NBP-92-79

Alewife (*Alosa pseudoharengus*) Species Profile 45 pp

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Narragansett Bay Estuary Program

ALEWIFE (Alosa pseudoharengus) SPECIES PROFILE

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NBP-92-79

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FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 , and the Narragansett Bay Project (NBP) was established in 1985. Narragansett Bay was designated an "estuary of national significance" in 1988. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a program of research and planning focussed on managing Narragansett Bay and its resources for future generations.

The NBP will develop a draft Comprehensive Conservation and Management Plan (CCMP) by December, 1991, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- management of fisheries
- nutrients and potential for eutrophication
- impacts of toxic contaminants
- health and abundance of living resources
- health risk to consumers of contaminated seafood
- land-based impacts on water quality
- recreational uses

The NBP is taking an ecosystem/watershed approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among federal, state and local agencies, as well as with academic researchers, in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. Funding was provided by the State of Rhode Island as part of Cooperative Agreement #CX812768 with the United States Environmental Protection Agency with an additional award provided by the National Marine Fisheries Service. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication as a technical report by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

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EXECUTIVE SUMMARY

This alewife profile is the fifth document in a series intended to provide background necessary for cooperative management of important finfish species occurring in Rhode Island waters.

This review of the biology of alewife, Alosa pseudoharengus, includes nomenclature, taxonomy, stock description, range, abundance in Rhode Island waters, life history habitat requirements, migration and movements. Also, included are information on reproduction, growth and development, food and feeding, predators, competitors, disease and parasites. In addition to the commercial and recreational value of the fishery a summary of Rhode Island regulations is also included.

The term "river herring" is collectively applied to both alewife and blueback herring (Alosa aestivalis) throughout their range along the east coast of the United States (U.S.). The river herring fishery is one of the oldest in North America and was exclusively a U.S. inshore fishery until the late 1960's when distant water fleets began fishing for river herring off the Mid-Atlantic coast. Fishing pressure on river herring has eased considerably since the foreign catch was restricted in 1976, although recovery to historic levels is not evident in any river system.

The alewife, which ranges from South Carolina to Newfoundland, Canada, spawns in rivers during the spring. Adults migrate upstream and spawn in ponds, lakes and slow-flowing rivers at water temperatures between 12-16°C. Alewives return to their natal river to spawn where the young remain in freshwater before migrating downstream during summer and autumn, and generally spend 2 to 4 years at sea until sexual maturity. Alewives are a schooling fish, dispersing only under the influence of violent stimuli such as the presence of predators and they will reassemble after this disturbance.

Species Profile: Alewife
<u>Alosa pseudoharengus</u>

Common Name: Alewife
Scientific Name: <u>Alosa pseudoharengus</u>
Author: Wilson 1811

Other Common Names: Gaspereau, sawbelly, kyak, branch herring, fresh-water herring, grayback (Bigelow and Schroeder 1953); spreau, kiack, river herring, glut herring (Scott and Scott 1988).

Classification:

Phylum:	Chordata
Subphylum:	Vertebrata
Class:	Osteichthyes
Order:	Clupeiformes
Family:	Clupeidae
Genus:	<u>Alosa</u>
Species:	<u>pseudoharengus</u>

VALUE

<u>Commercial</u>:

The term "river herring" is collectively applied to both alewife and blueback herring (<u>Alosa aestivalis</u>) throughout their range along the east coast of the United States (U.S.). This is based on the anadromous nature of both of these species (Richkus and DiNardo 1984). The river herring fishery is one of the oldest in North America and was exclusively a U.S. inshore fishery until the late 1960's when distant water fleets began fishing for river herring off the Mid-Atlantic coast (NMFS 1989). Fishing pressure on river herring has eased considerably since the foreign catch was restricted in 1976, although recovery to historic levels is not evident in any river systems (NMFS 1989). River herring stocks in several rivers along the east coast are still being exploited above optimal levels (NMFS 1991). Alewife historical catch statistics for New England (ME,NH,RI,CT) are presented in Figure 1. River herring fisheries in Massachusetts are distinct, in that towns control the fisheries on most of the major drainage systems. Landings in Massachusetts have fluctuated widely in the past 20 years, with the 1980 harvests the lowest reported (Richkus and DiNardo 1984). North Carolina, Virginia and Maine are the only states with substantial commercial fisheries accounting for approximately 90 percent (%) of total landings (NMFS 1991). Rhode Island commercial alewife landings are presented in Figure 2.

Total U.S. landings of river herring varied without trend (40-65 million pounds (LBS)) from 1950-1970 (Figure 3), but declined steadily thereafter to less than 12 million LBS by 1980 following a dramatic rise in foreign fleet landings (14-80 million LBS) from offshore waters during the late 1960's. Due to intensive quota management in the mid-1970's, the magnitude of foreign fleet landings of river herring was reduced to < 4,000 pounds annually by 1980. Despite conservation measures, total river herring landings from US fishermen during the mid-1980's remained well below the pre-1970's levels (Crecco and Gibson 1990).

A review of foreign mackerel fisheries in the mid-Atlantic Exclusive Economic Zone (EEZ) waters demonstrated that river herring are a bycatch of this fishery (ASMFC 1990; unpublished). Although present in the mackerel fishery, the river herring bycatch was less than 0.5 % of the total mackerel catch and subsequently did not appear to adversely impact the depressed alosid stocks of the Mid-Atlantic (ASMFC 1990;unpublished). Concerns remain that EEZ harvest of river herring may slow the recovery of depressed stocks in the Chesapeake and waters to the south (ASMFC 1990; unpublished). Bycatch of river herring in foreign directed fisheries is managed under the Mid-Atlantic Fishery Management Council's Squid, Mackerel and Butterfish Fishery Management Plan (FMP) (NMFS 1991).

River herring are caught primarily with pound nets which retain fish age 3 and older (Loesch et al. 1982a), and are also caught in weirs, traps, gill nets and dip nets (Scott & Scott 1988). Historically the commerical fishery occurs during the spring spawning runs (Fay et al. 1983; Scott and Scott 1988).

The majority of the U.S. landings are used for fish meal and fish oil that is added to fertilizer, pet food and domestic animal feed (Fay et al. 1983). Alewives may be marketed for human consumption, fresh, frozen, smoked, and salted or pickled. Alewives are also used as bait in the lobster and snow crab fisheries (Scott & Scott 1988).

<u>Recreational</u>:

According to NMFS (1989) recreational fishing for alewives is significant, but no estimates of landings are available. Individual total numbers and weights for alewives caught in the recreational fishery are unknown, because they are combined with the shads, menhadens, herrings, sardines and the false pilchard (NMFS 1991b).

An estimated total catch in numbers of "herrings" landed by recreational fishermen averaged 10,563,000 from 1984-1988 NMFS 1991). Apparently most of the recreational catch is used as bait for other sportfish (NMFS 1991b). Alewives are caught by dip net and hook and line (Fay et al. 1983; Richkus and Dinardo 1984).

STOCK DESCRIPTION

A determination of stock mixing and migratory routes is not possible, because no tagging studies have been conducted comparable with those on other anadromous species (Merriman 1941;Raney et al. 1954; Talbot and Sykes 1958; Chapoton and Sykes 1961; Leggett and Whitney 1972--cited in Neves 1981).

RANGE

Overall:

The alewife occurs only in the northwest Atlantic and tributary fresh waters (Scott and Scott 1988). In the Atlantic Ocean the alewife can be found from Paquet, northeastern Newfoundland (Winters et al. 1973), southward in the Gulf of St. Lawrence, the outer coast of Nova Scotia, Bay of Fundy, and along the Gulf of Maine to South Carolina (Burgess 1978; Scott and Scott 1988). In fresh water, alewife occurs inland throughout the Great Lakes, St. Lawrence River system, Finger Lakes and many other freshwater landlocked areas (Bigelow and Schroeder 1953; Scott and Scott 1988; Fay et al. 1983).

Within Narragansett Bay:

Alewives utilize Narragansett Bay and its tributaries, and Mt. Hope Bay and its tributaries during their spawning migration (Lynch pers. comm. 1991).

ABUNDANCE IN RHODE ISLAND WATERS

Ichthyoplankton collections conducted in the Providence and Seekonk Rivers from March through June 1989 found that alewife eggs were abundant in the May samples (New England Power Company 1990).

Alewife ranked number 1 (35%) in percent contribution for fish impinged on the Brayton Point Unit 1,2,3 screens in Mt. Hope Bay from August-October 1990 (Figure 3) (MRI 1991). Nearshore finfish populations in Mt. Hope Bay were sampled annually from 1972-1990 with a 60-foot (ft.) and 300 ft. beach seine (MRI 1991). Alewives were scarce in both nets in 1990 with only one fish collected in each net. MRI (1991) concluded that for the small seine, low catches were not uncommon since alewives were absent in eight of the 19 years in which sampling occurred. Also, the overall 1990 mean catch/haul was .04 (60 ft. net) and .08 (300 ft. net) which compared with the 18 year means of 4.8 and 17.7 respectively. Mean number of alewives per beach seine haul with 60-ft. and 300 ft. nets from 1972-1990 are presented in Figure 4 (MRI 1991).

Juvenile alewife seasonal abundance and distribution in Narragansett Bay has been monitored by beach seine annually at 15 stations since 1986 by the R.I. Division of Fish and Wildlife (Figure 5) with an additional sample site at Dyer Island added in 1990. Since 1986 juvenile alewives have been collected at all stations except 8 and 12 (Powell

1991). Powell (1991) found that while abundance was limited both spatially and temporally, there were similarities to previous years. Juvenile alewives were most abundant at Third Beach, Patience Is., Conimicut Pt. and Pojac Pt. respectively. He concluded that for anadromous clupeids this may be in part due to the fact that these stations are located near tributaries having documented or historical herring runs.

Lynch (1990;in press) indicates that indices of abundance (mean kilogram (kg) and mean number per tow) have fluctuated since 1979, and are most reflective of seasonal occurrence (Figure 7). The onset of spring warming and increased light intensity combine to trigger upstream miagrations of alewives (Cooper 1961; Richkus 1974; Lynch et al. 1976; unpublished). Spring abundance and temperatures are provided in Figures 8 and 9, respectively (Lynch 1990; in press). Alewife length frequencies are shown in Figure 10 (Lynch 1990; in press).

Seasonal occurrence is reflective of survey area preference and water temperature associated with the annual spawning cycle (Figure 6 & 7). A length frequency histogram is provided in Figure 8, and suggests that spring occurrence is dominated by 2+ year old fish. Annual mean length are provided in Figure 9.

Juvenile alewives were present in Quonochontaug Pond, Winnapaug (Brightman's) Pond, Charlestown and Green Hill Pond while adult alewives were found in Charlestown and Green Hill Ponds (Satchwill and Sisson 1990; Sisson and Satchwill 1990; Sisson and Satchwill 1991).

In Rhode Island anadromous fish restoration beginning with alewives was initiated in 1965 with the passage of the Anadromous Fish Act-PL 89-304 and since that time, a number of extirpated runs have been restored through fishway construction and the transplantation of pre-spawned adults (Gibson 1987b). Alewives were stocked into Brickyard Pond, Gilbert Stuart Pond, Potowomut Pond, Nonquit Pond and Burlingame Reservoir (Gibson 1991) to increase spawning biomass in weak alewife runs. A total of 14,500 alewives and blueback herring were transplanted from Massachusetts to Rhode Island streams (Gibson 1991).

A total of 11,009 alewives were estimated during their upstream migration in Gilbert Stuart Brook, the smallest run since observations began in 1980 (Gibson 1991). The average population size since 1980 has been 62,178 (SE=6,676) fish (Gibson 1991). Gibson (1991) inferred that no upward or downward trend in population size is statistically evident although the low return in 1990 is of concern. Gibson (1991) also monitored juvenile emigration from Gilbert Stuart Brook and found the mean catch per trap hour was 152.3 (SE=71.3) from July through October.

Alewives were also sampled from the Pawcatuck River and the Annaquatucket River, but analysis of these runs was limited to age frequency and mortality rate comparisons (Gibson 1991). Since 1989, 127 trips have been made to 20 known or suspected alewife runs from March to May (Gibson 1991). Of these sites, 13 or 65% were observed to have evidence of alewives at least once in 1989-1990. A summary of the suspected alewife runs is found in Table 1. Six populations were classified as active (> 50% positive, P. .50) and seven were classified as remnant (P< .50). Seven other sites had no evidence of alewives at all (P=0) (Gibson 1991).

LIFE HISTORY

The alewife, which ranges from South Carolina to Newfoundland, Canada, spawns in rivers during the spring. Spawning runs occur in a chronological south to north progression (Neves 1981). Adults migrate upstream and spawn in ponds, lakes and slow-flowing rivers at water temperatures between 12-16°C (53.6-60.8°F) (Bigelow and Schroeder 1953). Alewives return home to their natal river to spawn (Bigelow and Schroeder 1953; Thunberg 1968) where the young remain in freshwater before migrating downstream during summer and autumn, and generally spend 2 to 4 years at sea, until sexual maturity (Neves 1981). Alewives are light sensitive and tend to be in greater depths during daylight hours. Alewives are a schooling fish, dispersing only under the influence of violent stimuli such as presence of predators and they will reassemble after this disturbance (Cooper 1961).

