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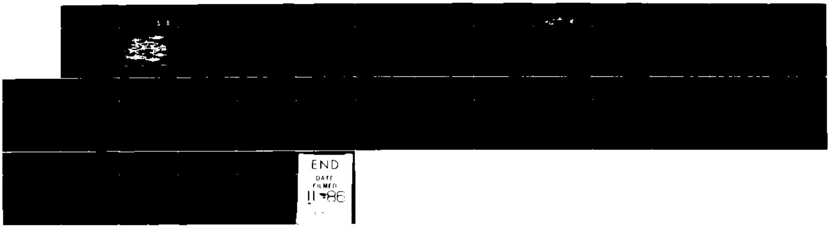

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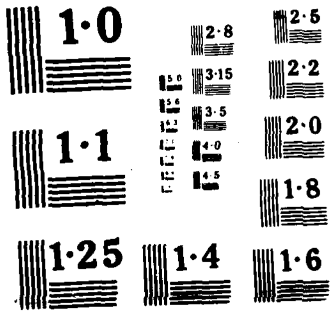
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Biological Report 82(11.38)
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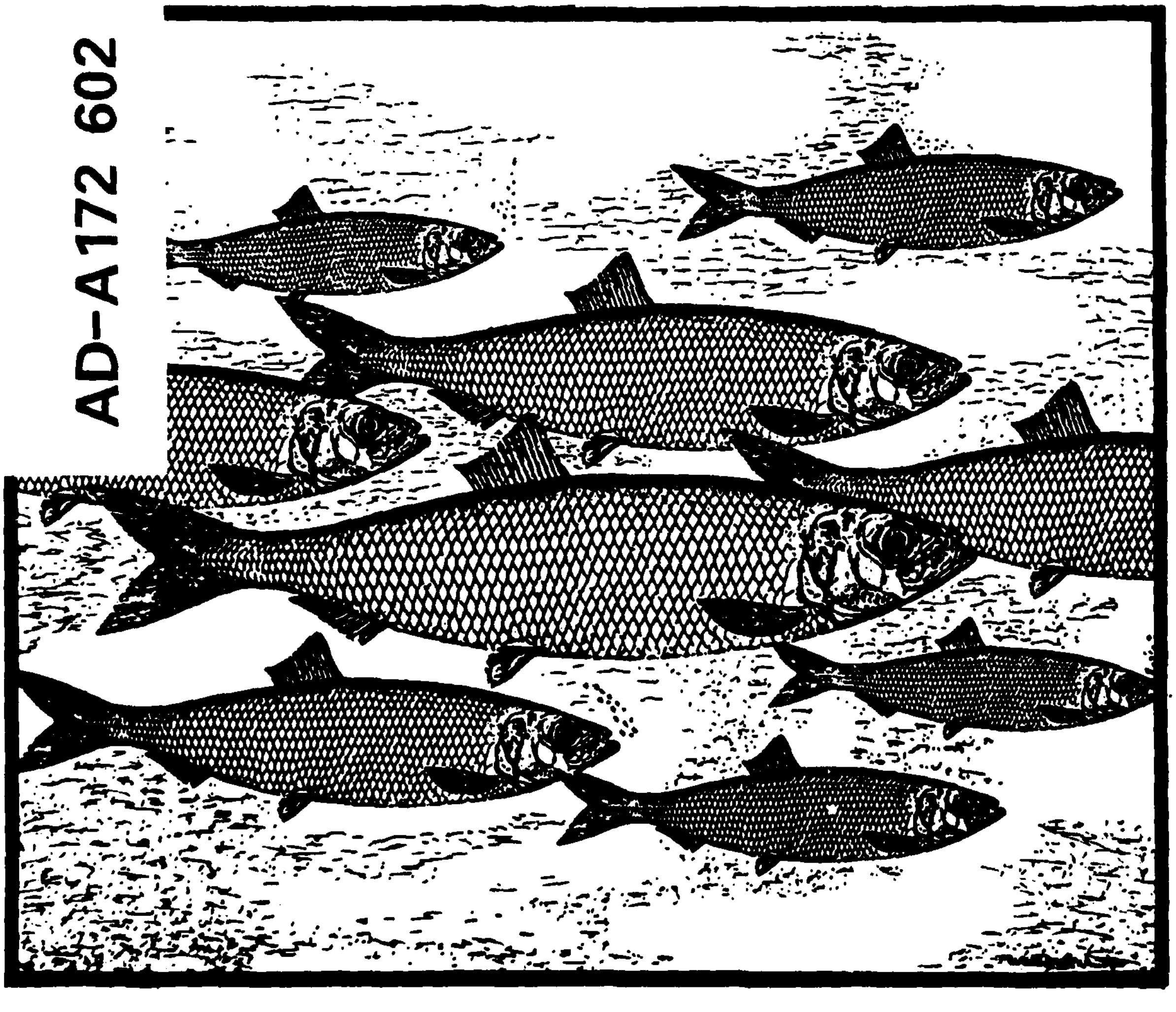

Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

ATLANTIC HERRING

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees	0.5556(°F - 32)	Celsius degrees

CONTENTS

ACKNOWLEDGMENTS

We thank David Stevenson, Maine Department of Marine Resources, West Boothbay Harbor, Maine, and Vaughn C. Anthony, National Marine Fisheries Service, Woods Hole, Massachusetts, for reviewing the manuscript.

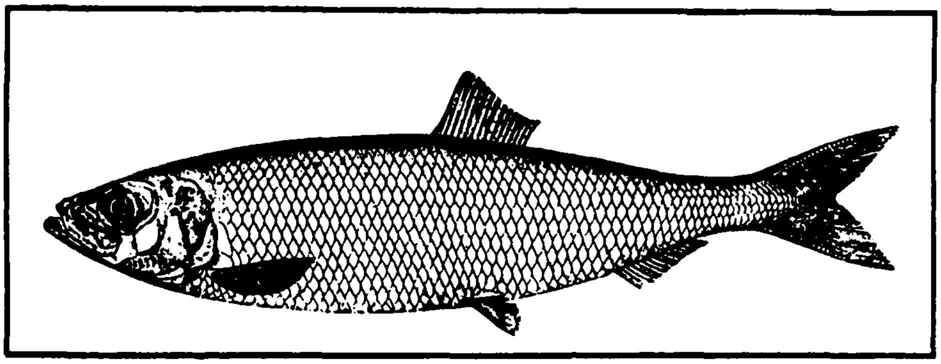

Figure 1. Atlantic herring (Clupea harengus L.).

ATLANTIC HERRING

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . Clupea harengus (Linnaeus) (American Fisheries Society 1980); Western North Atlantic populations of this fish are recognized as a subspecies in most current American and Russian literature, but as a distinct species (Clupea harengus) in Europe. The taxonomy of Clupeidae was extensively reviewed by Svetividov (1952).

Preferred common name . . . Atlantic herring (Figure 1)

Other common names . . . Sea herring, Labrador herring, sardine, sperling, brit (Bigelow and Schroeder 1953), herring (Hildebrand 1963).

Class . . . . Osteichthyes
Order . . . . Clupeiformes
Family . . . . Clupeidae

Geographic range: Atlantic herring in Northwest Atlantic waters range from Greenland to North Carolina. They are most abundant north of Cape Cod, and relatively scarce south of New Jersey. In Europe, where certain races enter brackish water, herring range from Spitsbergen and northern Norway south to the Strait of Gibraltar (Hildebrand 1963).

