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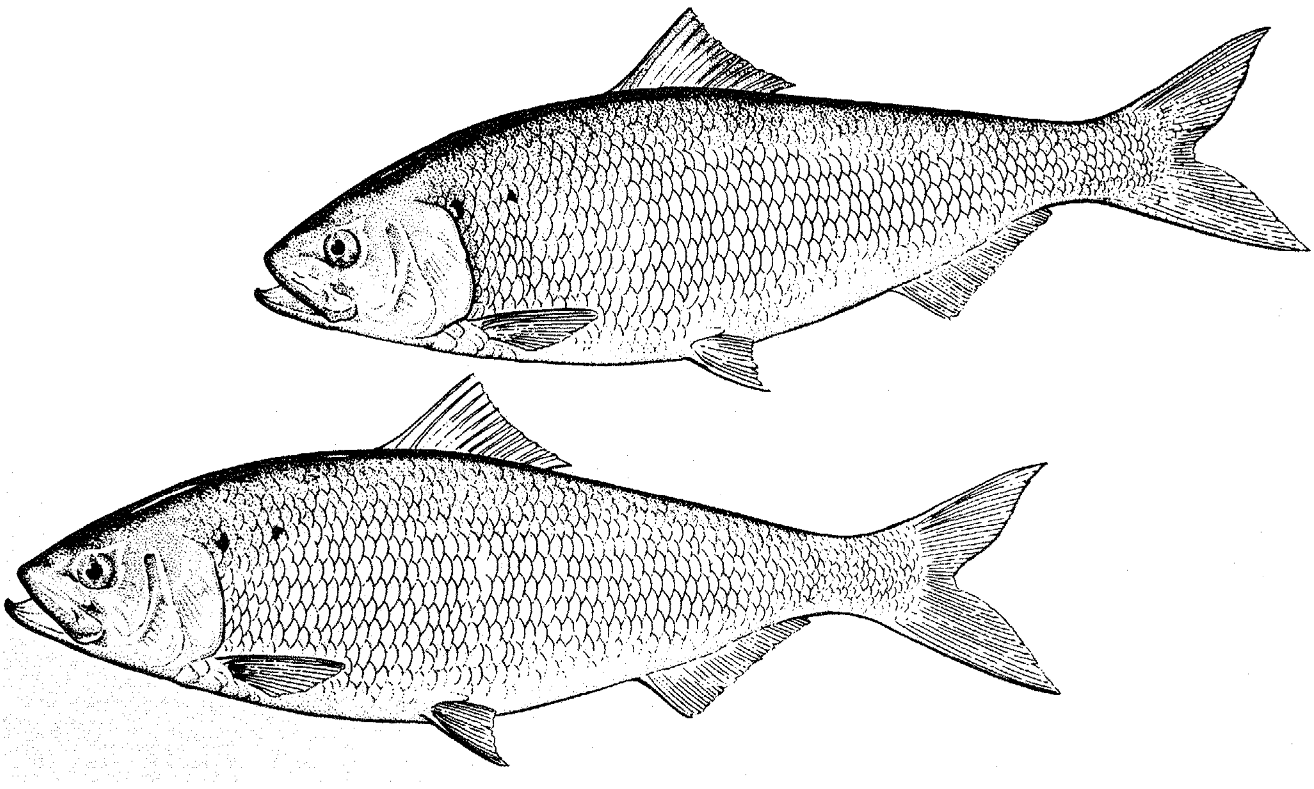

Fish and Wildlife Service

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 AND INSTREAM FLOW SUITABILITY CURVES: AMERICAN SHAD

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PREFACE

The American shad habitat suitability index (HSI) models were prepared by David Stier and are intended for use with the habitat evaluation procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980) for impact assessment and habitat management. The models were developed from a review 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 develop the HSI models and guidelines for model applications, including methods for measuring model variables, are described.

The Instream Flow Suitability Index (SI) curves were developed by Johnie Crance and are intended for use with the Instream Flow Incremental Methodology (IFIM) in assessment of instream flow alterations on riverine habitat of American shad.

Each model and SI curve is a hypothesis of species-habitat relationships, not a statement of proven cause and effect. The models and SI curves have not been field tested. For this reason, the U.S. Fish and Wildlife Service encourages model and IFIM SI curve users 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 you may have on the HSI models to the following address.

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Please send any comments or suggestions you may have on the IFIM SI curves to the following address.

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FIGURES

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ACKNOWLEDGMENTS

The habitat suitability index models for American shad were reviewed by Michael Dadswell, Canada Department of Fisheries and Oceans, St. Andrews, New Brunswick, and William Richkus, Martin Marietta Environmental Center, Columbia, Maryland. Constructive review and comments were also received from the staff of the National Coastal Ecosystems Team. We would also like to thank the Massachusetts Cooperative Fishery Research Unit for the use of their facilities and their helpful comments. Funding for model construction and publication was provided by the U.S. Fish and Wildlife Service. The cover was illustrated by Patrick J. Lynch.

The SI curves for use with IFIM are based primarily on information obtained from the results of a Delphi exercise. Gratitude goes to the following persons who participated in the American shad Delphi:

> Wayne Bowers, Oregon Department of Fish and Wildlife; Victor Crecco, Connecticut Department of Environmental Protection; Mark Gibson, Rhode Island Division of Fish and Wildlife; Robert Hesser, Pennsylvania Fish Commission; Harrel Johnson, North Carolina Division of Marine Resources; Alexis Knight, U.S. Fish and Wildlife Service; Joseph Loesch, Virginia Institute of Marine Science; Authur Lupine, New Jersey Division of Fish and Game; Billy McCord, South Carolina Wildlife and Marine Resources Department; Paul Perra, Atlantic States Marine Fisheries Commission; William Richkus, Martin Marietta Environmental Systems; and Jay Watson, U.S. Fish and Wildlife Service.