Specific information on the marine phase of the alewife's life history is lacking (Neves 1981).

HABITAT REQUIREMENTS

Type/Substrate:

Eggs and larvae:

Alewife eggs adhere to brush, stones, sand or whatever other substrate material is present at spawning (Cooper 1961).

Juveniles:

Young-of-year fish spend part or all of their first summer in the nursery area before migrating to the sea, where they grow to maturity (Durbin 1976).

Adults:

The alewife lives most of its adult life at sea, entering fresh water only to spawn (Bigelow and Schroeder 1953; Cooper 1961; Scott and Scott 1988). When at sea the alewife frequents coastal waters and is captured most often at depths of 56-110 meters (183-361 feet) (Scott and Scott 1988).

Temperature/Salinity:

Eggs/larvae:

Alewife eggs were incubated at seven constant temperatures ranging from 12.7-29.7°C (54.9-85.5°F) with maximum hatching success occurring at 20.8°C (69.4°F) (Kellogg 1982). Hatching success fell significantly when the eggs were incubated at 26.7-26.8°C (80.1-80.2°F) and no hatch occurring at 29.7°C (85.5°F). The upper tolerance limit of larvae acclimated to 14-15°C (57.2-59°F) and exposed to elevated temperatures for 24 hours was about 31°C (87.8°F) (Kellogg 1982).

Growth rates for larvae reared in freshwater were similar at temperatures ranging to 23.7°C (74.7°F), but at 26.4°C (79.5°F) growth rates were considerably lower for larvae reared in fresh water than for those reared in water adjusted to a salinity of 1.0-1.3 o/oo (Kellogg 1982). The highest growth rates occurred at 29.1°C (84.4°F) in the low salinity tanks, with no larvae surviving beyond 10 days at this temperature in the freshwater tank. However, mean total lengths of 5 larvae removed from each tank on the 6th day of the test indicated that the highest growth rates at that time occurred at 29.1°C (84.4°F) in both fresh and low-salinity water (Kellogg 1982). Also, the average length of larvae at the end of 6 days in freshwater was greater than that of larvae reared in low-salinity tanks at 29.1°C (84.4°F)

Juveniles:

Laboratory tests found the preferred temperatures of juvenile alewives ranged from 20-22°C (68-71.6°F) at salinities of 4-6 o/oo, with acclimation temperatures of 15-21°C (59-69.8°F) (Meldrim and Gift 1971). Juveniles as small as 25 mm Standard Length (SL) were tolerant of salinity changes of 0 to 32 parts per thousand (o/oo) (Richkus 1974).

Adults:

The ultimate upper incipient lethal temperature found by McCauley and Binkowski (1982) is in the range 31-34°C (87.8-93.2°F). They found adult alewives to have a higher thermal tolerance than reported in two previous studies by Graham (1956) and Otto et al. (1976) and based this on acclimation temperature (Figure 10).

A nonstressed alewife can efficiently osmoregulate in both fresh and sea water (Stanley and Colby 1971). Stanley and Colby (1971) studied the effects of temperature and salinity on ionoregulation in the alewife, and reported that concentrations of sodium, potassium and calcium in plasma and muscle were similar in fish adapted to fresh water and those adapted to sea water. These investigators found that acute exposure to cold caused a shift in plasma concentrations of sodium and calcium toward environmental conditions, i.e., these ions decreased in fresh water and increased sea water. Also, high temperatures had little effect on plasma electrolyte levels in fresh water whereas in sea water the concentrations of sodium, potassium and calcium were elevated. In muscle, sodium was reduced during exposure to acute cold in both fresh and sea water, with the effect of warm water on ion levels generally opposite that of cold. They found that salinity does not modify the capacity of alewives to tolerate acute temperature stress.

MIGRATION AND MOVEMENTS

River herring are widely distributed along the Middle Atlantic Bight during spring and appear to move north in the Nantucket Shoals, Georges Bank and coastal Gulf of Maine areas during summer and early autumn, and then return south to the mid-Atlantic coast in winter and early spring (Figure 11) (Neves 1981). The extent of overwintering in deep water off the continental shelf in unknown (Neves 1981).

Each spring the anadromous alewife, leaves the sea and begins it annual spawning migration into fresh water streams and ponds of the Atlantic coast from South Carolina to Newfoundland (Durbin 1976). Seaward migration of juveniles from the nursery grounds takes place during daylight hours (Cooper 1961). According to Cooper (1961) when a school of juveniles reaches a dam, it will move back and forth until the school becomes more dense, then it will allow the current to sweep them through the opening. The school retains its identity into brackish water (Cooper 1961). Extensive emigration occurred following increases in pond volume outflow, abrupt water temperature declines and/or precipitation (Richkus 1974).

Trawl catches indicated diel migratory activities by Young-of-Year (YOY) alewives, with bottom catches significantly greater during the day than at night; conversely, surface catches were significantly greater during the night than daytime (Loesch 1987).

REPRODUCTION

Mode:

The act of spawning is accomplished in groups of three or in pairs, with one or two males swimming side by side with the female (Cooper 1961). According to MacKenzie (1959) spawning alewives are often seen swimming rapidly counter-clockwise in a circle 3 to 6 feet wide, and in seconds the nuptial dance or swim ends in a "big splash". The eggs and sperm are extruded simultaneously with fertilization being external (Cooper 1961). Spawning occurs at all times of the day with no noticeable difference in intensity (Cooper 1961). An analysis of juvenile lengths and adult data indicate that wave spawning occurs in alewives and this maybe an adaptive strategy to insure reproductive success (Gibson 1989). Eight cases of hermaphroditism have been documented in literature by Edsall and Saxon (1968), Rothschild (1966) and Hlavek and Norden (1977)

Spawning Factors:

The alewife selects freshwater lentic (slow flowing or standing water) sites for spawning such as ponds, including those of barrier beaches, sluggish streams, and lakes then returns to the sea after spawning (Bigelow and Schroeder 1953; Cooper 1961; Richkus 1974; Loesch 1987). Alewives favor shore-bank eddies or deep pools for spawning (Loesch 1987). Spawning usually occurs over a detritus covered bottom composed of attached vegetation, sticks or other organic matter and occasionally over a hard sand bottom (Cooper 1961). Alewife will also occupy new systems or increase in abundance within systems when changes in physical or hydrological conditions permit or enhance entry (Loesch 1987). Alewives leaving the spawning grounds are thin and emaciated (Cooper 1961; Kissil 1974; Richkus 1974).

Cooper (1961) found that spawning occurred at all time of the day with no noticeable difference in intensity, although Graham (1956) and Edsall (1964) found the greatest activity apparently is at night. Spawning usually commences when water temperatures are 5.0-15.5°C (41-60.0°F) (Bigelow and Schroeder 1953; Kissil 1974; Lynch et al. 1976; Loesch 1987) and terminates at 21.6-27.8°C (70.8-82.04°F) (Edsall 1970; Lynch et al. 1976).

In Gilbert Stuart Brook, R.I., the spawning run began on 17 MARCH 1990 at a temperature of 11°C (51.8°F), with peak movement (based on visual counts) on 11 APRIL 1990 at 11°C (51.8°F) and terminated on 12 MAY 1990 at 18°C (64.4°F) (Gibson 1991). A summary of run chronologies and associated temperatures appears in Table 2.

Reproductive Capacity:

Fecundity of river herring is related to age, size and latitude, but is highly variable (Street 1969; Scherer 1972; Loesch and Lund 1977; PSEG 1984-cited in Loesch 1987). The maximal alewife fecundity occurs between the ages of 5 and 7, and then declines for older fish (Mayo 1974; Huber 1978--cited in Loesch 1987).

Estimates of fecundity for anadromous alewives range from about 100,00-467,00 eggs (PSEG 1984--cited in Loesch 1987). Female alewives in Bride Lake, CT., spawned 48,000-360,000 eggs each with an average of 229,000 (Kissil 1974). According to Foerster and Goodbred (1978) a landlocked but resident population in upper Chesapeake Bay produced only 60,000-100,000 eggs per mature female.

Rhode Island Spawning Season/Location:

Alewives are the dominant (≥ 90%) river herring species in New England (except in the upper Connecticut River) since they spawn in freshwater ponds which form the headwaters of most coastal streams in New England (Loesch 1987). In the mid-Atlantic and lower New England states, alewives commence spawning in late March or early April (Bigelow and Schroeder 1953;Cooper 1961; Saila et al. 1972; Richkus 1974; Lynch et al. 1976; Gibson 1985).

In Rhode Island alewives first begin spawning at age 2 for males and age 3 for females (Gibson 1985). Gibson (1991) found that repeat spawners comprised 50% of the 1990 sample, with females having a greater incidence of repeat spawning than males (66.7% vs. 35%) and since 1984 repeat spawners have made up 38.9% (SE=.56) of all fish sampled. Table 3 contains a summary of the spawning history of the fish sampled in 1990.

First spawning by river herring occurs from ages 3 to 6, with most virgin spawners dominated by 4 year old fish

(Loesch 1987). In general, spawning stocks of river herring are made up of 3 to 8 yeard old fish. Males tend to dominate age classes 3 to 5 with females living longer dominated the older age classes. Recruitment to the mature populoation by both species is virtually complete by age 5 (Loesch 1987).

GROWTH AND DEVELOPMENT

Egg:

Before the eggs of the alewife are water-hardened, they are demersal in still water and adhesive or pelagic in running water (Loesch and Lund 1977). After water-hardening (less than 24 hr) the eggs lose their adhesive property and enter the water column (Loesch and Lund 1977).

Unfertilized eggs are green and contain uneven spheres with thin transparent capsules (Jones et al. 1978), yolk is granular and dark amber in color and contain no oil globules (Lippson and Moran 1974). Diameter ranges from 0.80-0.95 mm with yolk diameter ranging from 0.07-0.85 mm (Lippson and Moran 1974; Jones et al. 1978).

Fertilized eggs are pink in color (Cooper 1961) with diameters ranging from 0.95-1.27 mm (Lippson and Moran 1974; Jones et al. 1978). Egg capsule is slightly rippled and transparent, with the yolk being granular and bright translucent amber to pale yellow in color, and lacks oil globules (Lippson and Moran 1974; Jones et al. 1978).

The average time to median hatch varied inversely with temperature, ranging from 7 days at 12.7°C (54.9°F) to 3 days at 23.8-23.9°C (74.8-75°F) and 26.7-26.8°C (80.1-80.2°F) (Kellogg 1982).

Embryonic Stages:

The following description of embryonic stages is given by Jones et al. (1978) at an average temperature of 20°C (68°F):

45 minutes	blastodiscs
1-3 hours	2 and 4 cell stages
3 hours	16 and 32 cell stages
4½ hours	32-cell, 64-cell and morula stages
11 hours	gastula; blastodermal tissue around ½ of yolk; yolk granulations less distinct
12-15 hours	blastophore formed; yolk paler; less granular.
Ca. 24 hours	blastophore closed; embryo differentiated; yolk no longer granular
65 hours	tail free; eyes, lenses, auditory vesicles and 28 myomeres formed
113 hours	heart, otoliths, pectoral buds, finfold, intestine, and vent formed; brown chromatophores over ventral 2/3 of yolk, sparsely scattered over eye

and in a line along ventral surface of gut; tail completely formed around yolk.

Hatching length 2.5-5.0 mm Total Length (TL) with the average size at the end of stage 5.1 mm TL. Maximum size at end of stage 5.8-6.0 mm TL with duration of stage 2-5 days (Jones et al. 1978).

Yolk-Sac Larvae Development:

Jones et al. (1978) described the following for alewives from yolk-sac larval development to larval development.

Recently hatched larvae have 37-41 preanal myomeres; at 3.3-3.5 mm TL postanal myomeres number 7-8. The following proportions are expressed as percent TL at hatching: Head-11.1; snout to vent-79.8. The following proportions are expressed as percent Head Length (HL): Eye-37.1;preanal to postanal length ratio-4.1-5.1 to 1 at hatching, 3.2-3.8 to 1 by the end of the yolk-sac stage.

At day 1, pigment is reduced on yolk-sac and above mid-ventral line, with the eye completely pigmented and flecked with gold (Figure 12). Melanophores are fewer in number but more pronounced and in defined rows on upper and lower gut. Two days after hatching chromatophores are concentrated along posterior and ventral edges of the yolk sac. Two elongate chromatophores are below the pectoral fin, with sparse and small chromatophores from posterior to vent. Three days after hatching anterior yolk-sac melanophores form an elongate dash in the throat region along the ventral surface, with the upper gut melanophores appearing as a thin extended line .

Larval Development:

Jones et al. (1978) described the following for alewives from larval development to juvenile development.

