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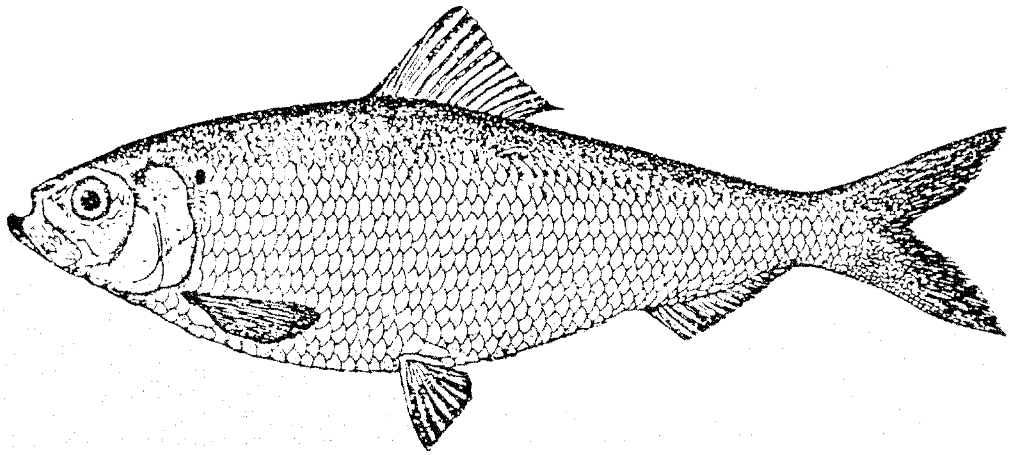
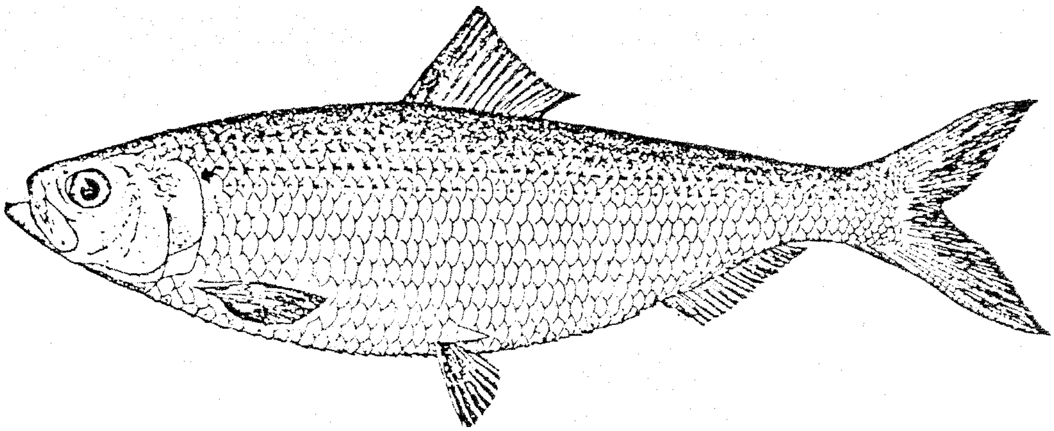
HABITAT SUITABILITY INDEX MODELS: ALEWIFE AND BLUEBACK HERRING





Fish and Wildlife Service

U.S. Department of the Interior

This model is designed to be used by the Division of Ecological Services in conjunction with the Habitat Evaluation Procedures.

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HABITAT SUITABILITY INDEX MODELS: ALEWIFE AND BLUEBACK HERRING

by

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PREFACE

The habitat suitability index (HSI) models for alewife and blueback herring (collectively, river herring) in this report are intended for use in impact assessment and habitat management. The models were developed from a review and synthesis of existing information and are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions used to transform habitat use information into the HSI models and guidelines for model application are described.

These models are hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. The models have been applied to six sample data sets that are included. Users are encouraged to convey comments and suggestions that may help increase the utility and effectiveness of this habitat-based approach to fish and wildlife management. Please send any comments or suggestions on the alewife and blueback herring HSI models to:

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CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index models and narratives for river herring was monitored, expertly reviewed, and constructively criticized by Dr. J.G. Loesch, Virginia Institute of Marine Science, Gloucester Point, and Mr. M.W. Street, North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City.

Thorough evaluations of model structure and functional relationships were provided by personnel of the U.S. Fish and Wildlife Service's National Coastal Ecosystems Team and Western 'Energy and Land Use Team. Model and supportive narrative reviews were provided by regional personnel of the U.S. Fish and Wildlife Service. Funding for model development and publication was provided by the U.S. Fish and Wildlife Service.

ALEWIFE (*Alosa pseudoharengus*)

and

BLUEBACK HERRING (*Alosa aestivalis*)

INTRODUCTION

Alewives and blueback herring are anadromous clupeids found along the Atlantic coast in marine, estuarine, and riverine habitats, depending upon life stage. Both are important commercial species, used fresh or salted for human consumption, and used as crab bait, fish meal (particularly in animal food manufacturing), and fish oil. Alewife and blueback herring are marketed collectively as "river herring," a term that will be used for both species in this report. River herring play important ecological roles. In marine, estuarine, and riverine food webs, they occupy a level between zooplankton, their principal food, and piscivores.

Distribution

Alewives range from Newfoundland (Winters et al. 1973) to South Carolina (Berry 1964). Blueback herring range from Nova Scotia (Scott and Crossman 1973) to the St. Johns River, Florida (Hildebrand 1963), and have established populations in the St. Johns and St. Marys Rivers and minor populations in the Nassau and Tomaka Rivers, Florida (Rulifson and Huish 1982).

