food for the pinniped populations as well. The harp seal, a major predator of capelin and herring in the Barent Sea, may consume up to 700,000 t of fish each year. About 250,000 t of this amount consists of capelin, with herring accounting for 200,000 t[51].

In the Bering Sea, the major pinniped predators include the fur seals, harbor seals and Steller sea lion. Both the Steller sea lion and the fur seal have declined in numbers since 1950, the sea lion by 80%[52]. In the case of the sea lion, this decline has been attributed in part to a change of diet. Populations of forage fish such as herring and sand lance have given way to pollock and large flatfish, both of which have a relatively low fat content. In the 1950s, over 80% of the Steller sea lion diet consisted of high-energy pelagic fish; by the 1980s, pelagic fish provided only 60% of their food[50].


National Marine Fisheries Service

A load of menhaden heading for the processsing plant, South Carolina

The Industrial Fisheries

About one third of current world annual landings by the capture fisheries, or over 30 million metric tons, goes for reduction to fish meal and fish oil rather than for direct human consumption. From this amount of fish, approximately 6.2 Mt of fishmeal and 1.2 Mt of fish oil are produced in about 400 fishmeal plants worldwide each year. The main producers in 2002 were Peru, Chile, China, Thailand, U.S., Denmark, Iceland, Norway, Japan, Russia, and the United Kingdom in roughly that order[53].

Along the Atlantic and Gulf of Mexico coasts of the United States, the only fish currently processed for fishmeal and fish oil in any quantity are the two species of menhaden, *Brevoortia tyrannus* and *B. patronus.* At the present time, there is only one menhaden reduction plant along the Atlantic coast—in Reedville, Virginia—and three in the Gulf of Mexico.

On the Pacific coast, there are about five small pelagic species that have, at various times, been fished for purposes of fishmeal production: the Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), chub mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*) and Pacific herring (*Clupea pallasi*).

The Pacific sardine at one time supported the largest fishery in the United States[8]. This fishery, which extended along the Pacific coast from Mexico to British Columbia, reached a peak in the 1930s and 1940s, with landings well in excess of 500,000 t, and then went into decline. By the mid-1960s, the fishery had completely collapsed, partially as a result of intensive fishing and partially due to adverse climate conditions caused by El Nino[60]. Beginning in the 1980s, the sardine population began to

An industrial fishing boat off the coast of Peru increase in numbers and presently supports an active fishery. Between 1990 and 2002, annual landings sharply increased from less than 2,000 t to nearly 100,000 t[61]. Currently, these fish are not processed for fishmeal but are sold for human consumption and for bait.

The anchovy fishery along the Pacific coast has been highly erratic during the past decade, with annual landings fluctuating between 1,000 and 20,000 t. Declining stocks resulted in the termination of the reduction industry in Mexico, and most of the fish landed are marketed (fresh, frozen, canned and paste) or sold for bait[62].

Like the Pacific sardine fishery, the chub mackerel stocks began to decline after the plentiful years of the 1930s and 1940s, and the fishery eventually collapsed, only to recover during the late 1970s and early 1980s. During the past decade, annual landings have ranged between 3,000 and 30,000 t. Few jack mackerel, on the other hand, have been landed in recent years, ranging between 1,000 and 3,000 t[62].

The majority of Pacific herring are landed in Alaska. This fishery began around 1880, when the herring began to be marketed for human consumption. During the past decade, annual landings have averaged around 45,000 t. Although a small percentage of the catch, e.g., 10%, is sold for food and bait, most of the herring now are harvested for their roe[63]. During the spawning season, these fish are captured in purse seines and transported to Japan, where the roe is removed and the carcasses and male fish are processed into fishmeal.

Herring deposit their eggs on the bottom, frequently in shallow water, and the roe is often obtained by scuba gear. Since some of the eggs adhere to kelp fronds in shallow water, they are also collected by rake or even by hand. Another technique is to transfer live ripe fish into enclosures, where the eggs are collected on suspended kelp fronds. The roe is highly prized in Japan.