Larval alewives range in size from 4.3-19.9 mm Standard Length (SL) (Figure 13 & 14). Caudal and pectorals are with or without incipient rays up to 5.4 mm. The number of myomeres present in larval alewives are summarized as follows:

LENGTH (SL)	NUMBER OF MYOMERES
Preanal	
4.0-5.9 mm	40-42 (usually 41)
6.0-13.9 mm	40-43 (usually 41)
14.0-14.9 mm	39-41
Between cleithrum and vent	
4.0-5.9 mm	39-40 (usually 39)
6.0-13.9 mm	38-41 (usually 39/40)
14.0-14.9 mm	35-39

Myomeres number from 7-9 ($\bar{x}$=8) between the insertion of dorsal fin and posterior margin of the vent. Predorsal myomeres number from 2[illegible]-27. Preanal to postanal length ratio at 6.7 mm TL is 3.5:1 and at 14.8 mm TL is 14.8 mm TL.

The larval alewife has a long, narrow body with the head being variable until around 6.0 mm when it become rounded and then flattened by the eighth day. The lower jaw is projected beyond the upper at 9.0 mm TL, also on the eight day. Notochord flexion occurs ca. 9 mm SL. The gut is straight at 9.0 mm TL and becomes striated between 10.4-15 mm. The preanal finfold is retained up to 16.5 mm.

Pigmentation for larval alewives is as follows: At 6.0 mm melanophores are in a row on the dorsal surface of the anterior half of the intestine and on the dorsal and ventral midline of tail near developing caudal. At eight days around 12 melanophores are along dorsal surface of anterior half of gut, with 22-24 melanophore on the ventral surface of posterior half of gut. Melanophores are scattered on lateral body wall and in the area behind the eye. At 9.0 mm TL melanophores on upper gut are more expanded, with caudal melanophores being more stellate and one large melanophore dorsal to pectoral fin insertion. At 10.4 mm TL melanophores along ventral surface between pectoral fins form an unjoined "V". At 12.1 mm TL pigmentation is increasing along upper and lower gut with small chromatophores reappearing above the lateral line. By 19.0 mm pigment has increased, particularly in gill area, otic region and on caudal fin. A dorsolateral row of chromatophores appears above the lateral line.

<u>Juvenile Development</u>:

Jones et al. (1978) described the following for alewives from juvenile development to adult development.

The minimum size described for juvenile alewives is 19.1 mm TL (Figure 15). At 19.1-32.2 mm TL teeth are on the maxilla, premaxilla and dentary. The number and location of myomeres in alewives at 19.1-32.2 mm TL are summarized as follows:

LOCATION	NUMBER OF MYOMERES
preanal	33-42
postanal	9-14
predorsal	15-23

The number of gill rakers present in juvenile alewives are as follows:

mm TL	NUMBER OF GILL RAKERS
30-49	25-33
50-69	32-36
70-89	30-39
90-109	35-38
110-129	36-40

At sizes over 35 mm TL the gill rakers are elongate and closely spaced. Scutes are sometimes evident at 22-25 mm TL and scales are first evident at 28-29 mm on side of the tail along the lateral line at about 43rd myomere. Body depth is 4 times in SL at 29 mm TL and by 100 mm body depth is adult-like with proportions expressed as percent SL at 23.5-35.5. At 32 mm the vent is located in the posterior 2/5 of body length.

Pigmentation at 19.1-32.2 mm TL bears increasing chromatophores on dorsolateral surface from head to caudal fin, with additional pigment on lower jaw, snout tip, top of head, caudal fin and dorsal margin of swim bladder.

Adult Development:

In both sexes, maturation is complete by age 6, i.e. no virgin spawners appear at age 7 (Gibson 1987a). Recruitment to the matured population is essentially completed by age 5 (Loesch 1987). Generally, 82-100% of male alewives and 60-95% of the females mature by age 4 (PSEG 1982,1984--cited in Loesch 1987). Gibson (1987a) disputed this because PSEG (1982,1984) reports cummulative virgin spawning frequency and viewed that each fish in an age group is examined to the number of times spawned previously, and he felt this was not strictly correct and more reflects maturation and mortality rates at earlier ages. Percent maturation is not the quantity being estimated by this method, but rather absolute numbers of virgin spawners at age which are a function of year class size at that time. Gibson (1987a) defined age-specific maturation rate as the fraction of immature fish of a given age which mature and join the spawning population. This definition allows both spawning and immature components to be treated seperately.

Mean lengths at age for male and female alewives from Gilbert Stuart Brook are found in Table 4. Mean lengths for females and males were 295.0 mm and 287.1 mm respectively. Age structure of the sample as determined by scale analysis was dominated by age V fish (59.4%). Males were younger than females with mean ages being 4.53 and 5.07 years respectively (Gibson 1991). A summary of age/length composition from 1980-1990 appears in Table 5. According to Gibson (1991) over the long term, age IV and V alewives have been the most abundant, comprising 71.5% of the samples.

FOOD AND FEEDING

In general, alewives are zooplanktivores, with the size range and diversity of available prey increasing as the fish grow and can accommodate larger items (Fay et al. 1983). Previous studies on food of adults during the National Marine Fisheries Service surveys indicate that alewives are vertical migrators, apparently following the diel movements of zooplankton in the water column (Neves 1981). In salt water, the food of the alewife consists mostly of small plankton forms, such as diatoms, algae, small crustaceans and other minute animals and plants (Belding 1921). Sea-run alewives do not feed while in fresh water (Durbin 1976).

Stomach contents of juvenile alewives from the Hamilton Reservoir, Rhode Island consisted of tendipedidae, ostracoda, cladocera and copepoda (Vigerstad and Cobb 1978).

Stone and Daborn (1987) found that amphipods, mysids, calanoid copepods and mereoplankton were the major forage items of alewives from Minas Basin, Nova Scotia. These investigators found that alewives favor a more benthic diet and have a broad food size spectrum as indicated by total food volume consumed consisting of benthic species such as amphipods, mysids and crangoids.

Stomach contents of alewife collected in the St. Lawrence at Cape Vincent contained nematods, cladocerans, copepods, ostracods, hydracarinas, amphipods, leptocerids, chironomids and fish (Ringler and Johnson 1982). These investigators found that alewives fed heavily on cladocerans, amphipods and copepods during July, with a small contribution by ostracods and the larvae and pupae of lectocerids and chironomids. In October amphipods become the most important food, followed by cladocerans and copepods. Also, ostracods disappeared from the diet, whereas fish, nematodes and water mites appeared in small quantities (Ringler and Johnson 1982).

Diet composition in relation to depth of capture for alewife showed they ate predominantly cladocerans at 5 meters and amphipods at 10 meters (Ringler and Johnson 1982). A study of feeding periodicity for alewife indicated that at 5 meters feeding activity increased after 2200 hours and reached a peak at 0600 hours, and at 10 meters peak feeding occurred at 2200 hours (Ringler and Johnson 1982).

Laboratory tests have shown that alewives exhibit three feeding modes: particulate feeding on individual prey (size selectivity highest), filter feeding with mouth wide open while swimming rapidly (size selectivity negligible) and consuming several prey at once but not at swimming speed of filter feeding mode (size selectivity moderate) (Janssen 1976).

PREDATORS

Table 6 summarizes the predators of the anadromous and landlocked alewife. Edsall (1964) and Kohler and Ney (1980) reported the cannibalism on egg, larvae and juvenile alewives by adult alewives.

COMPETITORS

Juvenile American shad in the Connecticut River grew slower below the Enfield Dam than upriver of it, and the slow growth was attributed primarily due to strong competition with juvenile alewives for food and space (Marcy 1976).

DISEASE/PARASITES

YOY alewives collected from the James and Chickahominy Rivers, VA were found to have kepone in concentrations > 0.3 ppm ("action level" for possible closure of the fishery) (Johnson et al. 1978; Loesch et al. 1982b). Kepone (concentrations < 0.3 ppm) was also found in young alewives from the Mattaponi and Pamunkey Rivers, VA but was not in detectable quantities in fish from the Rappahannock River, VA and the Potomac River, MD (Loesch et al. 1982b).

Three alewife with spinal deformities were taken in the Delaware River estuary from 1968 through 1981 (Howells and Miller 1983). Vertebral compression and spinal curvature as well as other related anomalies may occur due to natural or artificial causes such as heat shock, chlorine exposure, disease, dietary deficiencies and electric shock (Howells and Miller 1983). They felt that regardless of the origin of these anomalies, the low incidence of occurence as well as the absence of deformed embryos and larvae in plankton collections suggested that none of these potential causes affected the populations in Delaware River Estuary.

Females of Clavellisa cordata (Wilson) 1915, a parasitic copepod, were recovered from the gills of the alewife collected in the Miramichi River estuary, New Brunswick, in 1984 (Rubec and Hogans 1987). Predaceous cyclopoids (freshwater invertebrates) Acanthocyclops vernalis and Diacyclops thomasi(=Cyclops bicuspidatus thomasi) were found attached to alewife larvae (Hartig et al. 1982).

RHODE ISLAND ANADROMOUS FISH REGULATIONS

1. No person shall take from the fresh water streams and rivers of Rhode Island in any one twenty-four hour period more than twelve (12) alewives, unless she or he is in possession of a R.I. commercial lobster fishing license or a multi-purpose fishing license, and no person shall take any alewives from the defined freshwater streams and rivers without a valid R.I. freshwater fishing license.
2. A person in possession of a valid R.I. commercial lobster license or a multi-purpose fishing license and a freshwater fishing license may take in one twenty-four hour period one (1) bushel of alewives from a freshwater stream or river.
3. No person shall take alewives other than by bow net with a diameter of two and one half feet or less and held in and operated by hand, or by the use of a seine measuring eight by four feet or less.
4. No person shall place any artificial obstruction including lumber, stones, wires, or netting in any stream set aside for cultivation or in any way alter the natural stream bottom.
5. No person shall place a seine or netting more than half way across any stream or stream outflow or mouth.
6. The use of explosives of any type to aid in the taking of any fish in the above waters is prohibited.
7. Any person taking an alewife must remove it from the stream and keep it in their possession.

ALEWIFE REGULATIONS IN RHODE ISLAND

Licenses:	Fee:
Non-Commercial	
Resident(all persons age 15-65)	$ 9.50
Non-resident	$ 20.50
Non-resident Tourist(3-consecutive days)	$ 10.50
Commercial Fishing	
Fish Traps * (must be out of water 01Jan-28,29FEB)	
License	$100.00
Plus $10.00/trap	$ 10.00
Gill Nets	$100.00
Rod and Reel includes diving	$100.00
Individual (without boat)	$100.00
Commercial Vessels (finfish only)	
Commercial residents vessels*	
Up to 50' LOA	$100.00
50' to 99' LOA	$125.00
over 99' LOA	$ 10.00/ft.
Multiple purpose (good for all above)	$150.00
Plus $10.00 for a gill net license	$ 10.00
Non-resident otter trawler	$ 5.00/ft.

*** RESIDENTS ONLY**

Expiration of licenses:

Commercial licenses expire annually on December 31. (Rhode Island General Law 20-2-14).

Obtaining licenses:

All marine licenses are issued by the licensing section of the Department of Environmental Management, 22 Hayes St., Providence, R.I. 02908. Tel. No. 401-277-3576.

MANAGEMENT OF THE ALEWIFE FISHERY

Preparation of a Fishery Management Plan (FMP) for the anadromous alosids (American and hickory shad, alewife, blueback herring) of the East Coast of the United States was recommended by the Advisory Committee of the Atlantic States Marine Fisheries Committee of the Atlantic States Marine Fisheries Commission (ASMFC) and adopted by the Commission in 1981, in response to low current levels of commercial landings of all four species (ASMFC 1985).

The goal of the plan is to promote, in a coordinated coastwide manner, the protection, enhancement and restoration of Atlantic coast shad and river herring stocks (ASMFC 1990; unpublished). The plan's four objectives focus on harvest restrictions, improvement in habitat accessibility and quality, restoration and enhancement of existent and depleted alosid stocks respectively, and recommendations/support for research programs to provide data for management purposes (ASMFC 1990; unpublished).