MORPHOLOGY/IDENTIFICATION AIDS

The following information is from Hildebrand (1963) and Mansueti and Hardy (1967). Fin rays: dorsal 16-20, usually 17-19: anal 16-20, usually 17 or 18; pectoral 17-19. Scales between gill openings and caudal base ca. 56-62; ventral scutes weakly developed, ca. 39-46; vertebrae 55-57 (49-60: Mansueti and Hardy 1967), gill rakers on lower limb of first arch 37-52. Proportions as percent of standard length (SL) (may include some juveniles): body depth 20.0%-25.8%, head length 22.6%-26.4%; eye diameter 5.3%-7.7%. Body compressed. Maxillary rounded posteriorly, not quite reaching middle of eye, its margin with minute serrae; teeth on lower jaw, tongue, and in oval patch on vomer. Dorsal origin about midway along trunk, usually closer to caudal base than to tip of snout. Body iridescent, bluish above, silvery on sides and belly. Maximum total length (TL) about 450 mm, but most average about 300 mm.

Distinctive Characteristics

The following conspicuous field marks (Hildebrand 1963) distinguish postlarval and adult Atlantic herring from alewives (*Alosa pseudoharengus*) and shads (*Alosa* spp.): the point of origin of the dorsal fin is about midway along the trunk (considerably farther back than in *Alosa*), the body is not as deep, and the sharp midline of the belly is less strongly serrate.

REASON FOR INCLUSION IN SERIES

Atlantic herring are commercially important in the western North Atlantic, particularly in the Gulf of Maine and adjacent Nova Scotian shelf waters (Fogarty and Clark 1983). The main fishery for adults is concentrated in the Jeffreys Ledge (Figure 2) area of the western Gulf of Maine. The Georges Bank fishery, which peaked in 1968 at 374,000 t, collapsed in 1977 because of heavy fishing intensity from foreign nations and has shown no signs of recovery since. The main fishery for juvenile herring, or "sardines," is in the coastal waters of Maine and New Brunswick.

The Maine fishery has thrived for over a century and is still a valuable resource. For each $1 worth of herring landed in Maine, an income of $1.47 is generated within the State's economy (Briggs et al. 1982). The average annual value of Maine herring landings was $4.3 million in 1976-1982 (Table 1). Herring are also important prey of such commercial species as Atlantic cod, pollock, haddock, silver hake, red hake, white hake, swordfish, and bluefin tuna.

LIFE HISTORY

Spawning

Time of spawning. Atlantic herring spawn in the Gulf of Maine once a year, usually in late summer or fall (late August to early November). The spawning period is protracted in some years (Anthony and Waring 1980b). Bigelow and Schroeder (1953) reported that the heaviest spawning in the Grand Manan Island and Machias Bay areas took place in July, August, and September. Spawning in coastal waters to the south and west occurred progressively later and was briefer in duration: from mid-August to October

Table 1. Weights (thousands of pounds) and values (thousands of dollars) of herring landings by State, 1976-82. Data for 1976 are from National Marine Fisheries Service (1980); data for 1977-82 are preliminary and unpublished.

Year	Maine		New Hampshire		Massachusetts		Rhode Island		Connecticut	
	Wt.	Val.	Wt.	Val.	Wt.	Val.	Wt.	Val.	Wt.	Val.
1976	70,234	$3,054	<1	$<1	39,737	$1,281	394	$ 18	1	$ 1
1977	73,050	3,545	54	3	37,727	1,375	642	33	0	0
1978	66,895	3,782	<1	<1	40,548	2,690	3,722	238	NA[a]	NA
1979	89,375	4,584	<1	<1	50,790	3,586	2,825	NA	195	NA
1980	107,823	5,977	6,636	378	66,848	3,787	2,416	189	1	<1
1981	114,593	6,435	106	6	27,116	1,291	1,516	81	26	1
1982	51,161	2,758	1,217	63	15,703	707	3,004	156	28	1

[a]NA indicates data were not available.

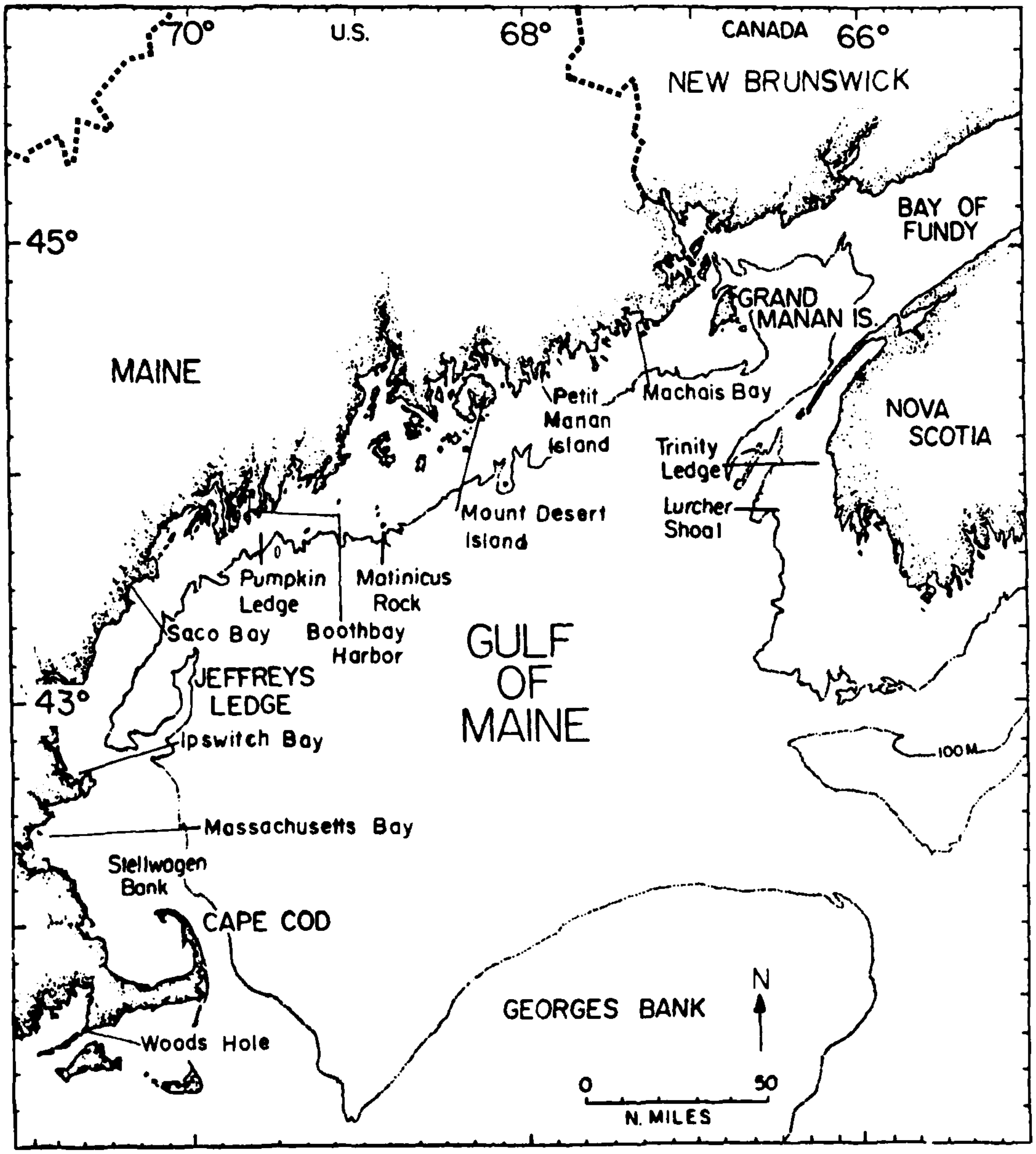

Figure 2. Gulf of Maine showing Atlantic herring spawning grounds as discussed in text.

around Petit Manan Island and near Mount Desert Island, Maine; in October in Ipswich and Massachusetts Bays, Massachusetts; and in late October and early November near Woods Hole, Massachusetts.