Catch. records over a 16-year period (1963-78) provide some information on the offshore distribution of river herring (Neves 1981). During summer and autumn, all catches of both species were- confined to the region north of 40° north latitude in three general areas: Nantucket Shoals, Georges Bank, and the perimeter of the Gulf of Maine. Winter catches were between 40" and 43" north latitude, and spring catches were distributed throughout the continental shelf area between Cape Hatteras, North Carolina, and Nova Scotia.

Life History Overview

Schools of river herring enter fresh- and brackish water once a year to spawn (Raney and Massman 1953). There is some evidence that they return to natal rivers to spawn (Reed 1964; Joseph and Davis 1965). Spawning periods range from March through July, occurring later as one proceeds north (Hildebrand 1963; Loesch 1969; Smith 1971; Tyus 1974; Loesch and Lund 1977). Alewives generally spawn 3-4 weeks earlier than blueback herring in sympatric areas, with peak spawning separated by 2-3 weeks (Jones et al. 1978).

Eggs of river herring are initially demersal and adhesive in still water or pelagic in running water (Loesch and Lund 1977; Jones et al. 1978). After water-hardening, all eggs become pelagic and lose their adhesive properties.

Yolk-sac larvae for both species are approximately 2.5-5.0 mm (0.1-0.2 inches) total length (TL) at hatching and average 5.1 mm (0.2 inches) at yolk-sac absorption (Mansueti 1962). Yolk-sac absorption takes 2-3 days for blueback herring and 2-5 days for alewives (Mansueti 1962; Cianci 1969). Transformation to the juvenile stage is gradual, but generally complete at approximately 20 mm (0.78 inches) TL, and individuals are usually fully scaled at 45 mm (1.8 inches) TL (Hildebrand 1963; Norden 1967).

Juveniles may remain in the lower ends of rivers where spawning occurred (Street et al. 1975). Some juveniles appear to move upstream in summer (Warinner et al. 1969; Burbidge 1974) before migrating downstream in late fall. Juvenile alewives were most abundant in surface waters through September before increasing in abundance at 4.6 m(15.1 ft) and on the bottom in September and October prior to emigration (Warinner et al. 1969). Juvenile bfueback herring densities remained high in and near surface waters throughout their freshwater phase (Warinner et al. 1969; Burbidge 1974) and were not collected in bottom trawls (Warinner et al. 1969).

In most Atlantic coast populations, juvenile river herring emigrate from freshwater-estuarine nursery areas between June and November of their first year of life (Burbidge 1974; Kissil 1974; Richkus 1975; O'Neill 1980). By this time alewives have attained a mean length of 44-113 mm (1.7-4.5 inches) (Joseph and Davis 1965 [measured fork length]; Davis and Cheek 1966 [measured fork length]; Marcy 1969 [measured total length]; Richkus 1975 [measured standard length]) and blueback herring a mean length of 36-71 mm (1.4-2.8 inches) (Hifdebrand and Schroeder 1928 [measured total length]; Burbidge 1974 [measured fork length]). Young-of-the-year alewives are reported to grow somewhat faster in Chesapeake Bay than young blueback herring (Hildebrand and Schroeder 1928); however, Davis and Cheek (1966) found similar growth rates in North Carolina. Weaver (1975) documented growth rates ranging from 0.004 to 0.020 g/day (0.0001 to 0.0007 oz/day) for juvenile alewives from the James River, Virginia.

Little information is available on growth rates for river herring between age 0+ and the time of first spawning. Age 1 alewives reached total lengths of 66-224 mm (2.6-8.8 inches) while spring age 1 blueback herring ranged from 64 to 119 mm (2.5 to 4.7 inches) TL (Hildebrand and Schroeder 1928). Age 2 alewives and bluebacks in Albemarle Sound, North Carolina, reached 153 and 148 mm (6.0 and 5.8 inches) TL, respectively, and at Georges Bank, age 2 fish of both species reached approximately 180 mm (7.1 inches) TL (Netzel and Stanek 1966). Females of both species are slightly larger and heavier than males of the same age (Cooper 1961; Netzel and Stanek '1966; Marcy 1969; Loesch and Lund 1977).

Age at first spawning, percentage of repeat spawners, and longevity in alewife populations fluctuate annually, but seem to increase slightly as One proceeds north. Spawning populations of alewives have not been determined for South Carolina, and consist primarily of 4- and 5-year-old fish in North Carolina (Sholar 1975, 1977; Street et al. 1975; Johnson et al. 1977; Fischer 1980; Hawkins 1980b; Rulifson and Huish 1982) except for a spawning population of 3-year-old fish in Lake Mattamuskeet (Tyus 1971, 1974). Spawning alewife populations are represented by ages 3-8 in Chesapeake Bay and the Connecticut River (Joseph and Davis 1965; Marcy 1969; Loesch and Lund 1977) and by ages 4-10 in Nova Scotia(O'Neill 1980). Percentage of alewife repeat spawners was

10%-45% for North Carolina (Tyus 1974; Street et al. 1975; Sholar 1977), 61% in Virginia (Joseph and Davis 1965), and 60% in Nova Scotia (O'Neill 1980). No alewives older than 9 years have been captured in North Carolina (Street et al. 1975; Johnson et al. 1977), but 10-year-old fish have been recorded in Nova Scotia (O'Neill 1980). Generally, males dominate age groups 3-5 on the spawning grounds, while females dominate age groups 7 and older.