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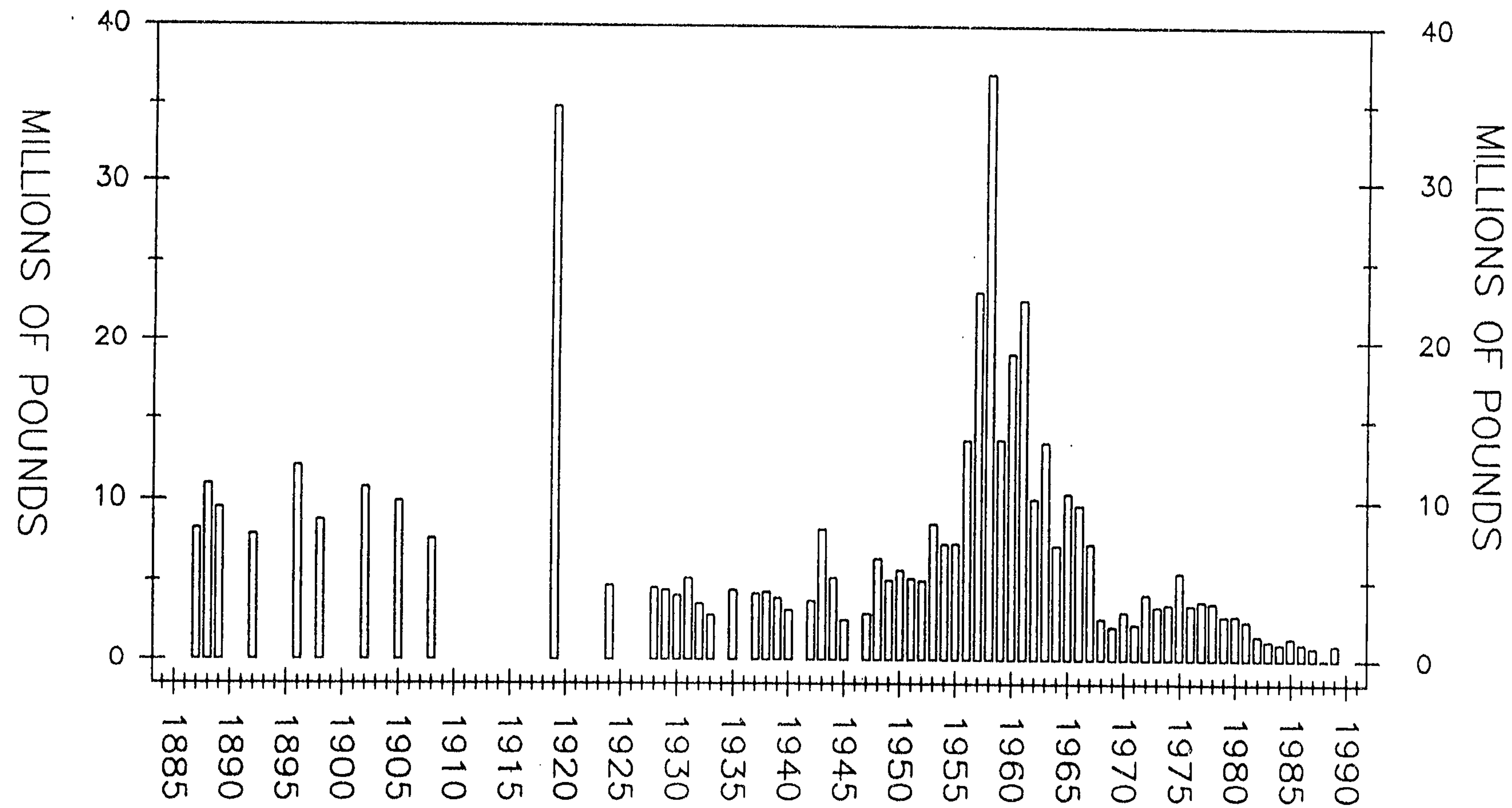
FIGURE 1

ALEWIFE HISTORICAL CATCH STATISTICS, NEW ENGLAND*

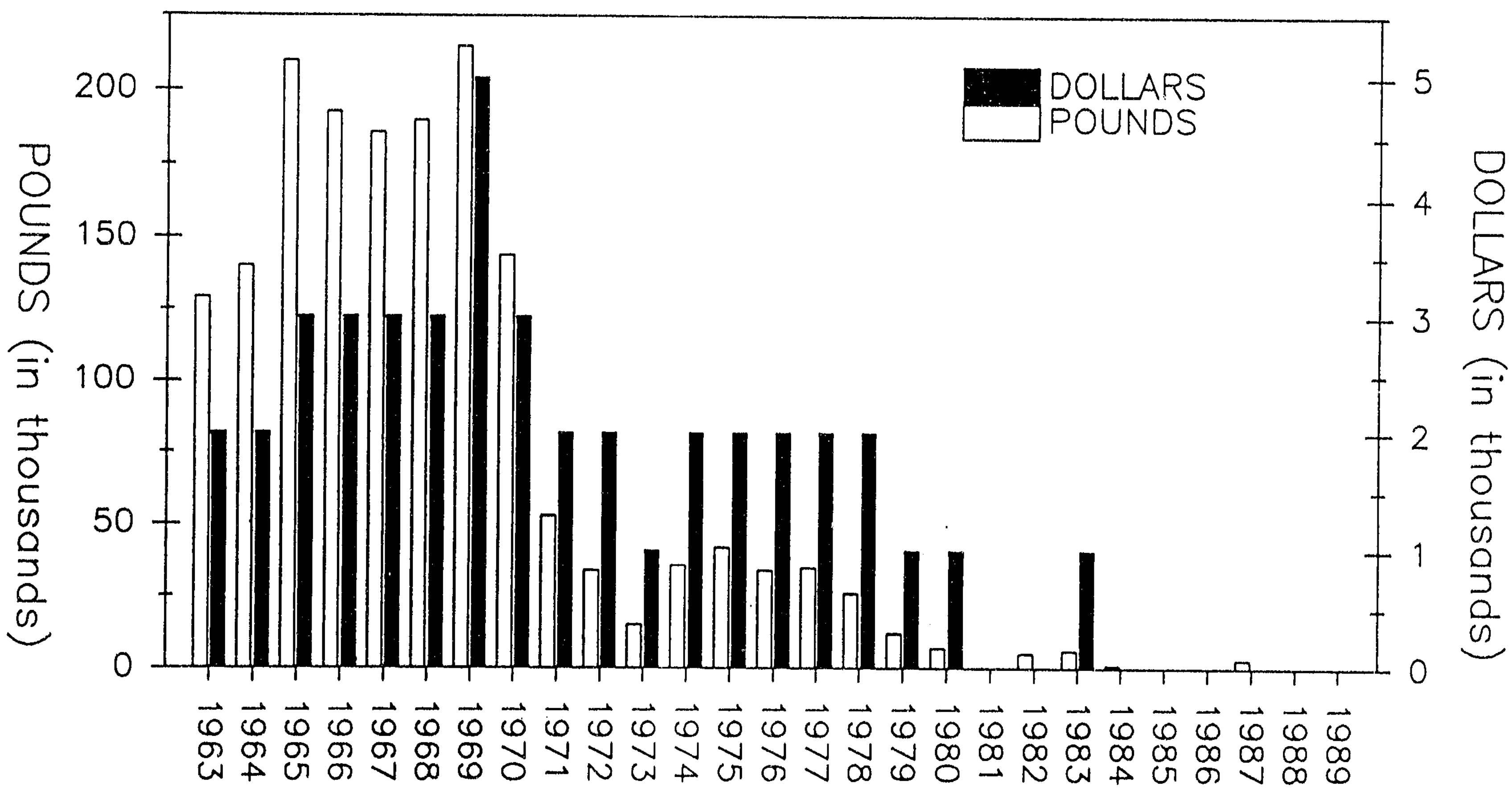


(Data Source: National Marine Fisheries Service Biostatistics Investigation, 1991)

* ME, NH, RI, CT

FIGURE 2

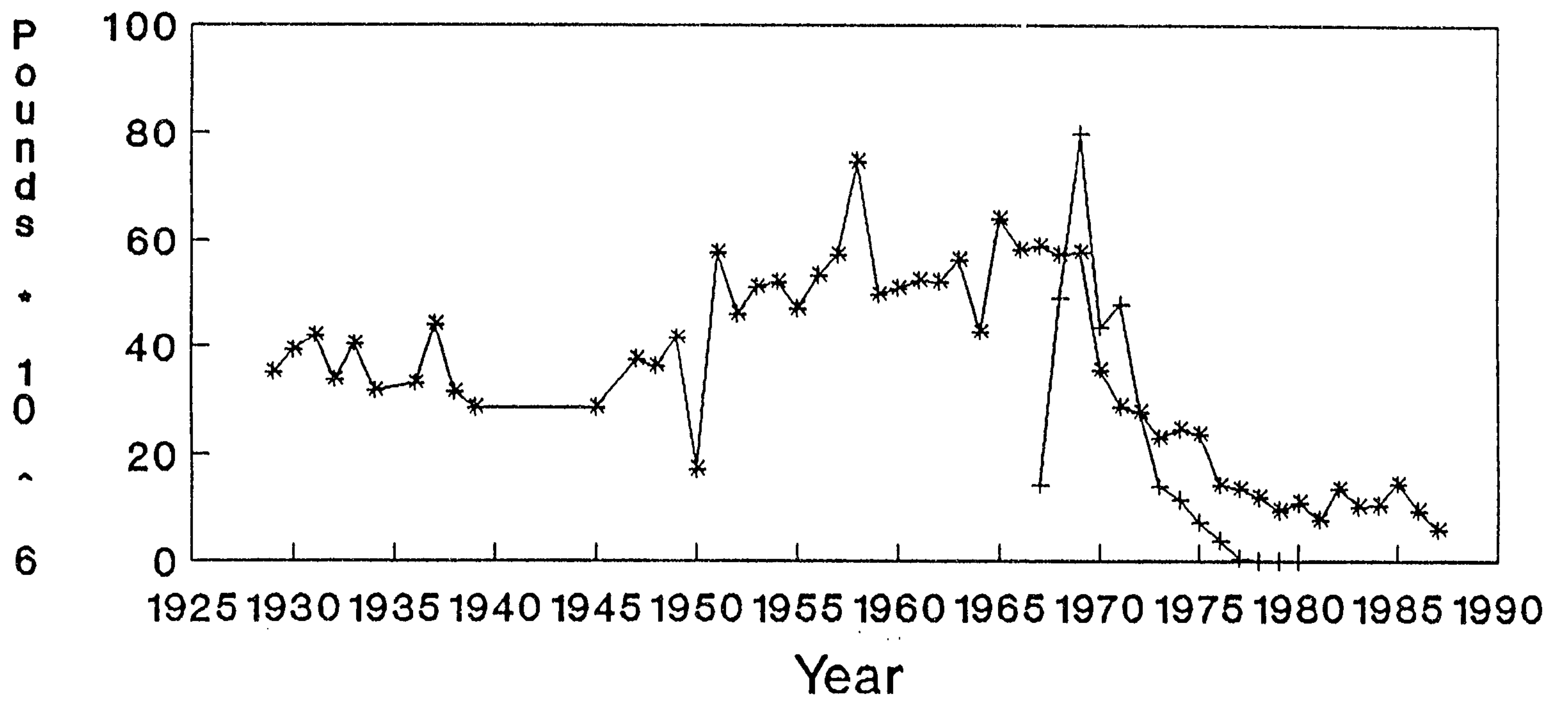
ALEWIFE COMMERCIAL LANDINGS IN RHODE ISLAND



(Data Source: National Marine Fisheries Service Biostatistics Investigation, 1991)

FIGURE 3

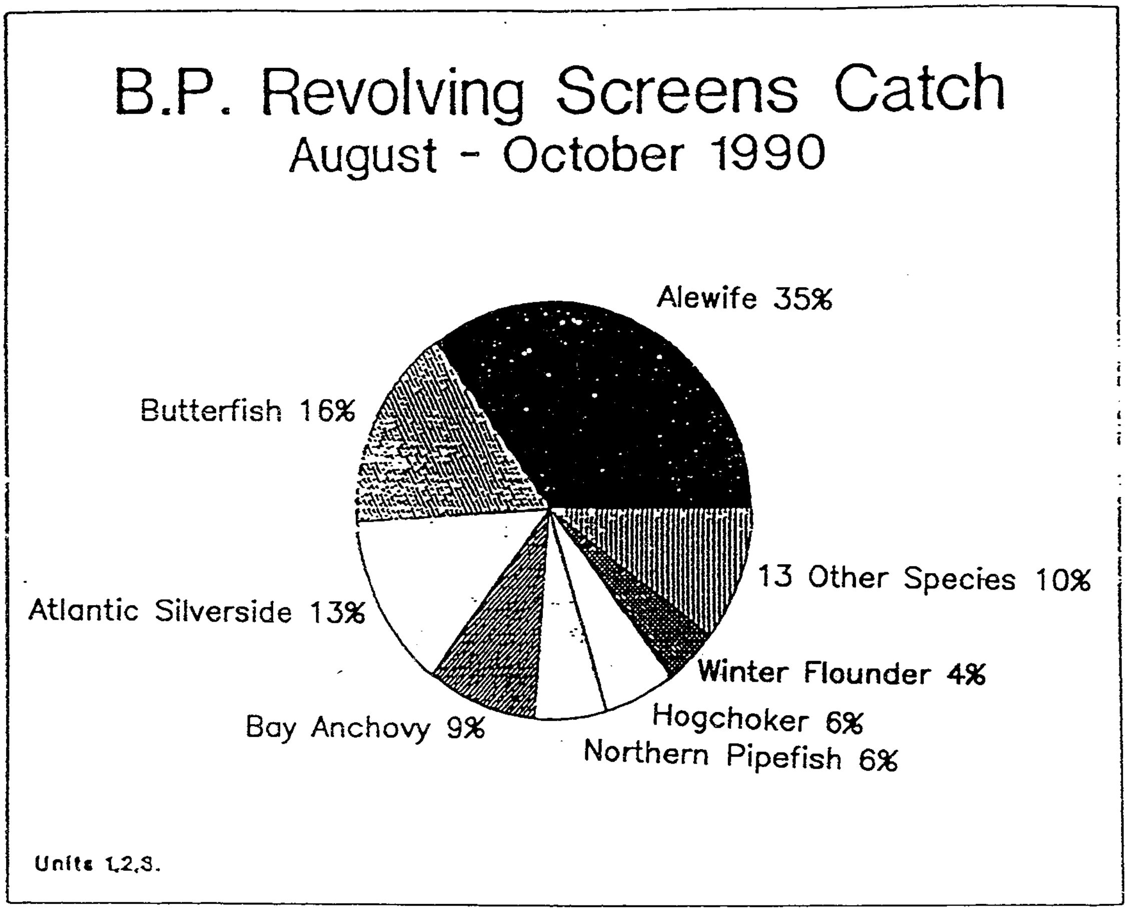
River Herring Landings
Along the Atlantic Coast 1929-1987