In 1960-65, spawning on Georges Bank and off Nova Scotia began in August and peaked in October. In the coastal Gulf of Maine, spawning began in August or September and peaked in either September or October, depending on the year (Boyar 1968).

Recent larval herring surveys indicate that herring begin spawning in late August and early September in waters of eastern Maine and in mid- to late September in midcoastal and western Maine (Graham 1982). Collections of yolk-sac larvae indicated that spawning on Georges Bank-Nantucket Shoals took place from mid-September to late December (Lough et al. 1979).

Spawning of Atlantic herring has been reported in spring in the Gulf of Maine, but it is apparently unsuccessful (Bigelow and Schroeder 1953; Boyar 1968; Sindermann 1979; Anthony and Waring 1980b). Spring spawning has not been reported for Georges Bank (Boyar 1968; Sindermann 1979).

Spawning sites. Several offshore spawning sites were found near the perimeter of Georges Bank (Boyar et al. 1973). Spawning concentrations of herring on Georges Bank in 1962 were reported to be as long as 64 to 80 km and wide as 6 to 13 km (Yudanov 1966). In the Gulf of Maine, spawning concentrations are less dense and the number of spawning sites has decreased in recent years. Recent larval surveys have indicated that the important spawning sites are located in Machias Bay along the eastern coast of Maine and in waters south of Boothbay Harbor and off Saco Bay (Graham 1982). As judged by the numbers of spawning and near-spawning adults, Jeffreys Ledge appears to be the most important spawning ground (Boyar et al. 1973). Other Atlantic herring spawning sites in the Gulf of Maine area are Lurcher Shoals and Trinity Ledge off Nova Scotia, and Grand Manan off New Brunswick, Matinicus Rock and Pumpkin Ledge off Maine, and Stellwagen Bank off Massachusetts (Sindermann 1979; Figure 2).

Spawning habits and depth. Atlantic herring are coastal oceanic spawners. During the act of spawning, the females press close to the bottom and deposit ribbons of adhesive eggs on the substrate (Blaxter and Holliday 1963). The males swim above the females and release milt into the water.

Spawning depths range from 10 to 100 m in the Gulf of Maine (Sindermann 1979), although herring have been reported to spawn as deep as 200 to 240 m in European waters (Blaxter and Holliday 1963). Herring in the Gulf of Maine and the Bay of Fundy were reported to spawn at depths of about 4 to 110 m (Bigelow and Schroeder 1953), both inshore along the coast and on shoals and ledges as far as 8 to 40 km offshore. Depths of two spawning sites on Jeffreys Ledge (western Gulf of Maine) in 1974 were 30 to 45 m and 40 to 50 m (Cooper et al. 1975).

Egg beds in Georges Bank in 1970 were in water 50 m deep (Caddy and Iles 1973). A spawning bed observed by Tibbo et al. (1963) in the Gulf of St. Lawrence, Canada, was only 2 to 6 m deep and eggs in Miramichi Bay, New Brunswick, were 0.9 to 4.3 m deep (Pottle et al. 1980). Herring spawned from close inshore to depths of 9.1 to 11.0 m in Newfoundland waters (Tibbo 1956). In areas where onshore winds caused turbulent surface water near shore, herring spawned in deeper waters.

Spawning substrate. Although Atlantic herring usually spawn over gravel or rock, vegetation and shells may also be used (Sindermann 1979). Underwater observations on Jeffreys Ledge revealed that 80% to 90% of the eggs adhered to the red alga Ptilota serrata, and the rest stuck to the upper surfaces of rocks and boulders (Cooper et al. 1975). Two types of spawning substrate were boulder/rock substrate with vegetation and coarse fragments of sand, gravel, and shells without vegetation. Three of the six spawning areas observed were composed of rough boulder/rock substrate; slope gradients ranged from 0° to 40°.

In Georges Bank waters, herring eggs were found only over a flat surface of fairly well-sorted, rounded glacial gravel, 2 to 10 mm in diameter; no eggs were seen on sand or shell fragments (Caddy and Iles 1973). In Miramichi Bay, New Brunswuck, scuba divers reported that eggs were deposited on algae--primarily Chondrus crispus, Palmeria palmata, Phyllophora sp., and Fucus sp.--with an apparent preference for the last two of these taxa (Pottle et al. 1980). In waters near Newfoundland, herring usually spawn on gravel or rock substrates where vegetation is abundant, though a few spawn on bare rock along sandy shores (Tibbo 1956).

Spawning temperatures and salinities. During spawning, water temperatures on two Jeffreys Ledge spawning beds ranged from 9 to 12 °C (Cooper et al. 1975). In the eastern Gulf of Maine and Grand Manan Island area, spawning temperatures of 8 to 11 °C were reported. Autumn spawners in European waters prefer temperatures of 8 to 15 °C (Blaxter and Holliday 1963).

Salinities in waters where herring spawn in the Gulf of Maine are normally near 33 ppt; Atlantic herring never spawn in brackish waters of the gulf (Bigelow and Schroeder 1953).

Water currents. A water current of at least 1 to 2 km/h is usually present during spawning (Sindermann 1979). Bottom water currents throughout a tidal cycle on the Jeffreys Ledge spawning grounds ranged from 0 to 2 km/h and averaged 0.3 to 0.5 km/h (Cooper et al. 1975).

Fecundity and Eggs

Estimates of the average number of eggs per female for Gulf of Maine herring indicate an increase in fecundity in recent years (Table 2). This increase may be compensation for a decrease in stock size (Anthony and Waring 1980b). For Gulf of Maine herring, fecundity is closely related to the weight of the fish, derived by the relation of the curvilinear form $F = aW^{b}$, where a = 40.39 and b = 1.413 (Morse and Morris 1981). The relation between fecundity and total length of the fish is determined by using the formula $F = aL^{b}$, where $a = 1.714 \times 10^{-7}$ and b = 4.756 (Morse and Morris 1981).

A relatively constant number of eggs seem to be produced by fish of a particular length but some eggs may be reabsorbed during maturation. In

Table 2. Estimates of fecundity (thousands of eggs) for Atlantic herring of different lengths in the Gulf of Maine.

Total length (cm)	Year		
	1963-64[a]	1980[b]	1982[c]
26	33.0	52.0	36.9
27	48.5	63.0	55.4
28	63.5	75.0	73.9
29	79.0	88.0	92.5
30	94.5	104.0	111.0
31	110.0	121.0	129.6
32	125.5	141.0	148.1
33	141.0	163.0	166.6
34	-	188.0	185.1

[a]Perkins and Anthony (1969).
[b]Morse and Morris (1981).
[c]Kelly (1983).

European herring, annual variations in fecundity have been related to differences in food intake (Hempel 1971; Bowers and Holliday 1960). Low fat content in females, caused by a scarcity of food, can reduce the number of eggs produced (Hempel 1971). Absolute fecundity probably increases with a decrease in stock density. For example, fecundity of the Georges Bank herring each year was inversely related to population abundance in the previous year (Anthony and Waring 1980b).

Egg diameter after fertilization is typically 1.0 to 1.4 mm (Bigelow and Schroeder 1953; Mansueti and Hardy 1967). Egg size at maturity may vary in different areas and at different times of the year (Bowers and Holliday 1960; Hempel 1971). In the southern Gulf of St. Lawrence, mean egg weights were 12.2 mg in spring and 7.5 mg in fall; fecundity of fall spawners was about 50% higher than in spring spawners (Messieh 1976).