Blueback herring vary more than alewives in age at first spawning, although, in general, maturation rates are similar for the two species (Joseph and Davis 1965; Street et al. 1975; Loesch and Lund 1977; O'Neill 1980). Like the longevity of the alewife, that of the blueback herring increases northerly with ages up to 7 and 8 years in Florida and South Carolina, respectively (Rulifson and Huish 1982), 9 in North Carolina (Street et al. 1975), and 10 in Nova Scotia (O'Neill 1980). Age group composition is dominated in the Southern States by 4-, 5-, and sometimes 6-year-old fish (Rulifson and Huish 1982) and by age group 5 in Connecticut (Loesch and Lund 1977). Blueback herring runs consisted of 80% repeat spawners in the Altamaha River, Georgia, 32%-52% in North Carolina (Street et al. 1975; Johnson et al. 1977), 65% in Virginia (Joseph and Davis 1965), 82% in Connecticut (Loesch and Lund 1977), and 75% in Nova Scotia (O'Neill 1980).

Fecundity estimates for alewives ranged from 60,000 to 100,000 eggs per female in Chesapeake Bay (Foerster and Goodbred 1978); and 48,000 to 360,000 in Bride Lake, Connecticut (Kissil 1974). Estimates for Connecticut River blueback herring ranged from 45,200 to 349,700 eggs per female (Loesch and Lund 1977). Fecundity-to-age relationships for Georgia blueback herring were not linear (Street 1969), and the relationship may be asymptotic for both species, with "fecundal senility" occurring in long-lived individuals (Street 1969; Loesch and Lund 1977).

SPECIFIC HABITAT REQUIREMENTS

River herring occupy distinctly different habitats depending upon life stage and 'time of year. Juvenile river herring are the dominant life stage found in freshwater and estuarine habitats; adults enter freshwater only to spawn. Specific habitat requirements are summarized for each life stage or group of combined life stages,

Food

Adult. Food habits of adult river herring are poorly documented. Both species are primarily size-selective zooplankton feeders, though fish eggs, other eggs, insects and small fishes may be important foods in some areas or for larger individuals (Bigelow and Schroeder 1953). They do not feed extensively during upstream spawning migrations (Biqelow and Schroeder 1953); but while in the ocean, adults apparently migrate vertically following the diel movements of zooplankton in the water column (Janssen and Brant 1981; Neves 1981).

Larva and Juvenile. Larvae (about 6 mm or 0.2 inches) begin feeding on relatively small cladocerns and copepods, adding larger species as they grow (Norden 1968; Nigro and Ney 1982). Young-of-the-year alewives in Hamilton Reservoir, Rhode Island, consumed primarily Chironomidea (Dipteran midges) in July, switching to cladocerans in August and September (Vigerstad and Cobb

1973). Young-of-the-,year blueback herring in the James River, Virginia, consumed Bosmina spp., copepod nauplii, copepodites, and adult copepods (Eurytemora affinis and Cyclops vernalis) most frequently (Burbidge 1974). Electivity (Ivlev 1961) was strongest for adult copepods, neutral for Bosmina spp. and copepodites, and strongly negative for copepod nauplii. Young-of-the-year of both species were compared (Davis and Cheek 1966) in the Cape Fear River, North Carolina. Blueback herring selected copepods and dipterian larvae more frequently than did alewives; alewives consumed more ostracods, insect eggs, and insect parts than did blueback herring. Crustacean eggs were eaten equally by both species.

Cover

Adult (spawning). Alewives spawn in large rivers, small streams, and ponds, including barrier beach ponds. Spawning substrates include gravel, sand, detritus, and submerged vegetation with sluggish water flows and water depths of 15 cm-3 m (5.9 inches-g.8 ft) (Edsall 1964; Hansueti and Hardy 1967). Blueback herring spawn in swift-flowing, deeper stretches of rivers and streams with associated hard substrate (Sholar 1975; Loesch and Lund 1977) and in slower-flowing tributaries and flooded low-lying areas adjacent to main strc .ins with soft substrates and detritus (Street et al. 1975; Sholar 1975, 1977; Fischer 1980; Hawkins 1980a).

Water Quality and Depth

Adult. Spawning runs for river herring begin in spring and minimum spawning temperatures are 10.5°C and 14°C (50.9' and 57.2°F) for alewives and blueback herring, respectively (Cianci 1969; Loesch and Lund 1977). Both species cease spawning when water temperatures exceed 27°C (80.6°F) (Loesch 1969; Edsal 1970). Alewife spawning runs occur in a chronological south-to-north progression at water temperatures between 12" and 16°C (53.6' and 60.8°F) (Bigelow and Schroeder 1953; Havey 1961; Thunberg 1371; Jones et al, 1978). Blueback herring spawn at water temperatures between 17°-26°C (62.6°-78.8°F) (Kuntz and Radcliffe 1917; Bigelow and Schroeder 1953; Hildebrand 1963; Sholar 1975, 1977; Hawkins 1980b).

Adult distributions of river herring are largely confined to depths less than 100 m (328 ft) at water temperatures between 2° and 17°C (35.6° and 62.6°F) (Neves 1981). They are widely distributed along the Middle Atlantic Bight during spring, appear to move north to 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 (Neves 1981). Catches of river herring off the North Carolina coast were in areas no deeper than 38.4 m (126 ft); most blueback herring were caught between 5.5 and 18.3 m (13 and 60 ft) and most alewives between 20.1 and 36.6 m (66 and 120 ft) (Holland and Yelverton 1973; Street et al. 1973). River herring were most often caught at bottom temperatures between 4° and 7°C (39.2° and 44.6°F) (Neves 1981). Both species may exhibit seasonal movements in conjunction with preferred isotherms or preferred prey isotherms (Collins 1952; Leggett and Whitney 1972), but direct evidence is lacking (Richkus 1974).