Data from ASMFC (1986), Harris and Rulifson (1989)

Source: Crecco and Gibson (1990)

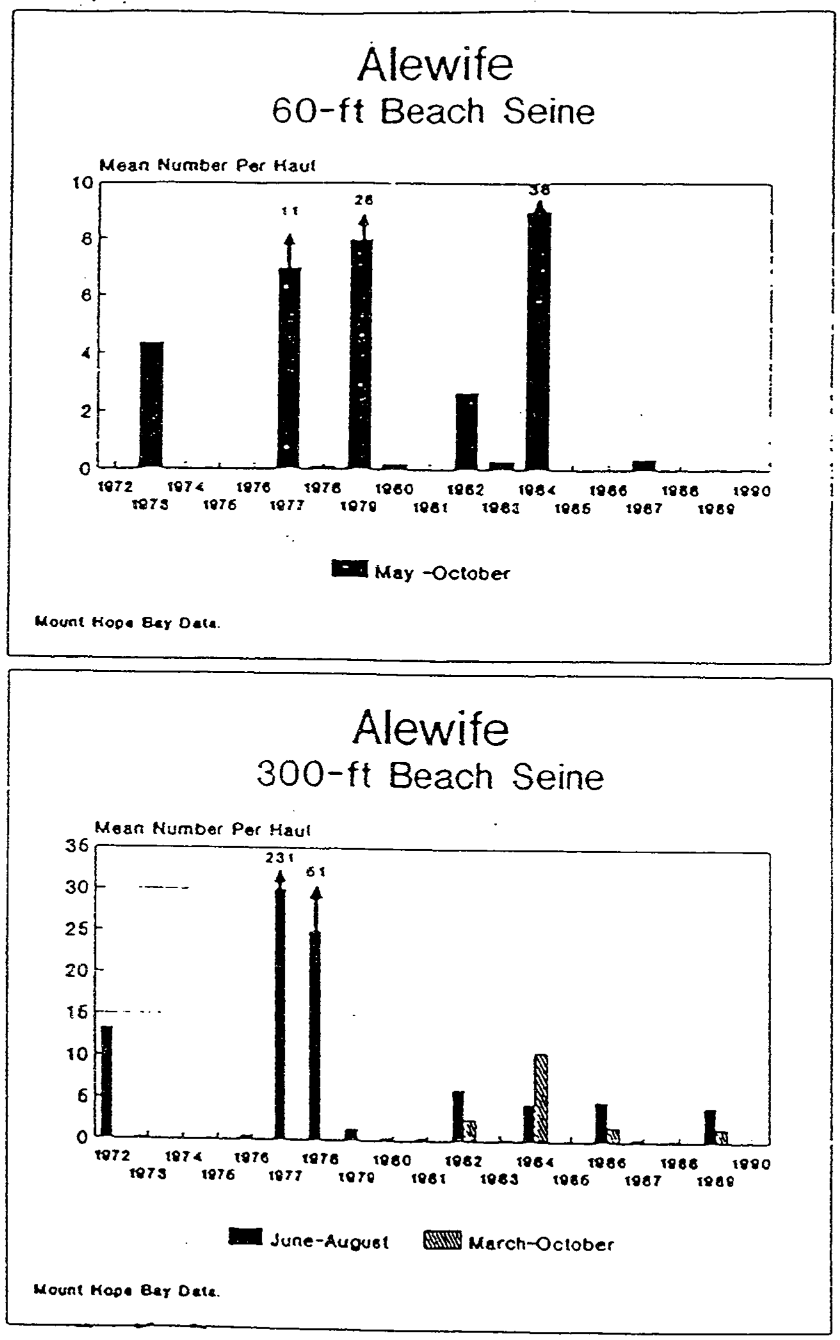
FIGURE 4



Percent contribution by species for fish impinged on the Brayton Point Unit 1,2,3 screens, August-October 1990.

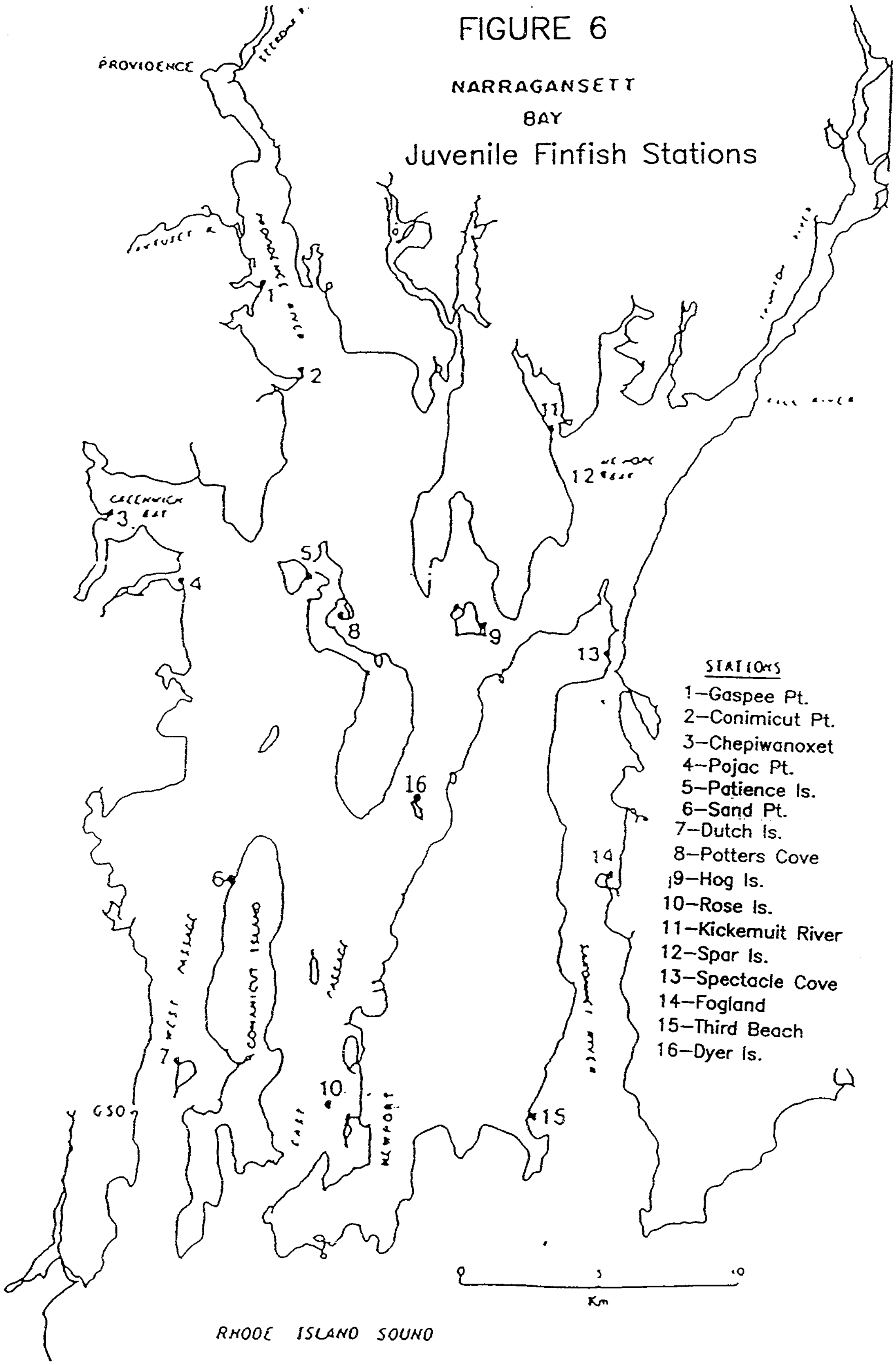
Source: MRI 1991.

FIGURE 5



Mean number of alewives per beach seine haul with 60-ft and 300-ft nets, 1972-1990.

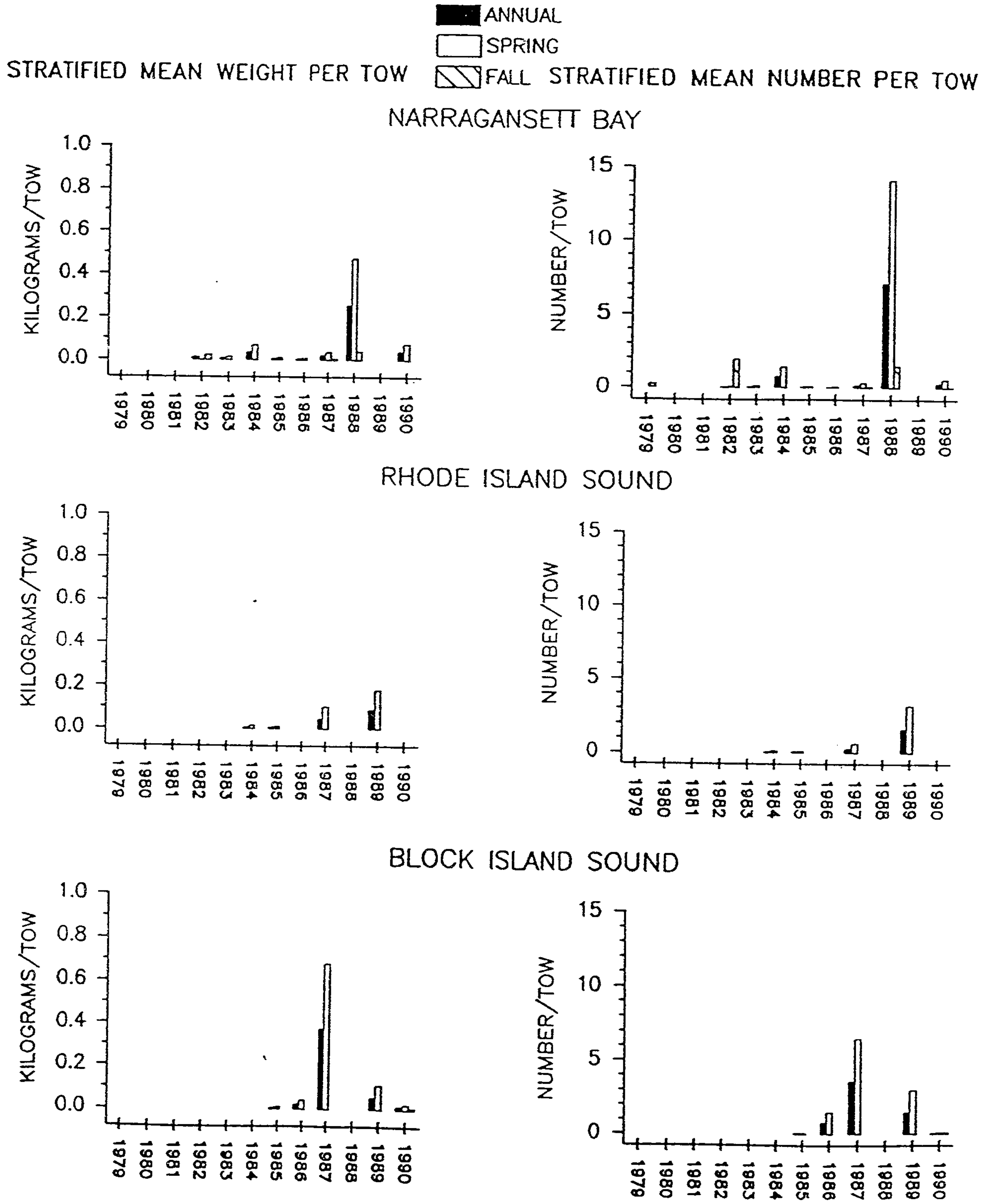
Source: MRI 1991.



Source: Powell 1986.