Egg incubation periods fluctuate with temperature. Periods reported in the Gulf of Maine are 10 to 15 days (Bigelow and Schroeder 1953). Hatching occurs after 8-9 days at 10 °C (Cooper et al. 1975).

Size of egg beds. On Jeffreys Ledge in 1974, the area of egg beds ranged from 700 to 1,300 m^2, and each bed encompassed a distinct and well-defined area (Cooper et al. 1975). Off Nova Scotia, a spawning area occupying 67,500 m^2 was reported by McKenzie (1964), but he did not indicate whether the bed was continuous. A spawning area of 375,000 m^2 off the Canadian coast was reported by Tibbo et al. (1963).

Thickness of layers of eggs. The number of egg layers in herring egg beds varies with the intensity of spawning. One egg bed on Jeffreys Ledge was composed of 3 to 15 layers and another contained 1 to 4 layers (Cooper et al. 1975). Egg layers were 1 to 2 cm thick on Georges Bank (Caddy and Iles 1973) and around 3.25 cm thick on Trinity Ledge off southwest Nova Scotia (McKenzie 1964). Baxter (1971) reported that the presence of three to four layers is not harmful to the survival of eggs in the lower layers; however, rates of development are not uniform throughout the egg layers, and egg survival is lowest in the bottom layers (Baxter 1971). According to Hempel and Schubert (1969), if the eggs mass is thicker than three or four layers, high mortality occurs in the deeper layers.

Larvae

Atlantic herring larvae are 5 to 9 mm long at hatching (Blaxter and Holliday 1963). The newly-hatched larvae become concentrated in the upper water column but are soon dispersed by surface and near-surface water currents (Lough 1975). An exception is yolk-sac larvae at spawning sites with vegetation; the larvae may stay in the vegetation for several days (Cooper et al. 1975). An estimated 75% of Atlantic herring larvae die within 4 days after hatching (Graham and Chenoweth 1973).

Larval food. The larvae depend on the yolk sac for food during their first few days of life, but the yolk sac is absorbed when the larvae are 8 to 12 mm SL (Blaxter and Holliday 1963). Some larvae begin feeding even before the yolk is fully absorbed. Larvae reared at 10 °C began feeding 2 to 3 days after hatching (Lough et al. 1982). Newly hatched larvae (7 to 20 mm long) prey principally on copepod nauplii and copepodites (Sherman and Honey 1971).

In winter, as the larvae become larger (21 to 30 mm), the diet shifts to larger food items, predominantly the copepods *Pseudocalanus minutus* and *Oithona* sp. (Sherman and Honey 1971). The particle range of sizes that larvae can ingest is related to the gape of the jaw, which increases as the larvae grow larger. The importance of a larger jaw gape, with an increasing size range of potential prey, is probably greatest during winter when food is scarce and small larvae of zooplankton are lacking (Sherman and Honey 1971). If herring larvae starve for 5 to 7 days, they essentially lose their ability to feed and become easy prey (Lett 1976). During zooplankton blooms in spring, herring larvae eat a wider variety of prey--principally cirriped larvae, crustacean eggs, tintinnids, and copepods (Sherman and Honey 1971). The larval phase of Atlantic herring lasts 6 to 8 months (Sindermann 1979).

Movement. Studies of larval drift patterns in the Gulf of Maine indicate that larvae, soon after hatching, either move directly into estuaries and embayments adjacent to the spawning areas or are carried along the coast by east to west coastal currents. As an indication of movement by east to west currents, larvae hatched off eastern Maine are regularly collected in the Sheepscot Estuary of western Maine by late autumn (Graham and Joule 1981; Graham 1982). The larvae make diurnal vertical migrations to move into the estuaries, using landward tidal currents (Graham 1972). Larvae spawned in Georges Bank waters in 1971 were widely dispersed but there was some indication of a drift toward the southwest. In contrast, most of those from spawning sites at Jeffreys Ledge, Cape Elizabeth, and Stellwagen Bank moved shoreward (Sindermann 1979).

Juveniles

Metamorphosis. When young herring are about 50 to 55 mm SL, they undergo metamorphosis, developing the morphological characteristics of adults; they are then identified as juveniles (Lough et al. 1982). Metamorphosis begins in April in the Gulf of Maine (Sindermann 1979). In laboratory studies, metamorphosis was completed in about 10 days at 15 °C (Blaxter and Holliday 1963). After metamorphosis, schooling behavior becomes prominent and lasts throughout life. As young herring begin to school, they moved inshore in large numbers.

Movement. The movements of juvenile herring in the Cape Cod - Bay of Fundy area are not well known. Herring schools of age groups I and II in the Gulf of Maine are known to move inshore in spring and remain there during summer. In southwestern Maine, juveniles tagged during summer often were recovered in Massachusetts Bay during winter, but those tagged in eastern Maine in summer tended to remain nearby in winter (Creaser et al. 1984). Juveniles tagged in southwestern and central Maine also were recovered farther east in the following summer, but most larvae from eastern Maine were recovered near where they were originally tagged. Fish tagged during winter in eastern and western Maine remained in the same area during the following summer (Creaser et al. 1984).

Light response. The response of juvenile herring to light is strongly negative. The fish move toward the surface at sunset and remain there during low light intensity. Laboratory studies indicate that juveniles are most active just after sunset and just before sunrise (Stickney 1972). Commercial catches of juvenile herring in Maine have been inversely correlated with moonlight intensity. Monthly peaks in catches coincided with the dark phase of the moon (Anthony 1971).

Food habits. Juvenile herring feed on a variety of zooplankton. Copepods are the most important prey throughout the year (Sherman and Perkins 1971). Larval decapods are important as food in spring and larval cirripeds in spring and summer. Other foods are larval pelecypods in summer, and cladocerans in summer and autumn (Sherman and Perkins 1971).

Adults

Age and maturity. In the Gulf of Maine and Northwest Atlantic, most herring of both sexes first spawn at age IV. Some fish become sexually mature at the age III though the number varies from year to year (Anthony and Waring 1980b). The percentages of Georges Bank herring that matured at age III ranged from 6 to 62 (mean = 29) for the 1960-65 year classes (Boyar 1968). Length at first spawning averaged 26 cm TL for fish of age group III and 27.5 cm for those of age group IV (Boyar 1968).

Migration. Adult herring sometimes travel long distances to spawning areas in late summer and early fall, then to warmer overwintering areas after spawning. In spring and early summer, they undertake feeding migrations. Migrating herring schools may consist of hundreds of thousands of fish. Each school is usually composed of fish about the same size and age (Hildebrand 1963). They seldom migrate seaward beyond on depth of 50 fathoms. Herring usually inhabit waters closer to the surface than the bottom, except in midwinter (Hildebrand 1963).

Tagging studies have shown that spawners from Jeffreys Ledge may overwinter south of Cape Cod and migrate in spring and summer to northern or offshore areas of the Gulf of Maine and into the Bay of Fundy (New England Regional Fishery Management Council 1978). Adults from southeast Nova Scotia move primarily northward into Chedabucto Bay in northeast Nova Scotia to overwinter, but after spawning many migrate south and west as far as Cape Cod. Many adults tagged in eastern Maine in the summer were recovered in Massachusetts Bay in winter (Creaser et al. 1984). Fish that spawn near the New Brunswick coast have been reported in the Cape Ann - Jeffreys Ledge area in winter (Creaser and Libby 1982).