Egg. Hatching times for fertilized alewife eggs vary with water temperature as follows: 2.1 days at 28.9°C (84°F) (Edsall 1970), 3.7 days at 21.1°C (70°F) (Edsall 1970), 3.4-5 days at 10.0°-12.0°C (50°-53.6°F) (Cianci 1969), 6 days at 15.6°C (60.1°F) (Hildebrand 1963), and about 15 days at 7.2°C (45°F) (Edsall 1970; Rulifson and Huish 1982). Fertilized blueback herring eggs hatch in 80-94 hr at 20°-21°C (68°-69.8°F) (Morgan and Prince 1976), 36-38 hr (Street and Adams 1969) and 50 hr at 22°C (71.6°F) (Bigelow and Schroeder 1953), and 55-58 hr at 22.2°-23.7°C (72°-74.7°C) (Cianci 1969; Rulifson and Huish' 1982). Typically, hatching requires 38-60 hr for blueback herring (Adams and Street 1969; Cianci 1969; Morgan and Prince 1976, 1977) and 80-95 hr for alewives (Edsall 1970).

Hatching success Of alewives is directly correlated with water temperatures (Kellogg 1982). Hatching was maximally successful at 20.8°C (69.4°F), fell si gificantly at 26.7°-26.8°C (80.1°-80.2°F), and did not occur at 29.7°C (85.5°F). Average time to median (middle) hatch varied inversely with temperature, ranging from 7.4 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).

Fertilized river herring eggs are extremely tolerant of suspended sediments (Auld and Schubel 1978) and probably other environmental variables such as flow rate and salinity.

Larva. Daily weight gains in young alewives were greatest at 26.4°C (79.5°F) and their temperature preference was estimated at 26.3°C (79.3°F) in thermal gradient tests (Kellogg 1982). Larvae in Chesapeake Bay apparently remain near or slightly downstream of presumed spawning areas and were collected only in areas with salinities less than 12 parts per thousand (ppt) (Dovel 1971). In Nova Scotian rivers, larvae are associated with relatively shallow (<2 m or <6.6 ft), sandy, warm areas in and near areas of observed spawning (O'Neill 1980).

Juvenile. Juvenile river herring migration from freshwater-estuarine nursery areas at age 0t is a response to heavy rainfall, high water, and water temperature declines (Cooper 1961; Kissel 1974; Burbidge 1974; Richkus 1975; O'Neill 1980). During the winter they have been found in lower portions of estuaries out to 8 km (5 mi) offshore (near outer limit of influence of estuary on salinity-temperature) at temperatures between 4.5" and 6.5°C (40.1° and 43.7°F), and salinities from 29 to 32 ppt (Milstein 1981). River herring in North Carolina sounds overwinter in the more brackish water areas during winter and disperse to the ocean the following May at adult spawning peaks (Street et al. 1975). Fish about 80 mm (3.1 inches) fork length may enter the ocean during the winter (Holland and Yelverton 1973).

Both species exhibit significant diel movement> (Kernehan 1974; Lindenburg 1976), moving toward the bottom during the day and toward the surface at night. Light intensity seems to be an important stimulant to these movements (Warinner et al. 1969) as does temperature (Meldrim and Gift 1971; Brandt 1978; Brandt et al. 1980).

Special Considerations

Timing of reproduction for clupeids is believed to have evolved as a mechanism to synchronize the occurrence of larval stages with the optimal phase of the annual plankton production cycle (Blaxter et al. 1982). Spawners, however, must depend on indirect signals like photoperiod and temperature to link the production cycle to spawning. Year-class failures, therefore, may be a mismatch between plankton and larval production, but this hypothesis has not been quantified. Spawners move from a marine environment in response to temperature and light intensity during spring and early summer into estuarine, riverine, and even pond and lake environments. During this period, habitat constantly changes and has not been quantified. The same problem occurs during late summer and fall when juveniles move downstream into lower estuarine areas in response to changes in temperature, water flow, light intensity, precipitation, and water leveis.

Although adults and older juveniles are extremely tolerant of a wide salinity range (0-28 ppt) (Chittenden 1972) and suspended sediments (up to 100 mg/l), environmental pollutants and habitat alterations such as dams and stream channelizations are considered detrimental. They create unsuitable habitat for river herring either through the effects of the contaminants and habitat alterations themselves or by creating adverse oxygen and other water quality conditions.

Mortality estimates as high as 70% have been reported for river herring (Johnson et al. 1977). The greatest limits to populations of river herring appear to be food availability, predation, and fishing mortality. Studies relating various levels of each of these environmental factors to river herring abundance have not been conducted.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

These models are designed to apply to river herring throughout their range on the Atlantic coast from Newfoundland to Florida in riverine and/or estuarine habitats.

Season. The habitat suitability index (HSI) models are designed to apply only during those seasons when habitats are used by river herring.

Minimum habitat area. Minimum habitat is defined as the minimum area of contiguous suitable habitat required for a species to live and reproduce. No minimum habitat size requirements for river herring have been identified in the literature.