The major forage fish in the Gulf of Alaska and the Bering Sea, along with the Pacific herring, include the walleye pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), Pacific sand lance (*Ammodytes hexapterus*) and rainbow smelt (*Osmerus mordax*). A directed fishery for forage fish in Alaskan waters is prohibited, and no more than 2% of the total catch of other species can consist of forage fish. There are over 60 fishmeal processing plants in Alaska which produced 47,000 t of meal in 2001[54]. Much of the raw material processed consists of fish scraps—heads, fins, viscera, etc.—rather than whole fish and comes from groundfish such as cod and flatfish.

In the northeast Atlantic, including the North, Baltic and Barent Seas as well as the waters around Iceland, the forage fish of primary importance are the Atlantic herring (*Clupea harengus*), blue whiting (*Micromesistius poutassiou*), capelin (*Mallotus villotus*), sprat (*Sprattus sprattus*), Atlantic horse mackerel (*Trachurus trachurus*), sand eel (*Ammodytes marinus*), and Norway pout (*Trisopterus esmarkii*)[53].

National Marine Fisheries Service

A full load of anchoveta on mother ship, Peru

The industrial fisheries in the northeast Atlantic began to develop during the 1950s. Initially the major effort focused on mackerel and herring because of their relatively large size and high fat content. When these stocks collapsed from overfishing during the 1970s, the fishing fleets turned their attention to smaller species, particularly the sprat and Norway pout. By the mid-1980s, these two species in turn had declined, and the sand eel became the object of intensive fishing pressure[55].

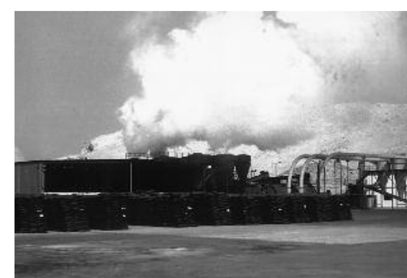
At the present time, these western European fisheries are regulated to varying degrees. Sand eels, capelin and Norway pout are considered of little use for human consumption and are generally sold for reduction. Blue whiting and sprat have a greater potential for human food, but the majority are processed for fishmeal. Almost all herring and horse mackerel are used directly for human consumption[53].

Aquaculture

In 2002, slightly over 6 Mt of fishmeal and 1 Mt of fish oil were produced from total industrial landings. About 35% of the fishmeal and 50% of the fish oil was used for aquaculture, primarily for feeding fresh and saltwater fish as well as shrimp, with the remainder sold as food for livestock, e.g., pigs, poultry and ruminants[5]. The importance of fishmeal in fish and livestock feeds is that it contains certain vitamins, micronutrients and fatty acids that are not found in traditional feeds. The result is greater weight gains, less mortality, and higher fertility among the animals provided fishmeal in their diet.

Aquaculture is an exciting industry that is growing rapidly, but there are certain costs associated with the culture of fish and crustaceans that are of concern[5]. In the process of constructing fish and shrimp ponds in mangrove swamps and wetland areas, there has been a considerable loss of natural habitat valued as nursery areas, flood control areas, water treatment and sediment containment. When cultured stock escape and intermingle with wild stock, the genetic makeup will be altered, possibly for the worse. In the intensive culture systems that are required in aquaculture, there is always the likelihood of disease, and the discharge of wastes from the culture systems may become a serious source of pollution.

Finally, there is concern as to how aquaculture relates to the capture fisheries and the wild fish stocks. Of major concern are the carnivorous species that are cultured—primarily salmon, trout, other marine fish and shrimp—because they require a diet consisting of 30-60% fishmeal and 2-25% fish oil. Intensive aquaculture systems use two to five times more fish protein, in the form of fishmeal, to feed the fish being cultured than is ultimately produced[5]. The aquaculture industry consumes 70% of the global production of fish oil and 34% of the fishmeal; it is projected that, by 2010, at least half of the fishmeal produced globally and perhaps all of the fish oil would be required to satisfy aquaculture's needs[55].