Food habits. Adult herring feed selectively on zooplankton, capturing prey by direct, predatory snapping action (Blaxter and Holliday 1963). In the North Atlantic Region, the principal prey is the euphausiid, *Meganyctiphanes norvegica*; of lesser importance are chaetognaths and the copepod, *Calanus finmarchius* (Maurer and Bowman 1975).

Growth Characteristics

Larval herring from coastal Maine grow about 2.0 mm per week from October to early January and from late February to early March; little growth, if any, occurs during midwinter (Townsend and Graham 1981). Other growth rates reported in the Gulf of Maine - Georges Bank area were 1.75 mm per week after hatching, 2.1 mm per week for larvae 20 days old in September and October, and <1.0 mm per week for fish 75 days old in winter (Lough et al. 1982). The average daily growth increment for larvae of Georges Bank-Nantucket Shoals was 0.2 mm (Lough 1976).

Most of the growth of juvenile herring is in summer. In New Brunswick, the average growth of 2-year-old herring during May to September ranged from 30 mm in 1965 to 55 mm in 1978 (Sinclair et al. 1981). Both sexes are about 90 to 125 mm TL at the end of the first year of life and 190 to 200 mm TL after the second (Bigelow and Schroeder 1953).

Anthony (1971), who compared juvenile growth in different areas of Maine, reported that modal lengths of fish of the 1960 year class (age group II) in October in eastern, central, and western Maine were 142, 155, and 175 mm, respectively. The lengths of the 1959 year class for the same age group and areas were 190, 216, and 214 mm. In fish up to 3 years old, growth was inversely related to population density and was faster in western than in eastern Maine.

Von Bertalanffy growth curve parameters, K (growth rate) and L (maximum length attained), were 0.251 and 37.4 cm in eastern Maine (Anthony 1971). The same values for southern and central Maine combined were 0.267 and 36.0 cm. A Newfoundland herring study provided little evidence to support density-dependent growth in the first year, but suggested density-independent growth regulated by temperature (Moores and Winters 1982).

Anthony and Waring (1980a) reported that adult herring reach their peak weight each year in August or September and are lightest in February-March. They also reported that herring (both sexes) from Nova Scotia, eastern and western Maine, and Jeffreys Ledge all had "oceanic" (offshore) growth characteristics *common to fish of the* Northeast Atlantic. The characteristics were the large maximum size, slow growth rate, and maximum ages of 15-18 years (Table 3).

Georges Bank herring are more similar in growth characteristics to Northwest Atlantic "shelf" (inshore) populations, which have a smaller maximum size, higher growth rate, and lower maximum age (Table 3; Figure 3).

Table 3. Von Bertalanffy growth parameters of Atlantic herring stocks of Northeastern U.S. (Anthony and Waring 1980a).

Area	L	K	T_{max}
Georges Bank	34.1	0.377	13
Jeffreys Ledge	36.7	0.311	15
Western Maine	35.1	0.335	16
Eastern Maine	38.0	0.277	16
Nova Scotia	39.0	0.179	18

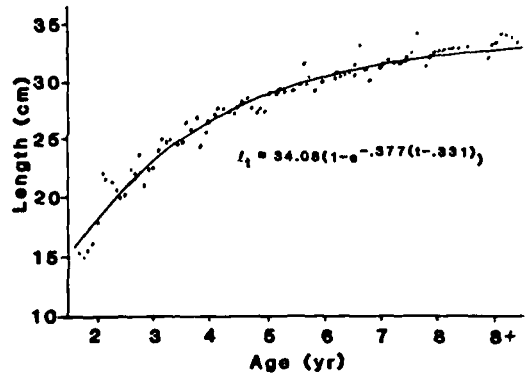

Figure 3. Von Bertalanffy growth curve for the Georges Bank herring (1960-1971 year classes included). From Anthony and Waring (1980a).

The Von Bertalanffy growth rate (K) of Georges Bank herring increased from 0.350 (year classes 1960-63) to 0.357 (year classes 1964-67) to 0.510 (year classes 1968-71). The increased growth rate of all year classes after 1968 may have been related to the decline in abundance (Anthony and Waring 1980a).

THE FISHERY

History of the Fishery

An extensive herring fishery exists between southern New England and Newfoundland (Figure 4). The Atlantic herring has supported a commercial fishery along inshore waters of New England for at least 400 years (Anthony and Waring 1980c). The canning of "sardines" began in Maine in 1875 and, along with the sardine fishery of New Brunswick, continues to be an important economic resource. The *coastal Maine and New Brunswick* fisheries are primarily fixed-gear (stop seine and weir) fisheries that concentrate on juvenile herring, primarily of age group II (Anthony and Waring 1980a). Currently, major fishing grounds in the Northwest

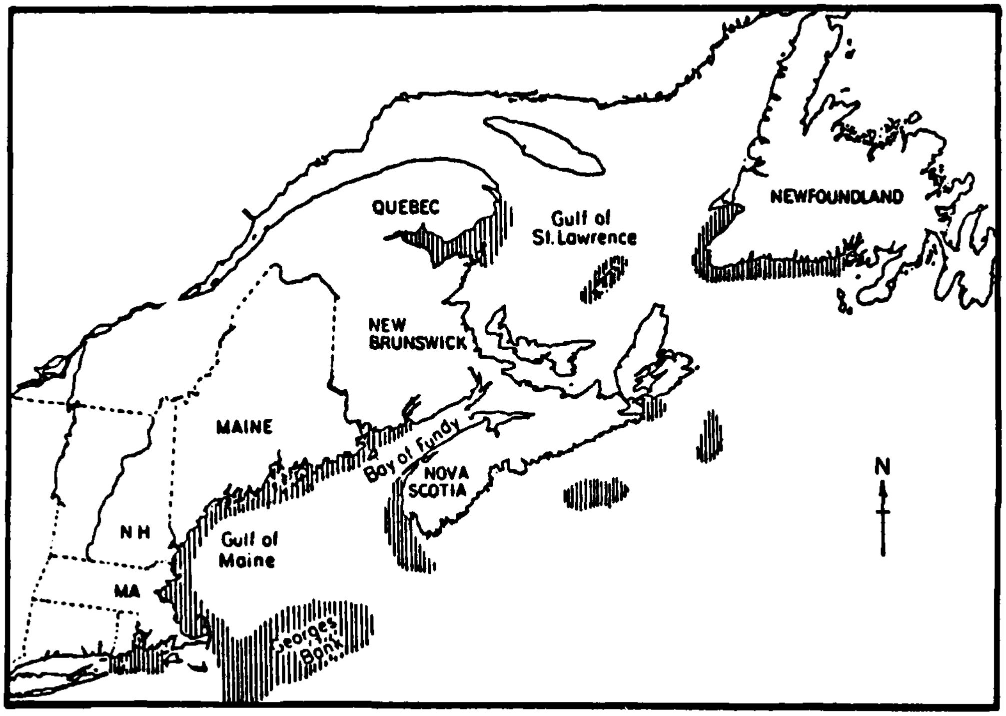

Figure 4. Herring fishing areas of the Northwest Atlantic (shaded areas indicate major fishing grounds, though Georges Bank does not support a significant fishery).

Atlantic are the Gulf of Maine, southwestern Nova Scotia, Chedabucto Bay, the Magdalen Islands area in the Gulf of St. Lawrence, and southwestern Newfoundland.

The juvenile catch in Maine has fluctuated greatly throughout the history of the fishery because of variations in recruitment, market demand, and vulnerability to new fishing gear. Yet, juveniles are still the dominant component of the Maine herring fishery (Table 4). A period of decline in catch began in the early 1950's in eastern Maine, historically the main source of juvenile fish (Bigelow and Schroeder 1953; Sindermann 1979; Anthony and Waring 1980a). Declines in western and central Maine began in the 1960's and lasted through 1971. The total

Table 4. Commercial landings (metric tons) of Atlantic herring of different ages in Maine, 1979-82.