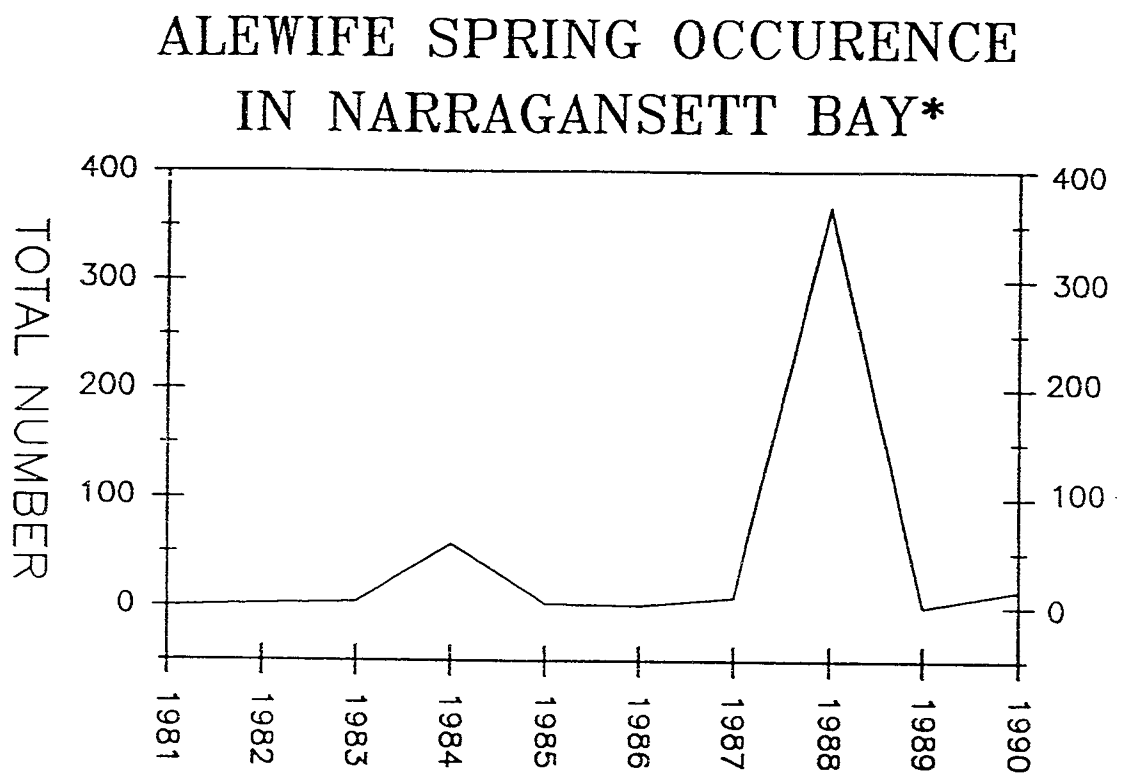
FIGURE 7

ALEWIFE MEAN NUMBER AND WEIGHT PER TOW



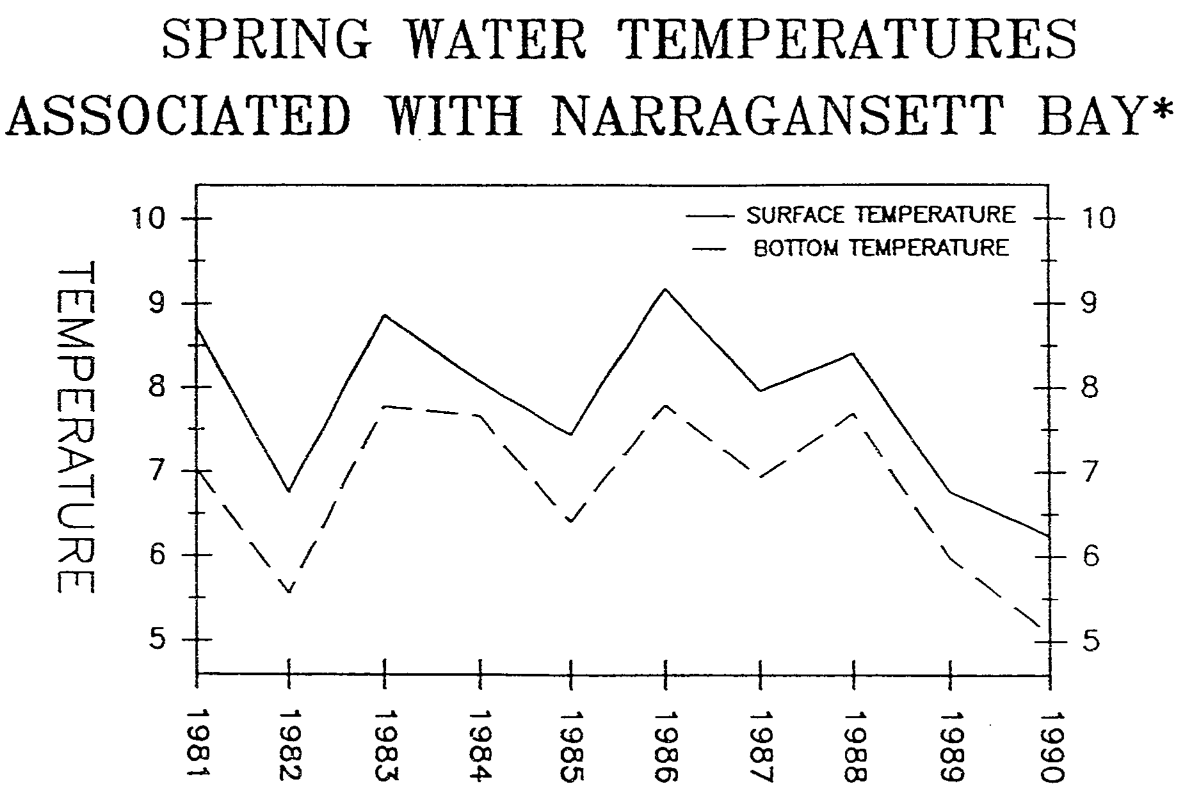
(Data Source: Rhode Island Coastal Fishery Assessment (Trawl Survey))

FIGURE 8



*1979 & 1980 spring data deficient
(Data Source: R. I. Coastal Fishery Assessment)

FIGURE 9



*1979 & 1980 spring data deficient
(Data Source: R. I. Coastal Fishery Assessment)

FIGURE 10

ALEWIFE LENGTH FREQUENCY

R. I. COASTAL FISHERY ASSESSMENT (TRAWL SURVEY)

1979–1990

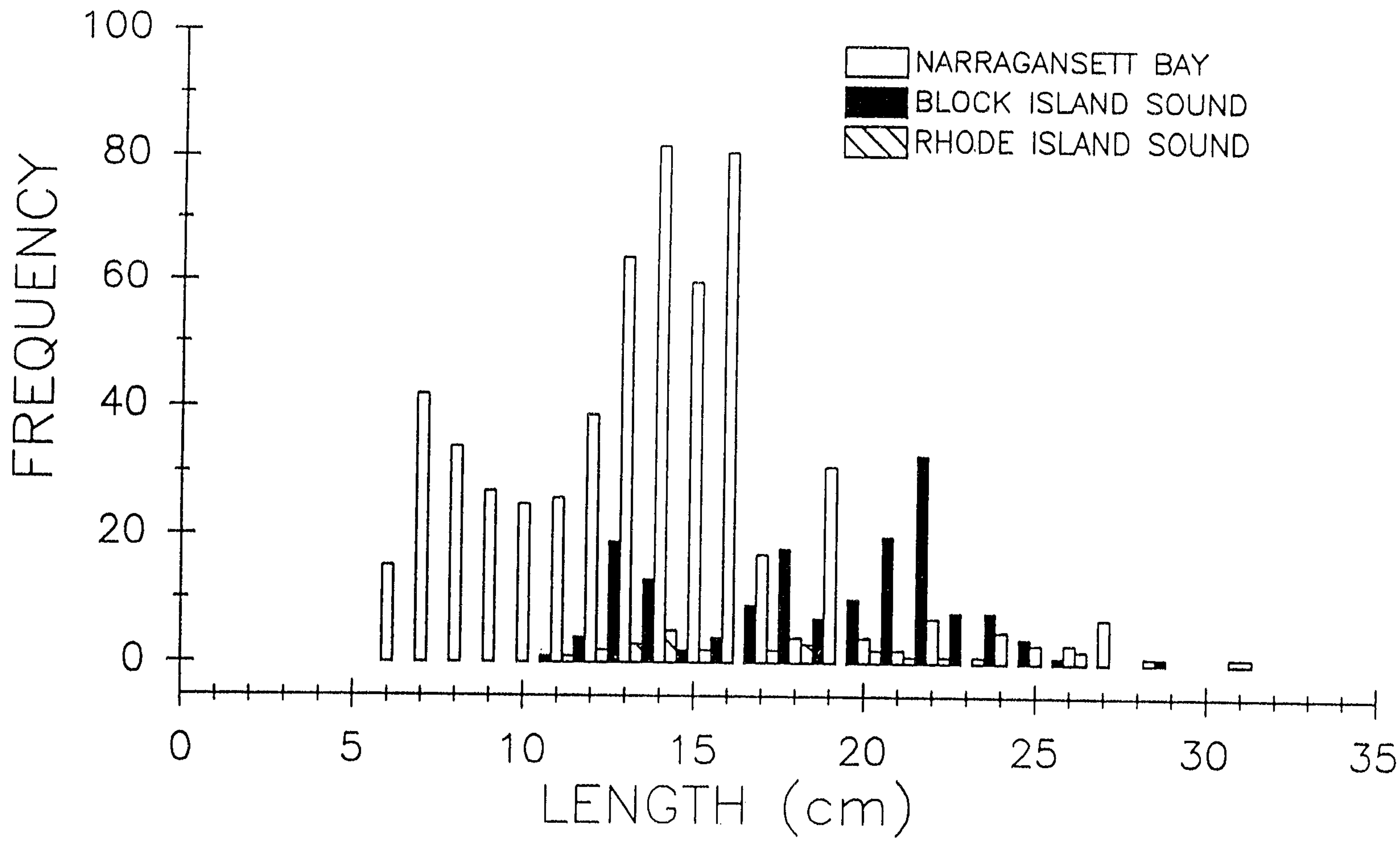
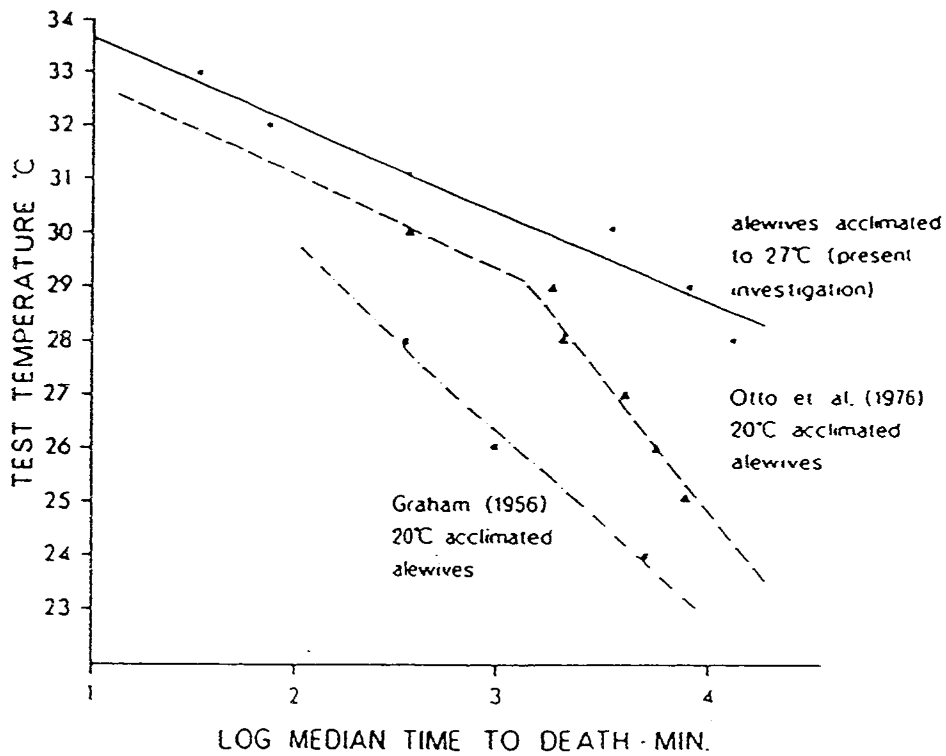