Verification level. Two biological experts outside the U.S. Fish and Wildlife Service reviewed and evaluated the river herring HSI models: Dr. J.G. Loesch, Virginia Institute of Marine Science, Gloucester Point; and Mr. M.W. Street, North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City. The models have not been verified in the field, but are based upon information documented in the literature. Adjustments to the model may be required after adequate field tests have been completed.

Model Descriptions

The HSI models provide an index between 0 (unsuitable habitat) and 1.0 (optimal habitat). Separate HSI models were developed for two distinct life stages of river herring. One stage involves the relatively brief period of spawning and development of eggs and larvae in riverine habitat. The second stage involves an extended period when juveniles (less than 1 year of age) are in riverine and/or estuarine environments. Two models were developed because certain areas may be good for spawning but poor for juveniles, or poor for spawning but good for juveniles.

No consideration was given to the marine phase of the river herring life history since it is not a habitat where users would likely apply the river herring models. Landlocked populations also have not been considered in the two models for either species.

Figure 1 illustrates the relationship of habitat variables in riverine-estuarine habitats to the HSI for the spawning adult, egg, and larval stages and the juvenile stage.

Spawning Adult, Egg, Larval Model

The HSI model for spawning adults, eggs, and larvae is composed of two life requisite components: cover and water quality. A food component is not included because spawning adults seldom feed and both eggs and larvae have a self-contained food source in the yolk and yolk sac.

Cover component. Substrate characteristics (VI) and associated vegetation are assumed to be a measure of the ability of a habitat to provide cover to spawning adult river herring and their eggs and larvae. The characteristics of substrate are influenced by long-term effects of flow. For example, in areas of constant high flow, little vegetation or detritus accumulates; in low flow areas, detritus and silt accumulate and vegetation occurs. Substrates with 75% silt or other soft materials containing detritus and vegetation, and sluggish water flows are considered optimal for river herring. Substrate type can be measured during any period of the year.

Water quality component. Water temperatures (V2) determine the time of spawning by each species and also dictate duration of egg and larval development. Temperature extremes can terminate spawning attempts or kill eggs and larvae. Optimum spawning temperatures are assumed to be 15°-20°C (59°-68°F) for alewives (V_{2a}) and 20°-24°C (68.0°-75.2°F) for blueback herring (V_{2b}). Temperatures should be measured in spring and early summer, depending on location, when adults would normally be spawning.

Juvenile Model

The juvenile river herring HST model has food and water quality life requisite components. No cover requirement for juveniles was indicated in the literature. The model can be applied in riverine and estuarine habitats.

Food component. The number of zooplankton per liter (V,) is assumed critical for survival and growth of juvenile river herring, Roth alewives and blueback herring are size-selective zooplankton feeders that move within the water column in response to their prey. The identification of zooplankton species is difficult under field conditions, but measuring their numbers is easy. Habitat suitability is assumed to increase as the number of zooplankton increases from 0 to an optimum of 100 or more individuals per liter. Adequate numbers of zooplankton are assumed to provide the species conposition and sizes needed by river herring.