National Marine Fisheries Service

Anchoveta reduction plant with sacks of fishmeal in foreground, Peru

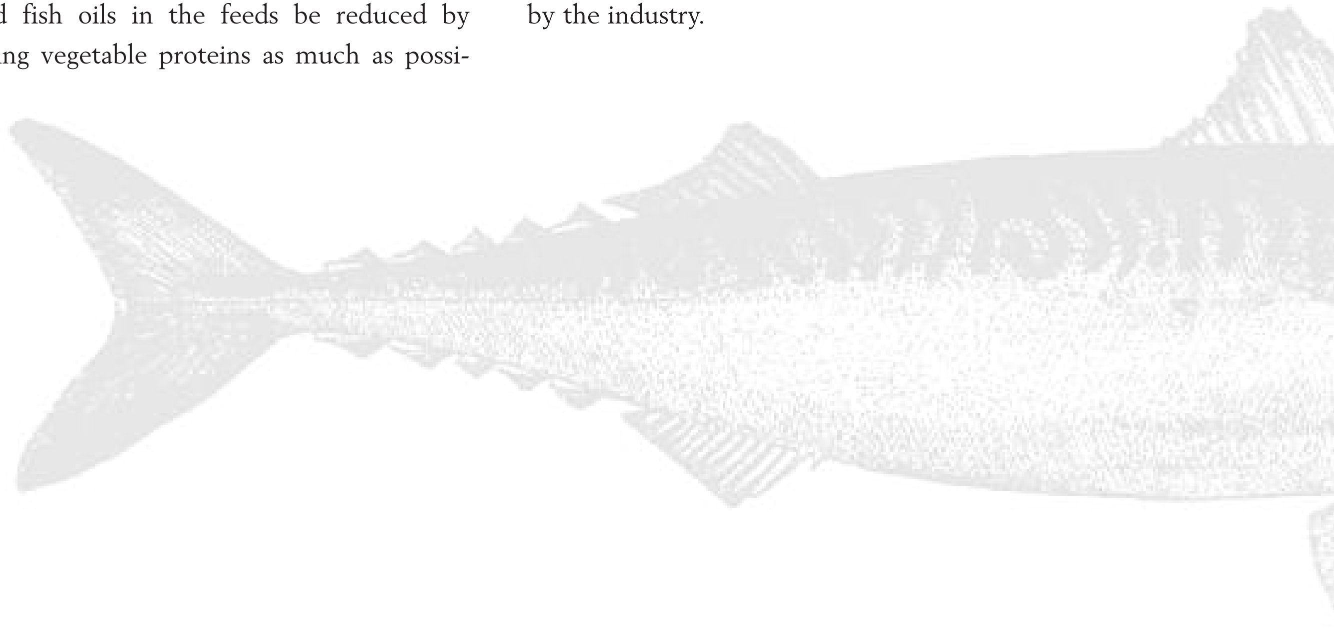
Conclusion

At least some spokesmen for the industrial fishing industry feel that "…fishmeal production remains the best method of utilizing small, bony, oily fish when there are limited food outlets for this catch, and it is also the best way to use waste fish from food processing. It is a valuable use of resources, which otherwise would contribute little to the human food chain"[56]. It is also argued by the industrial fishing industry that the forage fisheries are carefully regulated. "Almost all the resources are subject to TAC (Total Allowable Catch) limits, area limits, minimum mesh sizes, fleet capacity controls, closed areas and seasonal bans. Some are also subject to minimum landing sizes"[56]. The status of many of the principal forage fish fisheries are considered to be "within safe biological limits" and therefore exploitable.

In addition, the fishmeal and fish oil industry is an enormous one. In the United States alone, production in 2001 was valued at nearly 200 million dollars[64]; annual exports of fishmeal and oil from Peru frequently approach one billion dollars[65]. The economies of at least several countries—most particularly Peru and Chile—depend heavily upon this industry. In many coastal communities, such as Reedville, Virginia, the menhaden industry is the primary means of employment.