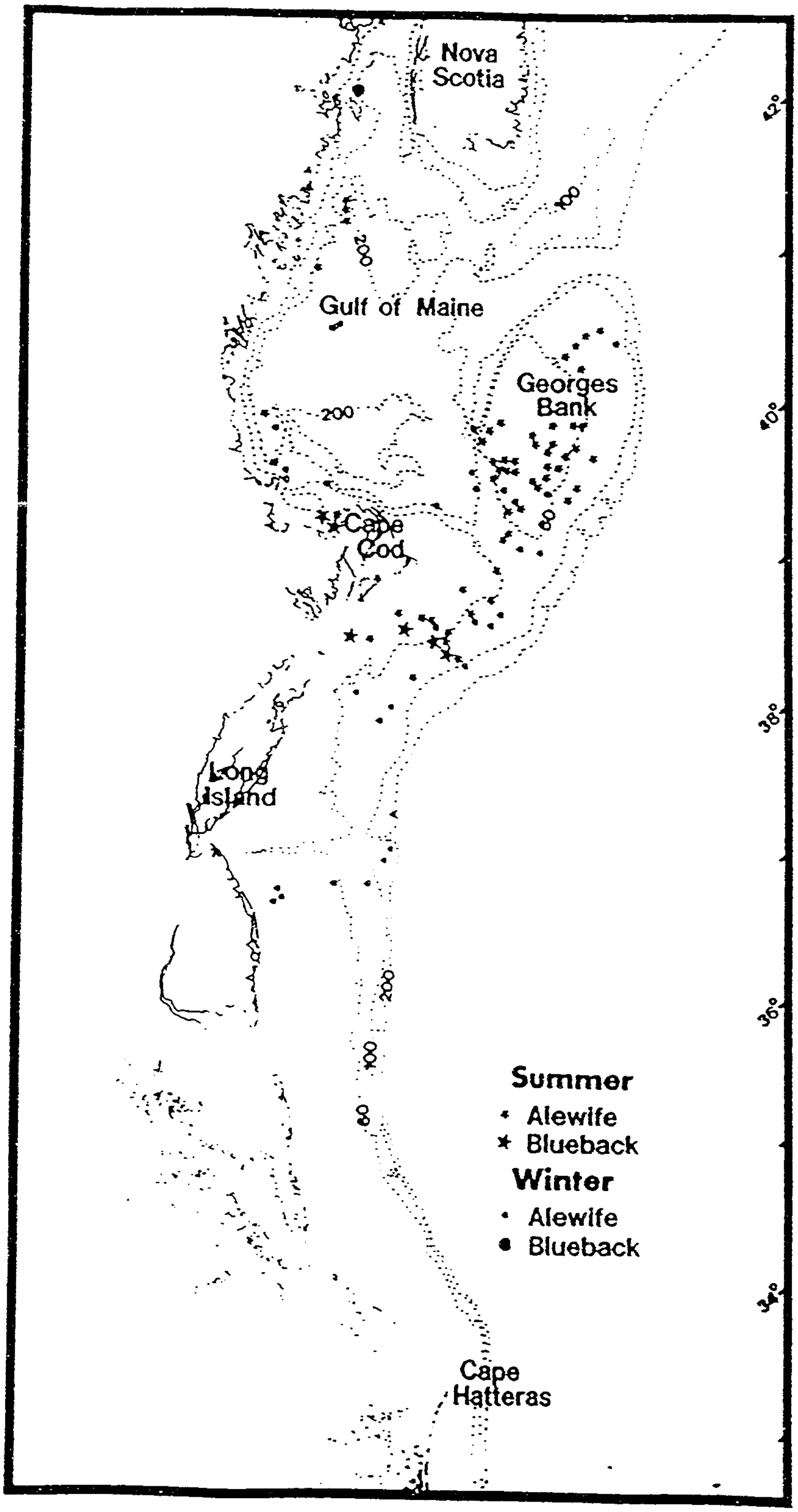
FIGURE 11



-Survival (log_{10} minutes) of adult alewives at upper lethal temperatures.

Source: McCauley and Binkowski 1982.

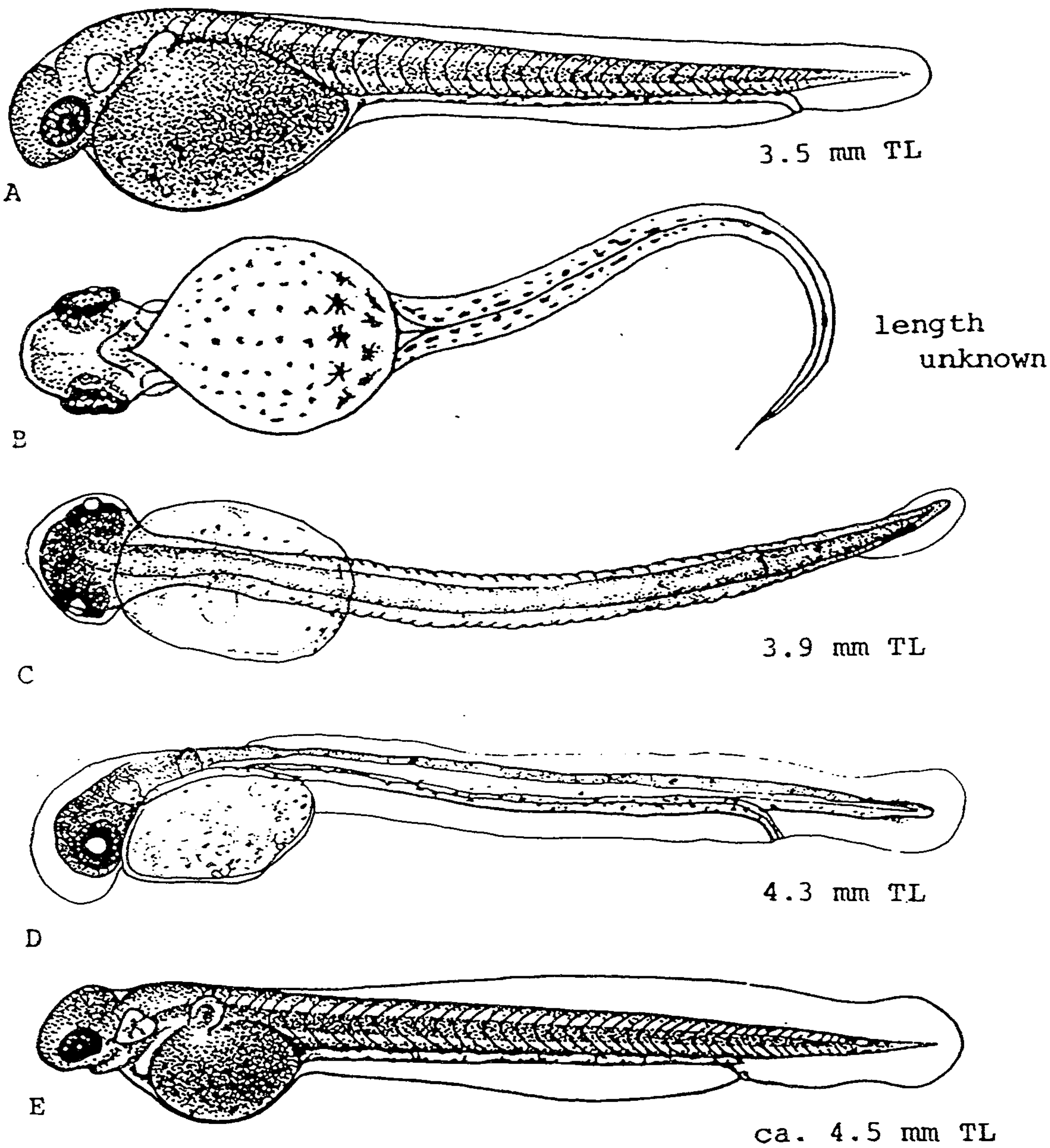
FIGURE 12



—Location of catches of alewives and blueback herring during summer and winter bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

Source: Neves 1981.

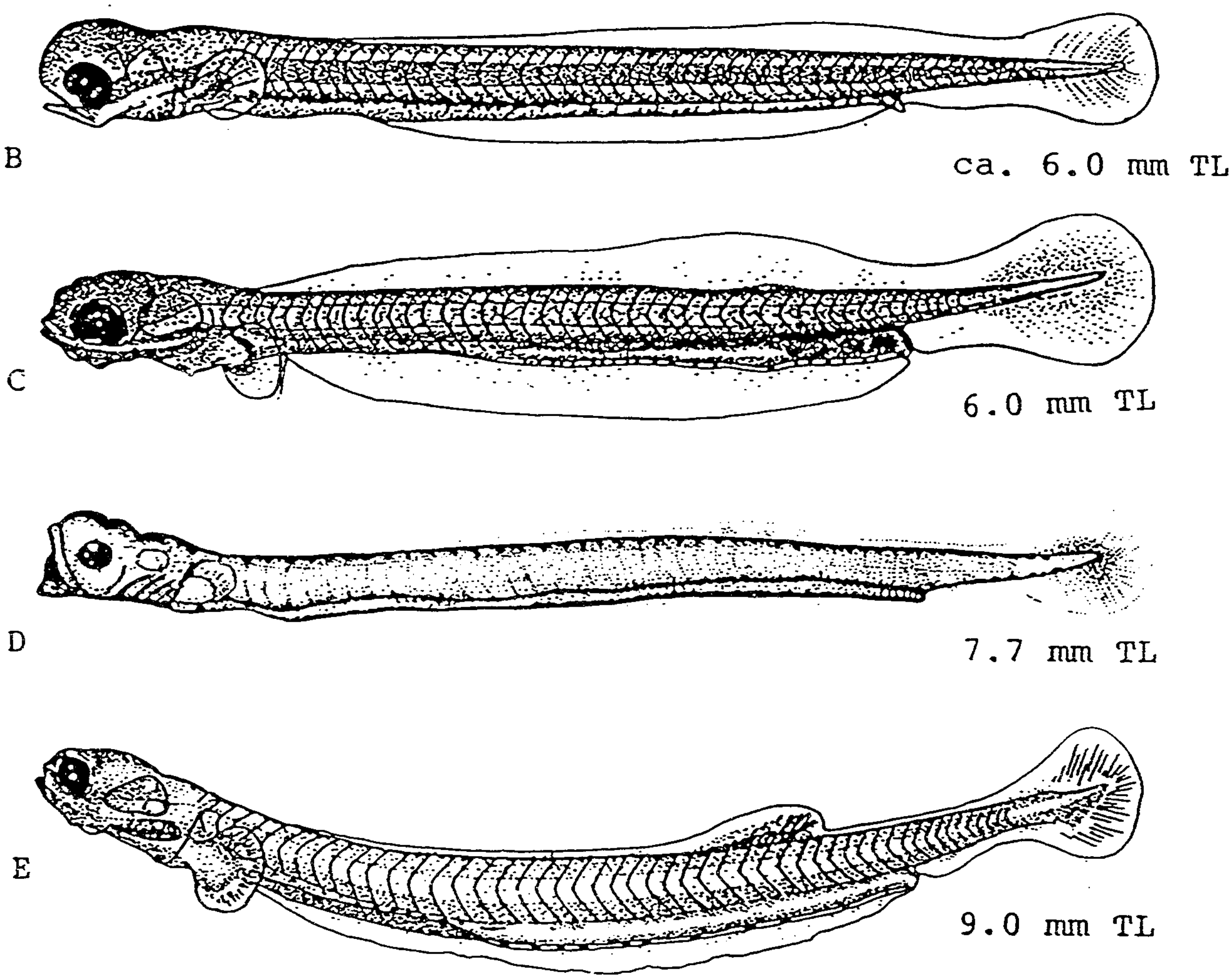
FIGURE 13



Alosa pseudoharengus, Alewife. A. Yolk-sac larva, 3.5 mm TL, recently hatched. Notochord reticulated. B. Yolk-sac larva, ventral view, recently hatched. C. Yolk-sac larva, 3.9 mm TL, ventral view, ca. 24 hours. D. Yolk-sac larva, 4.3 mm TL, recently hatched. E. Yolk-sac larva, ca. 4.5 mm TL, one day. (*A, B, E, Mansueti, A. J., and J. D. Hardy, Jr., 1967: figs. 27, A-C. C, D, Cianci, J. M., 1969: figs. 2A, C.*)

Source: Jones et al. 1978.

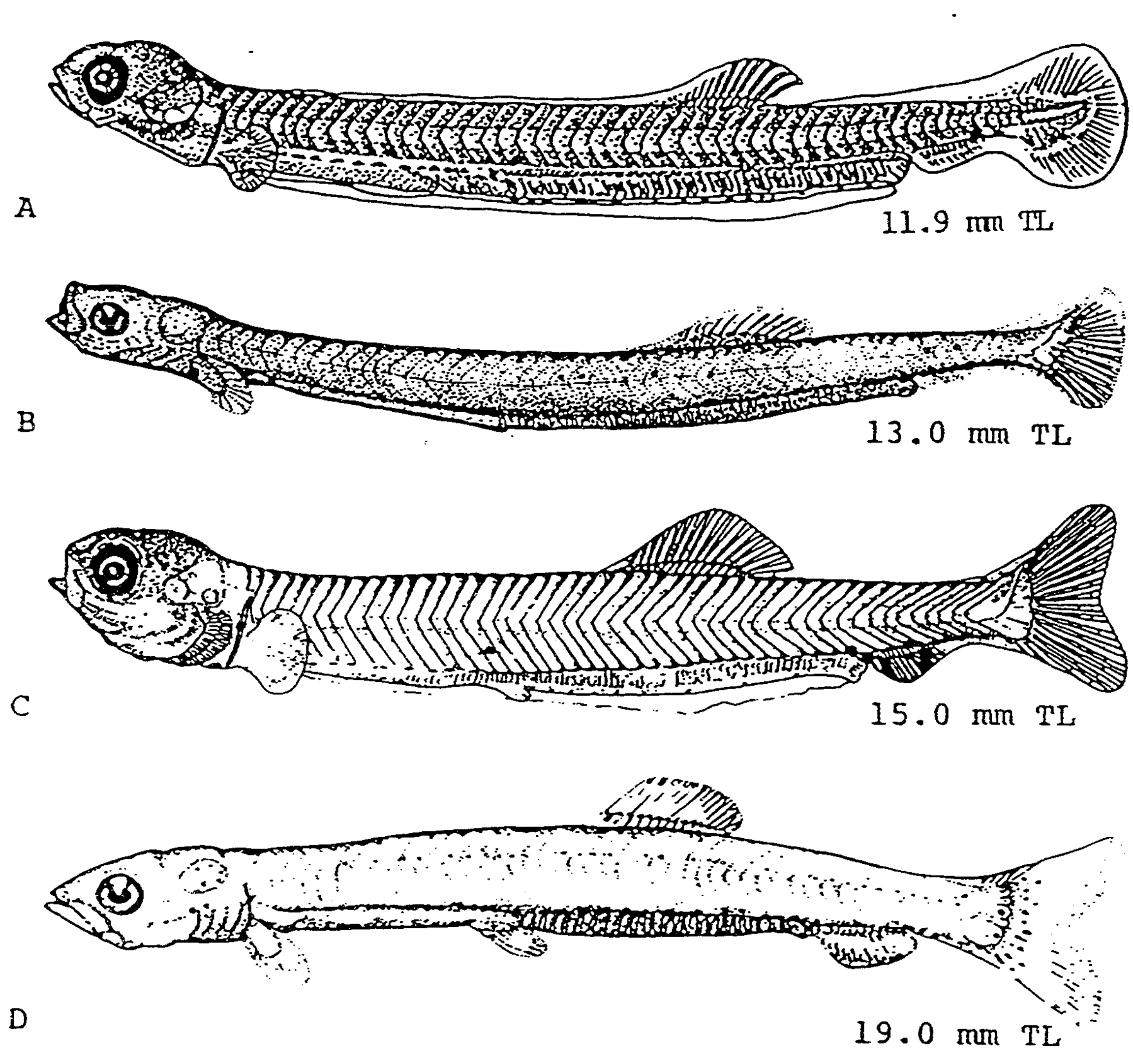
FIGURE 14



Alosa pseudoharengus, Alewife. B. Larva, ca. 6.0 mm TL. C. Larva, 6.0 mm TL, 5.9 mm SL. D. Larva, 7.7 mm TL. E. Larva, 9.0 mm TL, 8.8 mm SL. (*A, Cianci, J. M., 1969: fig. 4C. B, Mansueti, A. J., and J. D. Hardy, Jr., 1967: fig. 27E. C, E, Chambers, J. R., J. A. Musick, and J. Davis, 1976: figs. 5A, 6A. D, Norden, C. R., 1967: fig. 3B.*)

Source: Jones et al. 1978.