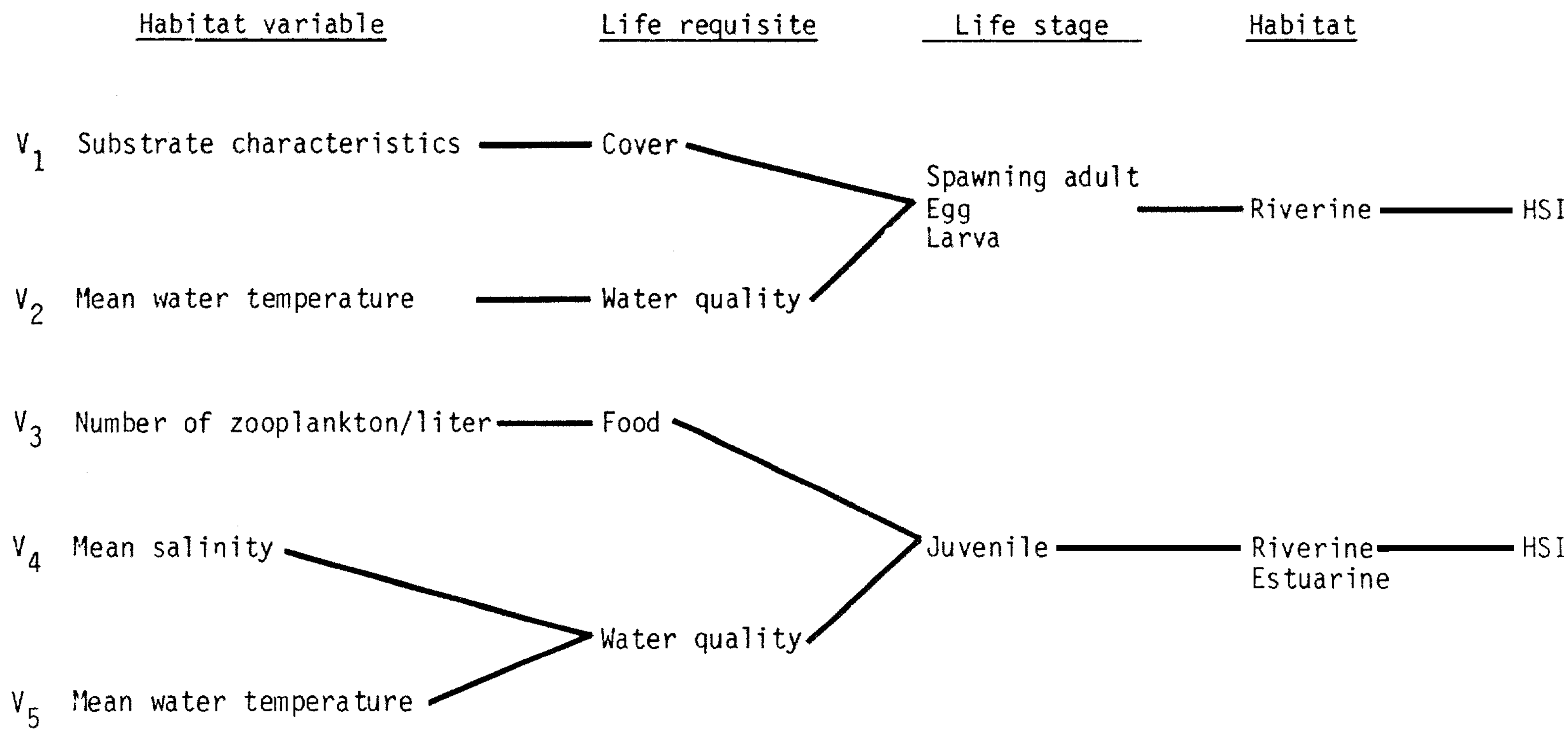


Figure 1. Relationship of habitat variables and life requisites to the habitat suitability index (HSI for river herring as spawning adults, eggs, and larvae or as juveniles.

Water quality component. Salinity (V_4) and temperature (V_5) comprise the water quality component of the juvenile model. River herring are tolerant of high salinities, but have preferences and are not normally found at salinities greater than 5 ppt. For purposes of this model, salinities of 5 ppt or less are considered optimal, and salinities greater than 5 ppt are less than optimal. Juvenile alewives were collected from areas with water temperatures up to 25°C (77°F), but they avoided higher temperatures. Optimal temperatures for alewives are considered to be between 15° and 20°C (59° and 68°F) (V_{5a}). All other temperatures are less than optimal. Juvenile blueback herring tolerate higher temperatures than alewives and optimal temperatures are considered to be between 20° and 30°C (68" and 86°F) (V_{5b}). All other temperatures are less than optimal. Water temperature is measured at the surface during summer and early fall.

Suitability Index (SI) Graphs for Habitat Variables

This section presents graphic representation of the various values of habitat variables and habitat suitability for the alewife and blueback herring in riverine (R) and estuarine (E) habitats. The suitability index (SI) values are to be read directly from the graph. Optimal suitability for a habitat is read as 1.0; SI values less than 1.0 indicate the corresponding values of the variable are less suitable for river herring. For those habitat variables that differ between species, each is designated as "a" for alewife and "b" for blueback herring. Components not labeled "a" or "b" are assumed identical for both species.

Equations for combining habitat variables into a composite HSI for riverine and estuarine habitats are presented in a following section. Data sources and assumptions associated with documentation of the SI graphs are presented in Table 1.