Age	Year[a]			
(Years)	1979	1980	1981	1982
I	27	1,012	120	451
II	5,839	9,051	39,575	13,311
III	11,485	26,538	1,627	3,410
IV	1,708	8,606	2,586	328
V	191	442	3,815	4,115
VI	329	24	366	2,045
VII	196	101	20	194
VIII	104	-	20	18
>VIII	179	133	120	135
Total	20,058	45,907	48,249	24,007

[a]Data for 1979-31 from Chenoweth (1982); data for 1982 from Fogarty and Clark (1983).

catch of juveniles in 1971 was only 5,400 t (Chenoweth 1982). The catch of juveniles in Maine then increased, peaking in 1981 at 41,200 t; however, the 1982 catch dropped to 17,000 t (Fogarty and Clark 1983).

Before 1961, only the inshore fisheries for juveniles in Maine and New Brunswick were important in the Northwest Atlantic; however, fishing intensity on adults by the USSR fishing fleet, primarily on Georges Bank, sharply increased in 1961. After 1961, other foreign nations also began to fish there. The Georges Bank herring fishery, nonexistent in 1960, rose to a production of 373,600 t in 1968 (Anthony and Waring 1980a).

In 1964, Canadian purse seine vessels sharply increased their fishing effort in the Gulf of St. Lawrence and off Newfoundland and Nova Scotia. The total catch for the Northwest Atlantic increased from 180,000 t in 1960 to 600,000 t in 1964 (Figure 5).

In 1967, the fishery for adult herring in the western Gulf of Maine intensified, and in 1969, all fisheries combined for a harvest of 967,000 t -- an all-time peak. Such heavy fishing pressure caused production to decline after 1973.

The adult herring landings on Jeffreys Ledge in the western Gulf of Maine declined to 7,600 t in 1982 -- a 50% drop from 1981, and a nearly 79% decline from the 1980 catch of 36,100 t (Fogarty and Clark 1983). Purse seines and pair trawls are primarily used in this fishery, which is active during fall and winter; however, there is also some fishing for adults along the Maine coast during summer and early fall. Catches of adults from central, eastern, and western Maine are not as large as those from Jeffreys Ledge; catches in Maine in 1978 and 1980, which were better than average, were 6,200 and 9,200 t, respectively (Chenoweth 1982). Maine and Massachusetts contributed most of the New England landings in 1976-82 (Table 1).

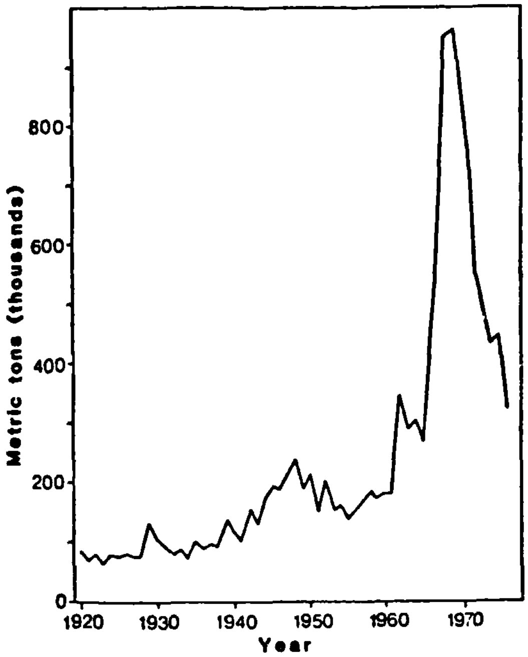

Figure 5. Annual landings of Atlantic herring from the Northwest Atlantic 1920-1975 (Anthony and Waring 1980a).

In 1972, the International Commission for Northwest Atlantic Fisheries (ICNAF) began establishing total allowable catches for adults. The catches were set more for economic than for conservation reasons (Anthony and Waring 1980a) and catches soon declined in all areas. The Fishery Conservation and Management Act of 1976 prohibited fishing by foreign vessels within 200 miles of shore, an area which includes Georges Bank. The Georges Bank catch in 1977 was almost nil (Anthony and Waring 1980a) and has improved little in 1978-83.

Current management of the herring fishery is at the State level until regional management can be formulated and established. A management plan by the New England Regional Fishery Management Council, which established catch quotas in Federal waters from 3 to 200 miles offshore, was abandoned in 1982.

A definition of unit stocks of herring in the Northwest Atlantic, which is essential for formulating management, has received much attention from biologists and managers, but has not been fully resolved. Management is currently based on the assumption that there are three herring stocks or stock complexes from Nova Scotia to southern New England: Georges Bank, the Gulf of Maine, and southwest Nova Scotia. Primary criteria for separating these groups are differences in spawning population sizes, meristic counts (fin rays and vertebrae), and growth rates (Anthony 1972). Current stock assessments provide population estimates for both the Gulf of Maine and the combined stocks of the entire region from Cape Hatteras, N.C. to Nova Scotia (Fogarty and Clark 1983). The latter "pooled" assessment recognizes season stock intermixing throughout the Gulf of Maine and Nova Scotian shelf (Fogarty and Clark 1983).

ECOLOGICAL ROLE

Atlantic herring are a significant part of the diet of many predatory fishes, marine mammals, and piscivorous birds. They also are important competitors of other planktivorous fishes, principally Atlantic mackerel, another commercially important pelagic species in the Northwest Atlantic. Chief predators of herring are cod, pollock, haddock, silver hake, mackerel, dogfish and other sharks, finback whales, and the common squid (Hildebrand 1963; Bigelow and Schroeder 1953). Schools of herring in the Gulf of Maine are also preyed upon by short-finned squid, striped bass, tuna, salmon, mackerel sharks (Bigelow and Schroeder 1953), and Atlantic white-sided dolphins (Katona et al. 1978). Herring are a common prey of rorqual whales (Overholtz and Nicolas 1979). Sooty shearwaters feed on herring in eastern Canadian waters (Brown et al. 1981).

A principal source of herring egg mortality is predation by ground fish, e.g., cod and haddock. Hempel (1971) estimated that on North Sea spawning grounds, one haddock ate the spawn of one herring each day of the spawning season. On Georges Bank, Caddy and Iles (1973) observed that heavy predation on herring egg beds caused steep-sided craters or depressions (up to 0.3 m in diameter) in the egg layer, sometimes exposing the underlying gravel. An estimated 8% of the spawn was removed by predators. Red hake were seen feeding on herring eggs; and moon snails, hermit crabs, and starfish were found in the egg mat depressions (Caddy and Iles 1973). McKenzie (1964) reported that haddock in the area off Black Point, Nova Scotia ate large quantities of herring eggs, and apparently were the main egg predator. On Georges Bank in fall 1970, herring eggs made up 28% of the weight of haddock stomach contents (Langton and Bowman 1980).

Analysis of food habits of Georges Bank and Gulf of Maine fishes in the 1960's and 1970's, in relation to fluctuations in herring and mackerel stock sizes, disclosed that herring accounted for 30% of the total weight of food eaten by Atlantic cod (Grosslein et al. 1980). The decline in herring and mackerel biomass in these years was accompanied by a decline in almost all demersal fish species, and crustaceans became slightly more important than fish in the cod diet (Grosslein et al. 1980). This study also revealed a high degree of diet overlap (71%) between herring and mackerel, due to the preference of both species for euphausiids. For example, euphausiids made up 51% of the herring diet and 52% of the mackerel diet on Georges Bank (Grosslein et al. 1980).