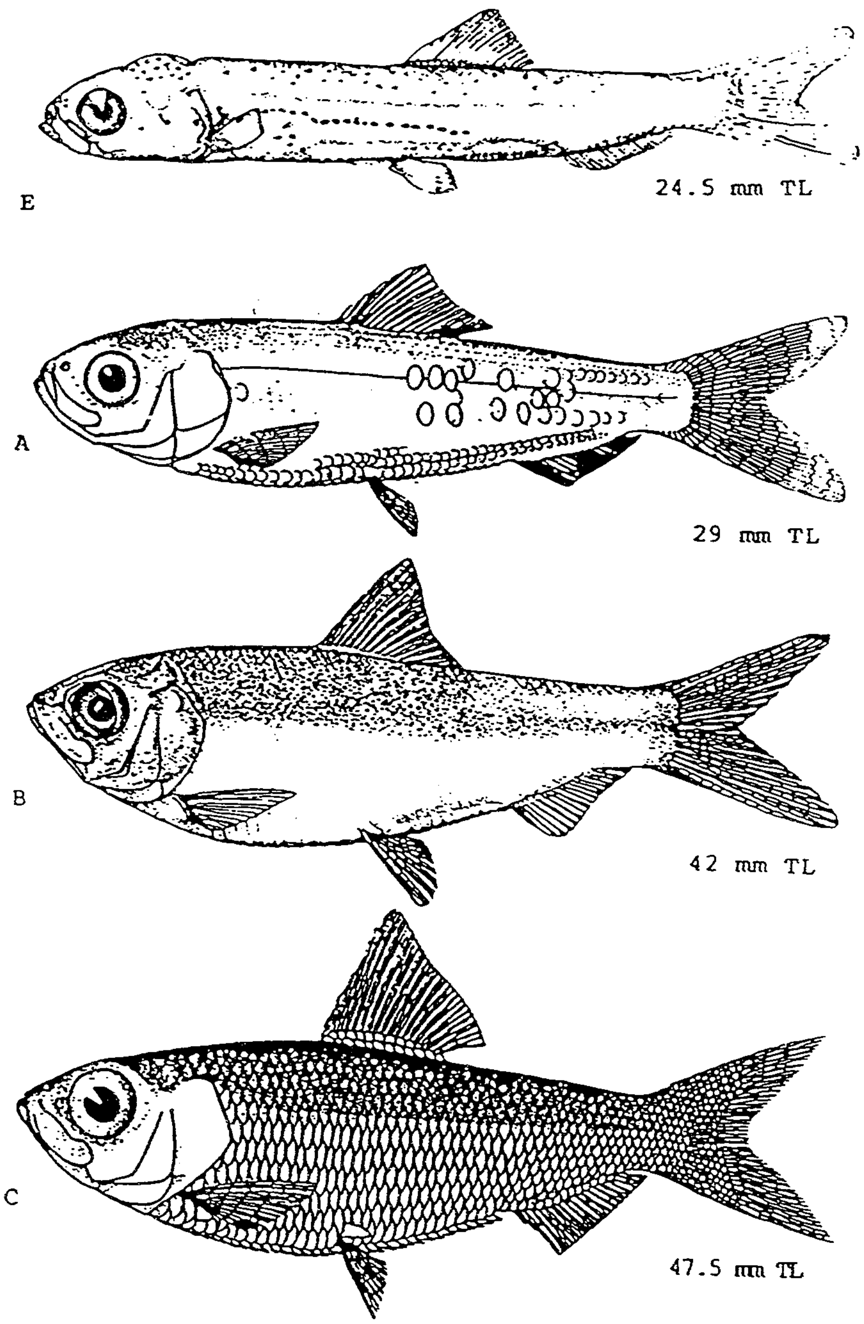
FIGURE 15



Alosa pseudoharengus, Alewife. A. Larva, 11.9 mm TL, 11.5 mm SL. B. Larva, 13.0 mm TL. C. Larva, 15.0 mm TL, 13.6 mm SL. D. Late stage larva, 19.0 mm TL. (*A, C, Chambers, J. R., J. A. Musick, and J. Davis, 1976: figs. 7A, 8A. B, D, E, Norden, C. R., 1967b: figs. 4, 5.)*

Source: Jones et al. 1978.

FIGURE 16



E. Juvenile, 24.5 mm TL. A. Juvenile, 29 mm TL, 22 mm SL. B. Juvenile, 42 mm TL, 34 mm SL. C. Juvenile, 47.5 mm TL. *(A, C, Hildebrand, S. F., 1963a: fig. 83. B, Mansueti, A. J., and J. D. Hardy, Jr., 1967: fig. 28B.)*

Source: Jones et al. 1978.

Table 1 - A Summary of the Roving Random Survey of Known and Suspected Alewife Runs in Rhode Island, Conducted During April and May 1989-1990.

System	No. Obs.	No. Pos. Obs.	P	SE(P)
Pawcatuck R.	10	8	.80	.13
Gilbert Stuart Bk.	17	13	.77	.10
Annaquatucket R.	11	7	.64	.15
Saugatucket R.	8	5	.63	.17
Gorton Pond	9	5	.56	.17
Nonquit Pond	6	3	.50	.20
Quicksand Pond	7	3	.43	.19
Tunapus Pond	5	2	.40	.22
Buckeye Bk.	8	3	.38	.17
Princess Pond	3	1	.33	.27
Brickyard Pond	5	1	.20	.18
Wesquage Pond	6	1	.17	.15
Bleachery Pond	6	1	.17	.15
Hunts R.	7	0	0	-
Green Hill Pd.	5	0	0	-
Cross Mills Pd.	5	0	0	-
Factory Brook	3	0	0	-
Kickamuit R.	3	0	0	-
Easton Pond	2	0	0	-
Echo Lake	1	0	0	-
Total	127	53	.42	.04

Source: Gibson 1991.

TABLE 2

Water Temperatures Associated with Phase Events in the Gilbert Stuart Alewife Run 1981-1990. Calendar Days are Given in Parenthesis.

Year	Initiation	Period of Run Peak	Termination
1981	9.3(88)	13.2(117)	17.0(141)
1982	8.8(85)	13.3(111)	17.0(102)
1983	9.5(91)	14.5(128)	17.5(110)
1984	8.3(85)	13.5(117)	17.0(107)
1985	8.5(82)	12.5(87)	17.5(100)
1986	7.2(75)	14.0(106)	18.0(116)
1987	7.0(82)	13.5(133)	17.0(148)
1988	9.0(87)	12.0(117)	17.9(149)
1989	9.0(85)	12.0(110)	17.6(139)
1990	11.1(76)	10.8(101)	18.0(132)
Means	8.8(83.6)	12.9(112.7)	17.4(136.4)
SD	1.17(5.04)	1.10(13.14)	.43(19.61)
CV	.13(.060)	.09(.117)	.02(.070)
SE	.37(1.59)	.35(4.16)	.14(3.04)

Source: Gibson 1991.

TABLE 3

Gilbert Stuart Alewife Spawning History 1990
Number of Fish by Sex, Age, and Spawner Type

Sex	Age	Virgin	Repeat	Double	Triple	Tot
M	IV	6	1	1	-	8
M	V	5	4	-	-	9
F	IV	1	1	-	-	2
F	V	4	5	1	-	10
F	VI	-	-	3	-	3
Totals		16	11	5	-	32

Source: Gibson 1991.

TABLE 4

Gilbert Stuart Alewives Mean Length (mm)
by Age and Sex 1990, With Standard
Errors in Parenthesis Below.

Sex	0+	II	III	IV	V	VI	VII
M	60.7	-	-	283	291	-	-
	(0.6)	-	-	(1.7)	(3.8)	-	-
F	60.7	-	-	286	293	308	-
	(0.6)	-	-	(0.5)	(2.1)	(7.3)	-

Source: Gibson 1991.

TABLE 5

A Summary of Gilbert Stuart Alewife Sample Data 1980-1990

Year	Population Size	Sex Ratio %Female	Mean Age M	Mean Age F	Mean Length (mm) M	Mean Length (mm) F
1980	54042	.589	4.93	5.09	297.2	309.0
1981	64297	.426	4.71	4.98	288.0	302.0
1982	88194	.240	4.50	4.97	291.2	309.0
1983	68919	.587	4.26	4.62	278.0	300.0
1984	52873	.318	3.90	4.46	286.4	301.9
1985	51405	.449	4.02	4.45	287.3	302.8
1986	78426	.627	5.02	5.20	291.7	310.5
1987	50893	.619	4.16	5.29	275.8	304.4
1988	74324	.413	3.43	4.52	268.6	295.6
1989	89577	.509	4.13	4.96	285.9	291.2
1990	11009	.471	4.53	5.07	287.1	295.0
Means	62178	.478	4.33	4.87	285.2	301.9

Age Structure by % of Total Sample

Year	II	III	IV	V	VI	VII	VIII
1980	0	.023	.465	.372	.116	.023	0
1981	0	.008	.315	.496	.173	.008	0
1982	0	.029	.441	.412	.118	0	0
1983	0	.077	.442	.404	.077	0	0
1984	.013	.133	.529	.258	.062	.004	0
1985	0	.303	.342	.211	.118	.026	0
1986	0	.017	.162	.504	.248	.060	.009
1987	.032	.173	.115	.365	.224	.071	.019
1988	.015	.576	.108	.158	.118	.025	0
1989	0	.097	.575	.270	.035	.018	.004
1990	0	0	.313	.594	.094	0	0
Means	.005	.131	.346	.369	.126	.021	.010

Source: Gibson 1991.

TABLE 6.-Reported predators on anadromous and landlocked alewife (all life stages).

FISH PREDATORS

American eel	Anguilla rostrata
Bluefish	Pomatomus saltatrix
Largemouth bass	Micropterus salmoides
Pumpkinseed	Lepomis gibbosus
Redfin pickerel	Esox americanus americanus
Salmon (chinook;coho;pink)	Oncorhynchus tshawytscha; O. kisutch; O. gorbuscha
Shiner (emerald;spottail)	Notropis atherinoides; N. hudsonius
Silver hake	Merluccius bilinearis
Striped bass	Morone saxatilis
Trout (brown; lake)	Salmo trutta; Salvelinus namaycush
Walleye	Stizostedion vitreum vitreum
Weakfish	Cynoscion regalis
White bass	Morone chrysops
White perch	Morone americana
Yellow perch	Perca flavescens

OTHER PREDATORS

Snapping turtle	Cheldydra serpentina
Northen water snake	Nerotea sipedon
Fish hawk	Pandion haliaetus
Heron (green; great blue; night)	Butorides virescens virescens; Ardea herodias; Nycticorsx nycticorsx
Herring gull	Larus argentatus
Mink	Mustella vision
White-tailed deer	Odocoileus virginianus

Sources: Belding (1921); Welsh and Breder (1924); Hollis (1952); Foye (1956); Stevens (1958); Hay (1959); Schaefer (1960); Cooper (1961); Edsal (1964); Trent and Hassler (1966); Kissil (1969); Manooch (1972); Shirey (1972); Tyus (1972); Richards (1976); Wells (1980); Kohler and Ney (1981); Hatch et al. (1981); Stewart et al. (1981); Ech and Wells (1983); Case and McCullough (1987); Loesch (1987); Kocik and Taylor 1987.