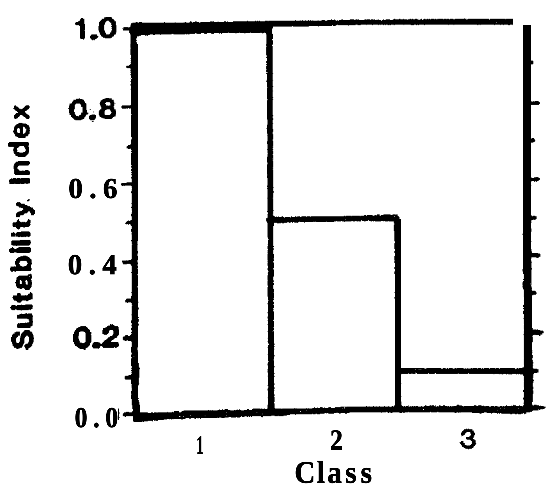
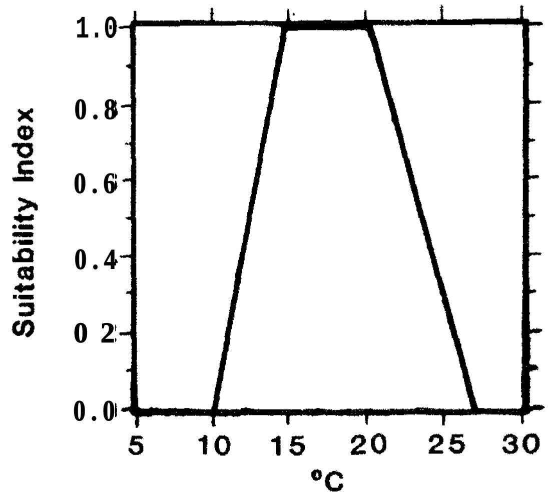
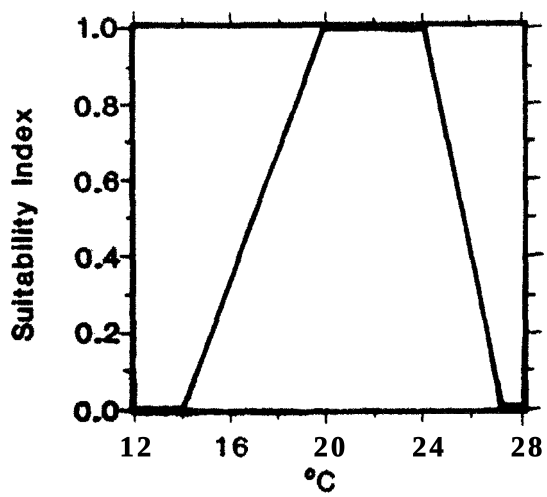
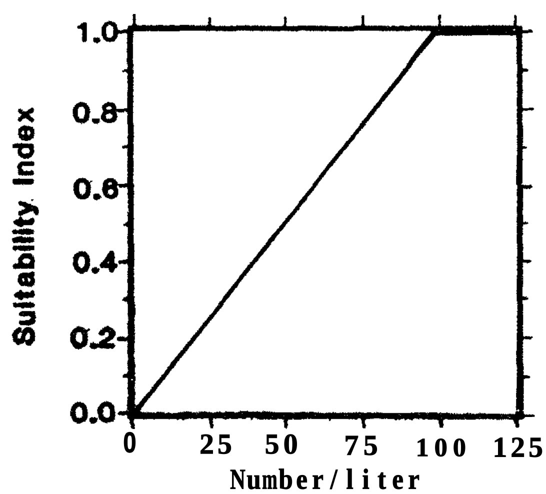
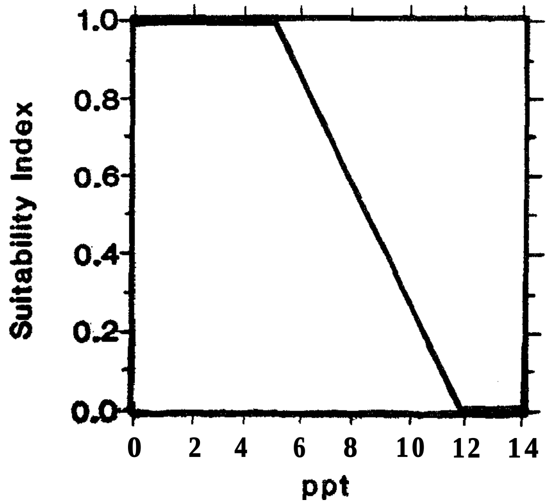
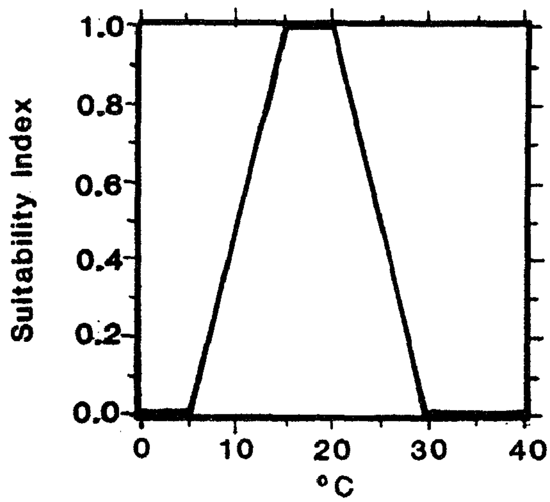
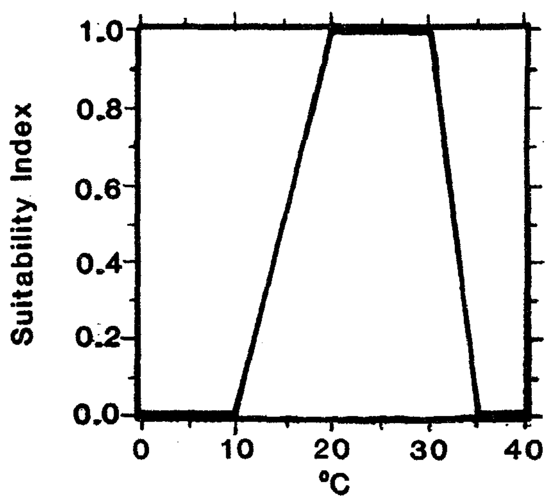
Habitat	Variable		Suitability Graph
R.E	V_1	Dominant substrate type for river herring spawning. 1) ~75% mud or silt or other soft material containing detritus and vegetation. 2) ≥ 50% mud or silt, some sand and vegetation. 3) ≥ 75% sand or other hard material with no vegetation.	

Table 1. Data sources and assumptions for river herring suitability indices.

Variable and source		Assumption
V_1	Edsall 1964 Mansueti and Hardy 1967 Sholar 1975 Street et al. 1975 Sholar 1977 Fischer 1980 Hawkins 1980a	The type of substrate over which river herring spawn most frequently is optimal.
V_2	Cianci 1969 Loesch 1969 Edsall 1970 Loesch and Lund 1977	Quantitative information on optimal spawning temperature for river herring is lacking. Mean daily water temperatures during the spawning season of 15°-20°C (59°-68°F) and 20°-24°C (68.0°-75.2°F) are assumed to be optimal for alewives and blueback herring, respectively.
V_3	Bigelow and Schroeder 1953 Norden 1968 Burbidge 1974 Vigerstad and Cobb 1978 Nigro and Ney 1982	One hundred or more zooplankton per liter is an optimal food resource for river herring.
V_4	Dovel 1971 Street et al. 1975 O'Neill 1980	Low salinity waters are optimal for juvenile river herring prior to fall migrations.
V_5	Meldrim and Gift 1971 Brandt 1978 Brandt et al. 1980 Street (pers. comm.)	Optima7 temperatures for juvenile river herring are those that result in optimum growth.

Habitat	Variable		Suitability Graph
R,E	V_{2a}	Mean daily water temperature during spawning season (alewife).	
R,E	V_{2b}	Mean daily water temperature during spawning season (blueback herring).	
R,E	V_3	Mean number of zooplankton per liter.	