On the other hand, it has been asserted that the industrial fisheries "…take excessive by-catches of immature fish of protected species some of which, if left in the sea, would survive both to become available to the human consumption fisheries and to contribute to the reproductive potential of these stocks." Furthermore, the industrial fisheries "…deplete the food supplies of human consumption fish stocks and of other predators such as seabirds, seals, cetaceans and salmonids"[57]. Given the complexity of the marine ecosystem, and the difficulties inherent in assessing the health of fish stocks, the effectiveness and/or fairness of current regulations are uncertain. It seems to be generally accepted that intensive fishing may result in the collapse of a fishery[58], but stocks have frequently been known to collapse even in the absence of fishing pressure of any kind[42], and shifts in climatic conditions, such as the El Nino event, have usually been considered the primary cause.

With respect to the future of marine aquaculture, it has been recommended that focusing on the culture of fish at a lower trophic level—herbivorous species such as tilapia and carp—should be pursued, and that the amounts of fishmeal and fish oils in the feeds be reduced by substituting vegetable proteins as much as possible[5]. It has also been suggested that, instead of processing fish at sea and dumping the offal overboard, the offal should be contained and made available to the fishmeal industry[59]. Although these suggestions may be useful, it seems doubtful that, for economic reasons, they will be readily adopted by the industry.



References

[1] FAO, 2000. The State of World Fisheries and Aquaculture. Food and Agriculture Organization, United Nations, Rome.

[2] Moore, G. and S. Jennings, 2000. Commercial Fishing: The Wider Ecological Impacts. British Ecological Society. Blackwell Science. 66 pp.

[3] Pauly, D., V. Christensen, J. Dalsgaard, R. Froese and F. Torres. 1998. Fishing Down Marine Food Webs. Science, 279: 860-863.

[6] Cushing, D. H. 1975. Marine Ecology and Fisheries. Cambridge University Press. 278 pp.

[7] Csirke, J. 1997. Review of the State of World Fishery Resources: Marine Fisheries. FAO Fisheries Circular No. 920. 15. Southeast Pacific. FAO, Rome.

[8] Baumgarten, T. and P. Beller,. 2000. *Sardinops sagax cerulean:* California pilchard, Pacific sardine, sardine Monterey. San Diego Natural History Museum, Ocean Oasis, Field Guide: 3 pp.

[9] Cochrane, K. 1997. Review of the State of World Fishery Resources: Marine Fisheries. FAO Fisheries Circular No. 920. 7. Southeast Atlantic, FAO, Rome.

[10] Lamboeuf, M. 1997. Review of the State of World Fishery Resources: Marine Fisheries. FAO Fisheries Circular No. 920. 4. Central Atlantic. FAO, Rome.

[11] Conrad, E. 1954. Gulf Stream North. Doubleday & Co.: 253 pp.

[12] Franklin, H.B. 2001. The Most Important Fish in the World. Discover, 22 (9): 10 pp.

[14] Anderson, H. 2000.A History of Menhaden Fishing. Maryland Marine Notes, 18 (1).

[15] Ellison, W. A. 1951. The Menhaden. pp 85-107 in: Survey of the Marine Fisheries of North Carolina (H. F. Taylor, Ed.). Univ. of North Carolina Press, Chapel Hill, North Carolina.

[13] Garrity-Blake, B. J. 1995. The Fish Factory. Univ. of Tennessee Press, Knoxville: 160 pp.

[18] Bigelow, H. B. and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull. Of the Fish and Wildlife Service, Fish. Bull. 74, Vol. 53: 577 pp.

[19] Chesapeake Bay Ecological Foundation, Inc. 2001. Atlantic menhaden (*Brevoortia tyrannus*). Dec 1.

[20] Price, J. 2003. Striped Bass Suffer as Overfishing Eats Away at their Prey, Menhaden. Bay Journal, Vol. 13 (9).

[21] Anon. 2002. Menhaden Resource Council. 1901 N. Fort Myer Drive, Arlington, Virginia, 22209, USA.

[16] Frye, J. 1978. The Men all Singing. The Downing Company, Publishers: 242 pp.

[17] Vincent Corporation. 1996. Pressing Fish Waste. Tampa, Florida, Issue 49.

[22] Whitehead, P. J. P. 1985. FAO Species Catalogue, Vol. 7.

[23] Chenoweth., S. 1989. A Herring's Tale. Maine Dept. Mar. Res., D.M.R. Research Reference Document 89/12.