Herring populations may be affected by predation of adult mackerel on herring larvae and by cannibalism of older herring on their own young in the Gulf of St. Lawrence (Lett and Kohler 1976). Apparently, the growth rate of yearling herring declined rapidly in response to an increase in abundance of young-of-the-year mackerel, probably because both forage for zooplankton of the same sizes. Yearling mackerel feed on smaller plankton and do not compete heavily with herring (Lett and Kohler 1976).

ENVIRONMENTAL REQUIREMENTS

Temperature

When water temperatures are 8 to 13 °C, the average incubation period of herring eggs in the Gulf of Maine is 10 to 15 days (Hildebrand 1963; Bigelow and Schroeder 1953). On Jeffreys Ledge, eggs hatched in 7 days at 13 °C and in 12 days at 8 °C (Boyar et al. 1973). Much of the primary work on temperature effects on egg and larval development was done with European herring. Meyer (1878), as cited by Blaxter and Holliday (1963), reported that egg development was normal at 1 to 22 °C but was fatally low at -0.8 °C. Slightly lower minimum temperatures for development have ranged from -1.2 to 0 °C for herring stocks off northern Europe (Soleim 1942; Blaxter and Hempel 1961; Blaxter and Holliday 1963). The jaw may develop abnormally at low temperatures and reduce the ability of the larvae to capture prey (Alderdice and Velsen 1971).

Two equations were developed for predicting hatching time (days) in relation to water temperature (°C): $D = 4 + 44.7e^{-0.167T}$ (Hela and Laevastu 1962); and $D = -2.0 + 165.0/T+1.34$ (Blaxter 1956). Experiments at Grand Manan, New Brunswick, showed that temperatures above 20 °C and below 5 °C were lethal to eggs (Bigelow and Schroeder 1953).

Yolk-sac stage duration varies with temperature. Temperatures and durations of the yolk-sac stage were 2.5 days at 14.5 °C and 4.5 to 14 days at 8 °C (Mansueti and Hardy 1967). Lough et al. (1982) reported yolk absorption times of 4.5 days at 10 °C and 6 days at 8 °C.

Temperature also affects the availability of plankton for food. If the water temperature is too low, production of plankton of suitable size is inadequate to support an abundance of herring larvae (Lett 1976); optimal water temperatures induce improved growth and high survival of herring larvae. Furthermore, swimming ability increases and predator avoidance and feeding ability are improved (Lett 1976).

Upper and lower temperature tolerances of newly hatched herring larvae are 22 to 24 °C and -0.75 to -1.8 °C for fish acclimated to temperatures between 7.5 and 15.5 °C (Blaxter and Holliday 1963).

Barker et al. (1981) tested thermal tolerances of herring under conditions associated with passage through condenser cooling systems of electrical generating stations. Larvae were exposed to rapid temperature increases from a base temperature of 8 °C, held for a standard period of time, and then rapidly returned to the original base temperature. The temperature changes ranged from 16 to 25 °C at exposure times of 5, 15, 30, and 60 min. Larvae acclimated to 8 °C survived temperature changes of 17 °C for up to 60 min and higher temperatures (27 to 29.1 °C) for shorter (<30 min) periods.

At water temperatures of 19.5 to 21.2 °C, mortality of juvenile herring (11.1 to 21.9 cm TL) was about 50% after 48 h. Tolerance to high temperatures was greater among small fish (Brawn 1960a). The mean freezing point of herring blood is -0.95 °C, decreasing to -1.01 °C during winter (Blaxter and Holliday 1963). Below these temperatures, herring blood quickly freezes unless supercooling or freezing point depression takes place (Blaxter and Holliday 1963). The freezing point is 0.75 °C for the fluids of ripe eggs and 0.92 °C for sperm and parental blood (Blaxter and Holliday 1963; Blaxter and Hunter 1982).

The migration and distribution of herring are linked with thermal oceanic fronts between colder, less saline continental shelf water and warmer, more saline continental slope water (Sindermann 1979; Iles and Sinclair 1982). In these fronts, plankton and other fish food organisms are usually abundant. Intrusions of warmer slope water into spawning areas in the Gulf of Maine influence spawning success and cause annual variations in commercial catch (Sindermann 1979). Higher water temperatures in September to March seem to favor spawning and recruitment success (Anthony 1972).

Salinity

Variations in salinity can affect early development, particularly of newly spawned eggs. Herring eggs are freely permeable immediately after spawning and, therefore, have no protection against osmotic imbalance (Holliday 1965). Because they are isotonic with seawater, the eggs are larger than average in low salinities and smaller in high salinities. The closure of the blastopore after gastrulation--which occurs in 24 h at 17 to 24 °C (Mansueti and Hardy 1967)--causes the egg to become more tolerant to changes in salinity. In general, both extremes of salinity are damaging (Blaxter 1965).

Laboratory studies indicate that fertilization, egg development, and hatching can succeed in salinities of 5.9 to 52.5 ppt (Holliday and Blaxter 1960). Maximum fertilization is at 25 ppt or more, and hatching success is greatest at 20 to 35 ppt. Egg fertilizations reported by Holliday and Blaxter (1961) were 70% at 5 to 12 ppt, and 100% at 25 to 55 ppt.

Atlantic herring larvae tolerate a wide range of salinities under experimental conditions. Blaxter and Hunter (1982) reported a tolerance to salinities of 1.4 to 60 ppt for 24 h and 2.5 to 52.5 ppt for 7 days. The salinity isosmotic with body fluids was 12 ppt. Yolk-sac larvae, however, survive longer in salinities between 10 and 20 ppt (Holliday 1965). The plasticity that is apparent in salinity tolerance of Atlantic herring eggs and larvae may be indicative of divergent physiological races (Alderdice et al. 1979).

Atlantic herring show an apparent preference for higher salinities as they become older. The lower level of tolerance for juveniles is about 5 ppt (Brawn 1960b). Although herring enter Northwest Atlantic bays and estuaries freely, they are rarely observed in salinities less than about 3 ppt (Hildebrand 1963).

Although Atlantic herring in European waters sometimes spawn in shallow inshore waters with salinities of 5 to 35 ppt (Alderdice et al. 1979), herring from the Northwest Atlantic are known to spawn only in water of 32 to 33 ppt (Hildebrand 1963).

Oxygen

Probably because oxygen is rarely a limiting factor in the marine environment, studies on oxygen-related effects on herring are scarce. DeSilva and Tytler (1973, cited in Blaxter and Hunter 1982) reported that larval 96 h LD_{50} at 10 °C ranged from about 1.9 to 3.6 mg/l. Braum (1973) reported low hatching success for herring eggs held in water with dissolved oxygen below 20% saturation. Larvae 3 to 4 days old died in 6 h at 11.6% oxygen saturation (Bishai 1960).

Sediments and Turbidity

A proposal to dredge a channel 35 nautical miles long in Miramichi Bay, New Brunswick, an important herring fishing ground, prompted Messieh et al. (1981) to investigate the effects of suspended silt and clay sediments on early life stages of Atlantic herring. Normal suspended sediment concentrations of less than 20 mg/l were expected to be replaced by concentrations of up to 2,000 mg/l during dredging and dumping. Experiments conducted by Messieh et al. found 100% mortality in eggs covered with 1 cm of sediment and 85% mortality in eyed eggs covered with only a thin film of sediment. These tests indicate that at least a portion of the egg must be exposed free of sediment if the egg is to survive.