Habitat	Variable		Suitability Graph
R,E	V_4	Mean salinity during spring or summer.	
R,E	V_{5a}	Mean surface water temperature (alewife).	
R,E	V_{5b}	Mean surface water temperature (blueback herring).	

Component Index Equations

The SI values for habitat variables must be combined into a component index for each life requisite included in the models. Suggested equations follow:

Spawning adult, egg, and larval model.

Component	Equation
Cover (C)	SI_{V_1}
Water Quality (WQ)	$SI_{V_{2(a\ or\ b)}}$

Juvenile model.

Component	Equation
Food (F)	SI_{V_3}
Water Quality (WQ)	$(SI_{V_4} \times SI_{V_{5(a\ or\ b)}})^{1/2}$

HSI Determination

A limiting factors approach is used to determine an HSI for the spawning adult, egg, and larval (SAEL) stage and the juvenile (J) stage for alewife or blueback herring. Similarly, when appropriate, an overall HSI for all life stages combined may be determined by the limiting factors approach. The following steps must be taken to determine an HSI for any application.

1. Review the section on model applicability for validity of model use.
2. Identify the boundaries of the evaluation area and obtain data for each model variable.
3. Determine the corresponding SI value for,each measured variable and the component indicies.
4. Calculate the HSI as:

$HSI_{(SAEL)}$ = WQ or C, whichever is lower

$HSI_{(J)}$ = F or WQ, whichever is lower

$HSI_{(SAEL + J)} = HSI_{(SAEL)}$ or $HSI_{(J)}$, whichever is lower

Six sample data sets with suitability indices and overall HSI index values derived from the models' equations are listed in Table 2. Three

Table 2. **Calculation of suitability** indices (SI) and life stage habitat suitability index (HSI) for three alewife and three blueback herring data sets, using habitat variables (V), suitability indices (SI), and **model equations.**

Model component	Alewife						Blueback herring					
	Data set 1		Data set 2		Data set 3		Data set 4		Data set 5		Data set 6	
	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
V_1	[1]	1.0	[2]	0.5	[3]	0.1	[1]	1.0	[2]	0.5	[3]	0.1
"Pa	18°C	1.0	24°C	0.43	8°C	0						
V_{2b}							22°C	1.0	18°C	0.67	27°C	0
V_3	100	1.0	50	0.5	25	0.25	100	1.0	50	0.5	25	0.25
V_4	6 ppt	0.86	14 ppt	0	20 ppt	0	6 ppt	**0.86**	**14 ppt**	**0**	**20 ppt**	**0**
V_{5a}	**18°C**	**1.0**	**10°C**	**0.5**	**30°C**	**0**						
V_{5b}							**18°C**	**0.8**	**10°C**	**0**	**20°C**	**1.0**
HSI (SAEL)	**1.0**		**0.43**		**0**		**1.0**		**0.5**		**0**	
HSI (J)	0.93		0		0		0.83		0		0	

hypothetical data sets are shown for the alewife and three are also shown for the blueback herring.

Field Use of Models

Because alewives and blueback herring have different habitat requirements, a habitat should be evaluated separately for each species. As a rule, use the spawning adult, egg, and larval model in known spawning areas. Use the juvenile model in areas where there is no spawning. The user may wish to combine the life stages into an overall HSI for each species when all life stages are known to be present.

The simplicity of the HSI model for either alewives or blueback herring eliminates the need for extensive field sampling and all but the most basic of collecting gear. Suggested techniques for measuring habitat variables are provided in Table 3. This simplified version of the many biological and physiochemical parameters that may affect alewife and blueback herring distribution and abundance necessitates careful measurement of the identified habitat variables used in this model. One-time measurements of variables are not recommended because model reliability will depend, in part, upon having sufficient data.

Table 3. Suggested techniques for measuring variables in riverine/estuarine habitats for application in the alewife-blueback herring HSI models.

Habitat variable	Technique[a]
V_1	Substrate samples can be obtained with a coring device such as an Ekman dredge or Ponar grab, and visually examined for percent composition of the various substrate materials. Rooted aquatic vegetation may be visually estimated.
V_2 and V_5	Temperature can be measured with any of a variety of thermometers at or near the surface to provide a usable instantaneous value.
V_3	Zooplankton may be collected with a Kemmerer water sampler, concentrated through a 10-micron mesh net, subsampled and counted under a simple compound microscope.
V_4	Salinity can be determined by using a refractometer, or a conductivity meter, or by titration.

[a]Collection and chemical methods can be found in American Public Health Association (1976).

The model user is required to measure flow during the site visit. This is easily done by measuring the average time required in repeated trials (minimum of 3) for an object to float past a known distance (usually 15 m or 49.2 ft). Simple calculations then provide surface flow in feet per second (ft/sec). If the surface flow is between 0 and 1.0 ft/sec, conditions appear suitable for spawning, egg, and larval development; and the user is instructed to proceed with the model. If the surface flow is 0 or greater than 1 ft/sec, the HSI = 0. Surface flow is measured along the bank in that zone of depths ranging from 15 cm to 3 m (5 inches to 10 ft), where spawning usually occurs during the spring season.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop habitat models for alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). The models are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for riverine and estuarine areas of the Atlantic Coast. Habitat suitability indices are designed for use with habitat evaluation procedures previously developed by the U.S. Fish and Wildlife Service. Guidelines for model applications and techniques for estimating model variables are described.

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