[25] Clayton, G., C. Cole, S. Murawski, and J. Parrish. 1978. Common Marine Fishes of Coastal Massachusetts. Univ. of Mass., Coop. Extension Service, Contribution No. 54: 231 pp.

[24] Overholtz, W. 2000. Atlantic herring. Status of Fisheries Resources off Northeastern United States. Northeast Fisheries Science Center, National Marine Fisheries Service, Kingston, RI.

[26] Carscadden, J. E. and H. Vihlsalmsson. 2002. Capelin - what are they good for? Introduction. ICED Jour. Mar. Sci. 54:863-869.

[27] Dept. of Fisheries and Oceans. 2001. Capelin of the Estuary and Gulf of St. Lawrence. DFO-Science, Stock Status Report b4-03, Ottawa.

[29] Overholtz, W. 2001. Atlantic mackerel – Status of Fisheries. Fishery Resources of Northeastern United States, NOAA Tech. Memo., NMFS – FINEC.

[30] Guadanzo, L. 2003. The mackerel fleet. Provincetown Banner, June 5, Provincetown, MA.

[32] Scott, J. S. 2000. Sand lance. Underwater World, Dept. Fish. and Oceans, Ottawa.

[33] Kocik, J. 2000. River herring. Northeast Fish. Sci. Cen., NMFS, Kingston, RI.

[34] Cadrin, S. K. 2000. Longfin inshore squid. Status of Fisheries Resources off Northeastern United States. Northeast Fisheries, Science Center, NMFS, NOAA.

[35] Hendrickson, L. 2000. Northern shortfin squid. Status of Fisheries Resources off Northeastern United States, Northeast Fisheries Science Center, NMFS, NOAA).

[36] Anon, 2000. Squid. Underwater World, Dept. of Fish. and Oceans, Ottawa.

[37] Vouglitois, J. J., K. W. Able, R. J. Kurtz and K. A. Tighe. 1987. Life History and Population Dynamics of the Bay Anchovy in New Jersey. Trans. Amer. Fish. Soc. 116(2): 141-153.

[38] Hildebrand, S. F. and W. C. Schroeder. 1972. Fishes of Chesapeake Bay. Smithsonian Institute Press, Washington, D.C.: 388 pp.

[39] Chesapeake Bay Ecological Foundation, 2002. Atlantic menhaden (*Brevoortia tyrannus*). Nov. 20.

[48] Crawford, J. M. and J. Jahncke. 1998. Comparison of Trends in Abundance of Guano-producing Seabirds in Peru and South Africa. Sea Fisheries Research Inst, Capetown, South Africa.

[44] Gisiason, H. 2003. The Effects of Fishing on Non-target Species and Ecosystem Structure and Function. pp 255-274 in: Responsible Fisheries in the Marine Ecosystem (M. Sinclair and G. Valdimarsson, Eds.). FAO and CABI Publishing, Rome: 426 pp.

[46] Rose, G. A. and R. L. O'Driscoll, 2002. Capelin are Good for Cod: Can the Northern Stocks Rebuild without Them? ICES Jour. Mar. Res. 59: 1018-1026.

[53] Anon, 2003. Fishmeal from Sustainable Stocks 2003. Fishmeal Information Network, Petersborough, Cambridgeshire, U.K.

[5] Naylor, R. L., R. I. Goldburg, J. Primavera, N. Kautsky, M. C. M. Beveridge, J. Clay, C. Folke, J. Lubchenko, H. Mooney and M. Troell. 2000. Effect of Aquaculture on World Fish Supplies. Nature, 405: 1017-1024.

[57] Anon, 2003. Industrial fisheries. Fisheries Research Services, Aberdeen, Scotland.

[55] Anon, 2003. Fish Food for Thought. Cape Business News, Capetown, South Africa.

[58] Breverton, R. J. 1990. Small Marine Pelagic Fish and the Threat of Fishing: are they Endangered? Jour. Fish. Biol. 37: 5-16.