Though hatching success apparently was not affected by suspended sediment concentration or egg density, larvae hatching at low sediment concentrations (0-540 mg/l) tended to be larger. High egg density tends to cause premature hatching and larvae at hatching were smallest when egg densities were high, regardless of sediment concentration. Messieh et al. (1981) noted no deleterious effects of suspended sediments on hatching success at any sediment concentrations up to 7,000 mg/l. Hatched larvae suffered 100% mortality after 48 h at 19,000 mg/l.

Tests indicated that juvenile Atlantic herring avoided suspended sediment concentrations between 9.5 and 12 mg/l; some juveniles avoided concentrations as low as 2.5 mg/l. In feeding experiments, the number of larval herring feeding at any one time was significantly reduced at suspended sediment concentrations greater than 3.0 mg/l (Messieh et al. 1981).

Water Movement

Water currents are important to Atlantic herring in the Gulf of Maine and on Georges Bank because they transport and entrain larvae and plankton into estuaries and coastal areas during autumn and winter. The net alongshore drift carrying larvae in the Gulf of Maine is principally shoreward from east to west (Graham 1970). Larvae migrate vertically in the water column to take advantage of landward tidal currents (Graham 1972).

Adequate water exchange is an important environmental requirement for herring spawning grounds. Sindermann (1979) reported that a current velocity of at least 0.27 to 0.52 m/sec must be present; Caddy and Iles (1973) observed bottom currents of 0.5 to 1.0 m/sec on a Georges Bank spawning area.

Environmental Contaminants

The effects of copper on eggs and larvae of Atlantic herring were reported by Blaxter (1977). Mortality of newly hatched larvae was high at copper concentrations of 1,000 micrograms per liter. Eggs incubated in 30 µg/l during incubation had relatively high mortality and premature hatching; 70% of the larvae hatched were deformed. Larvae were more resistant to copper than eggs; survival of larvae was impaired only at concentrations of $\geq$ 1,000 µg/l. The vertical migration of larvae was impaired at copper concentrations of $\geq$ 300 µg/l.

Tests on the effects of sulfuric pollutants ($FeSO_4$ and H_2SO_4) showed that a dilution of 1:8,000 significantly reduced egg fertilization and hatching success, decreased egg diameter, retarded embryonic growth, shortened the incubation period, and increased the rate of structural abnormalities in newly hatched larvae (Kinne and Rosenthal 1967). Larval prey-catching ability was impaired in

1:32,000 and 1:24,000 dilutions; locomotory performance was seriously affected at a 1:16,000 dilution; and paralysis, shrinkage, permanent deformities, and death occurred within a few days at 1:8,000 dilution.

Studies of dinitrophenol effects on herring embryonic development indicated that low concentrations (0.01 to 0.05 µmol/l) increased embryo activity and altered heart rates significantly (Rosenthal and Stelzer 1970). Various embryonic malformations were also observed. A dinitrophenol concentration of 0.1 µmol/l caused an up to 400% increase in the normal embryonic respiration rate (Stelzer et al. 1971).

Blaxter and Hunter (1982) reported that eggs and larvae held under films of crude oil in concentrations of 1 to 20 ml/l, or in emulsions, experienced toxicities that varied with the origin of the oil. For oil from a particular source, the fractions with the lower boiling points seemed more harmful (Kuhnhold 1969). In tests on oil dispersants, larvae did not avoid horizontal gradients, but swam into surface dispersant layers and were narcotized (Wilson 1974). The survival of herring eggs and larvae was highest in water with low biological oxygen demand and low nitrate levels (Baxter and Steele 1973).

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15. Supplementary Notes

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the morphology, range, life history, and environmental requirements of coastal aquatic species of animals. They are designed to assist in environmental impact assessment. Atlantic herring (Clupea harengus) spawn offshore, depositing sheets of eggs on the bottom. They usually spawn in late summer or in fall. Fecundity of Atlantic herring in the Gulf of Maine ranged from 33,000 to 185,000 eggs/female. After spawning, adults usually migrate to warmer areas to overwinter. All life stages feed on zooplankton. Adult herring reach their peak weight in August or September. The Atlantic herring supports a major fishery in Massachusetts and Maine; the average annual value of Maine landings was $4.3 million for 1976-82. Atlantic herring are significant in the diet of many predators. For juvenile herring, the lower level of salinity tolerance is about 5 ppt; older herring probably prefer higher salinities, and spawning occurs only at 32-33 ppt. Sediment deposition may cause egg mortality. Copper concentrations of $\geq$1,000 mg/l and sulfuric acid and ferrous sulfate at dilutions of $\geq$1:8,000 cause heavy larval mortality.

17. Document Analysis a. Descriptors

Estuaries	Life cycles	Fisheries
Fishes	Temperature	Sediment
Growth	Salinity	Contaminants
Feeding habits		

b. Identifiers/Open-Ended Terms

Atlantic herring
Clupea harengus
Spawning
Habitat requirements

c. COSATI Field/Group

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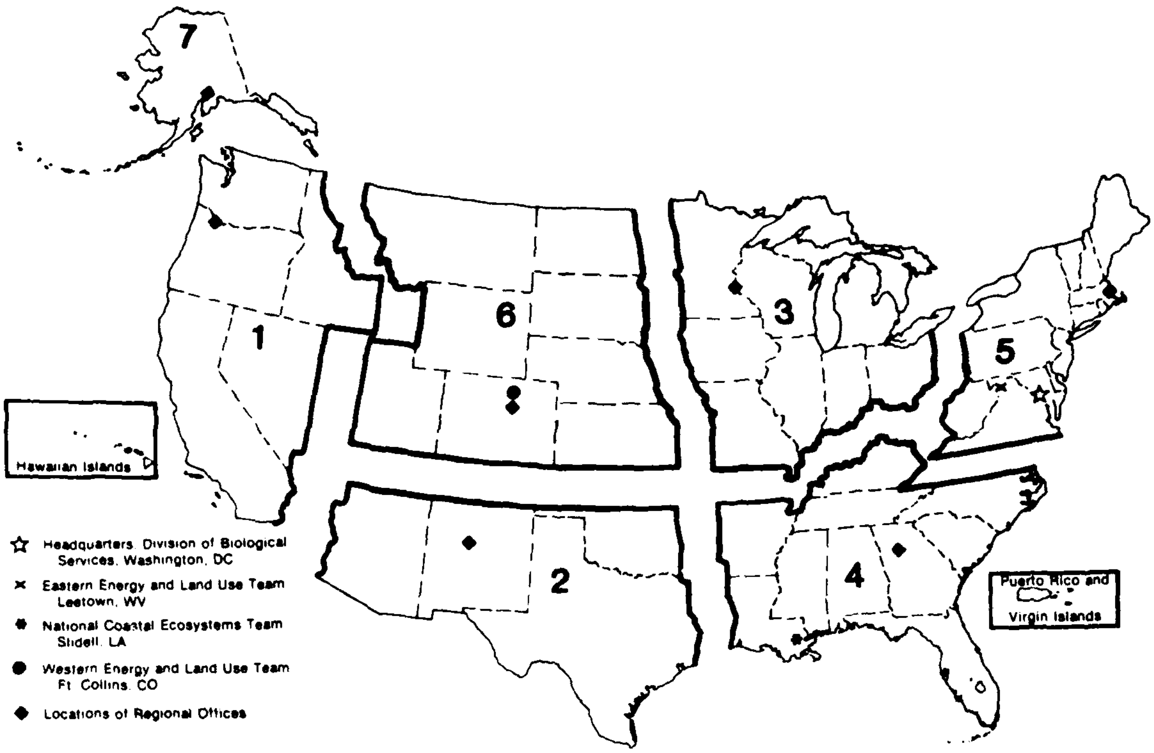

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