[50] Trites, A. W., V. Christensen and D. Pauly. 1997. Competition Between Fisheries and Marine Mammals for Prey and Primary Production in the Pacific Ocean. Jour. Northwest Atlantic Fish Science 22: 173-187.

[41] Furness, R. W. 2002. Management Implications of Interactions Between Fisheries and Sand Eel-dependent Seabirds and Seals in the North Atlantic. ICES Jour. Mar. Sci. 59: 261-269.

[55] Anon, 1997. From Fish to Fodder. Greenpeace International. 5 pp.

[4] Christensen, S. G., S. Guenette, J. J. Heymans, R. Watson and D. Pauly. 2003. Hundred-year Decline of North Atlantic Predatory Fishes. Fish and Fisheries, 4: 1-24.

[40] Buckel, J. A., M. J. Fogarty and D. O. Conover. 1999. Foraging Habits of Bluefish, *Pomatomus saltatrix*, on the U. S. East Coast Continental Shelf. Fish. Bull. 97: 758-775.

[45] Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien and L. Ejsymont. 1981. Congruent Shifts in Sand Eel Abundance in Western and Eastern North Atlantic Ecosystems. Nature, 291: 486-489.

[31] Nizinski, M. S., B. B. Collette and B. B. Washington. 1990. Separation of Two Species of Sand Lance, *Ammodytes americanus* and *A. dubius*, in the Western North Atlantic. Fish. Bull., 88: 241-255.

[52] Rosenberg, A. A. 2003. Multiple Uses of Marine Ecosystems. pp 189-196 in: Responsible Fisheries in the Marine Ecosystem ((M. Sinclair and J. Valdimarsson, Eds.), FAO and CABI Publishing, Rome: 426 pp.

[49] Tamura, T. 2003. Regional Assessments of Prey Consumption and Competition by Marine Cetaceans. pp. 143-170 in: Responsible Fisheries in the Marine Ecosystem (M. Sinclair and J. Valdimarsson, Eds.), FAO and CABI Publishing, Rome: 426 pp.

[56] Barlow, D. 2001. Fishmeal and Oil – Supplies and Markets. International Fishmeal and Fish Oil Organization, U.K.

[59] Anon, 2003. Fish Food for Thought. Cape Business News, 23 November, Capetown.

[42] Springer, A.M. and S. G. Speckman, 1997. A Forage Fish is What? Summary of the Symposium. Pp 773-805 in: Forage Fishes in Marine Ecosystems. Univ. Alaska Sea Grant College Program, Report No. 97-01: 816 pp.

[47] Brownlee, S. and L.Tangley, 1997. The Wrath of El Nino. U. S. News and World Reports, Oct. 6, 1997.

[51] Gjosoeter, H. 1997. The Barents Sea Capelin Stock (*Mallotus villosus*): a Brief Revue. pp. 469-484 in: Forage Fishes in Marine Ecosystems. Univ. Alaska Sea Grant College Program, Report No. 97-01: 816 pp.

[54] Anon, 2001. By Product Development. Alaska Dept. Community and Economic Development, Office of Fisheries Development.

[60] Enea, R. 2001. The Politics of the California Sardine. The Sardine Fisheries. J.B. Phillips Historical Fisheries Report, Marine Maritime Museum of Monterey, Vol. 2 (1).

[61] Parrish, R. 2000. Monterey Sardine Story. The Sardine Fisheries. J.B. Phillips Historical Fisheries Report, Marine Maritime Museum of Monterey, Vol. 1 (1).

[62] Csirke, S. 1997. Review of the State of World Fishery Resources: Marine Fisheries. FAO Fisheries Circular No. 920. 13. Eastern Central Pacific. FAO, Rome.

[63] Bakon, A. 1977. Review of the State of World Fishery Resources: Marine Fisheries. FAO Fisheries Circular No. 920. 11. Northeast Pacific. FAO, Rome.

[64] Anon, 2002. Fisheries of the United States. Fisheries Statistics and Economic Div. NOAA Fisheries.

[65] Anon, 2003. Globefish Publications, Fishmeal and Fish Oil Commodity Update.

Back cover photograph by Greig Cranna
Blacks Harbour, New Brunswick