AMERICAN SHAD (*Alosa sapidissima*)

INTRODUCTION

The American shad, an anadromous species, is the largest member of the herring family (Clupeidae) and is native to North America (Talbot and Sykes 1958; Hildebrand 1963; Walburg and Nichols 1967).

Historically, the commercial fishery for American shad on the Atlantic coast was widespread and intense; in 1896 the estimated catch was 22.7 million kg (50 million lb). By 1960, however, the estimated catch had dropped to slightly more than 3.6 million kg (8 million lb), according to Walburg and Nichols (1967). Pollution, overfishing, and dams constructed across streams that prevent shad from reaching their spawning grounds have caused partial or total depletion of stocks (Hildebrand 1963). Several programs aimed at restoring American shad to their former range have been initiated by Federal and State agencies,

Distribution

American shad inhabit waters of the Atlantic coast from Labrador (Dempson et al. 1983) to Florida (Scott and Crossman 1973); however, no spawning populations north of the St. Lawrence River in Canada are known (Leggett 1976). American shad are most abundant about the center of their range, from Connecticut to North Carolina (Leim 1924; Walburg and Nichols 1967). On the Pacific coast, American shad were introduced into the Columbia and Sacramento Rivers in 1871 (Walburg and Nichols 1967) and now are found from the Mexican border to Cook Inlet, Alaska (Roedel 1953; Neave 1954). American shad also occur on the eastern shore of Kamchatka, USSR (Svetovidov 1963).

Life History Overview

American shad remain in the ocean for 2 (Walburg and Nichols 1967) to 6 years (Talbot and Sykes 1958). Both sexes mature at a minimum of 2 years (males, mean age 4.3; females, mean age 4.6), according to Leggett (1969). Mature males range from about 305 to 447 mm (12.0 to 17.6 inches) fork length (FL) and mature females range from about 383 to 485.1 mm (15.1 to 19.1 inches) FL (Walburg 1960). Cating (1953) reported shad 11 years old and 584 mm (23 inches) long.

Spawning runs begin in November in the southern portion of the American shad range (Hildebrand 1963), and as late as June (Foster and Atkins 1869; Leach 1925) or July (Cheek 1968) in the northern portion of their range.

American shad spawn only in freshwater (Leim 1924; Massman 1952; Walburg 1960), but there does not appear to be any required distance above brackish water (Massman 1952). As the spawning season approaches, schools move shoreward and to native streams (Talbot and Sykes 1958). Mature shad return to their natal tributary within a specific river system to spawn (Hammer 1942; Hollis 1948; Dodson and Leggett 1974; Carscadden and Leggett 1975).

Shad runs typically reach far upriver and often to the headwaters (Mansueti and Kolb 1953). Stevenson (1899) reported that shad migrated up to 328.2 km (204 mi) on the Connecticut River.

There is a clear latitudinal trend in gonadal development at the time of entry into the rivers. Gonads of the St. Johns River, Florida, shad are the least developed; gonads of Virginia populations are intermediate in condition; and those of the Connecticut River are the most fully developed (Glebe and Leggett 1981).

American shad also exhibit a pronounced latitudinal cline in post-spawning survival; southern populations are semelparous (spawn once and die), while northern populations are strongly iteroparous (repeat spawners) (Leggett and Carscadden 1978). As the proportion of repeat spawners increases, relative and absolute fecundities decrease. The reciprocal trends in relative fecundity and frequency of reproduction tend to reduce differences in mean lifetime egg production between southern and northern populations (Leggett and Carscadden 1978). Female American shad produce between 58,534 and 659,000 eggs (Walburg 1960; Roy 1969). Reports of lower fecundities are apparently in error (Lehman 1953; Jones et al. 1978).

Sex ratio is not constant throughout the period of upstream migration: the cumulative proportion of males decreases as the run progresses (Stevenson 1899; Prince 1907; Leach 1925; Hildebrand and Schroeder 1928; Nichols and Tagatz 1960; Walburg and Nichols 1967; Chittenden 1975). Spawning occurs at night in clear water, apparently from sunset to midnight or later (Leim 1924; Whitney 1961), or occurs all day in turbid rivers (Chittenden 1976). During the spawning act, the female is accompanied by several males; the spawning fish swim vigorously close to the surface, leaving a visible wake. The female broadcasts the eggs in the water column, where they are fertilized by the males (Talbot and Sykes 1958; Walburg and Nichols 1967; Roy 1969; Scott and Crossman 1973). Initially, the eggs are slightly adhesive (Chittenden 1969), but later become nonadhesive (Talbot and Sykes 1958; Walburg and Nichols 1967; Scott and Crossman 1973). Unfertilized eggs are about 1.8 mm (0.07 inch) in diameter (Leach 1925) and have a pale amber wrinkled egg capsule (Ryder 1887). Fertilized eggs are about 2.5-3.8 mm (0.10-0.15 inch) in diameter (Ryder 1887; Marcy 1976) and are transparent, pale pink, or amber (Scott and Crossman 1973). The eggs are carried by the currents and, being slightly heavier than water, gradually sink (Walburg and Nichols 1967).

The length of American shad larvae at hatching is about 5.7-10.0 mm (0.22-0.39 inch) total length (TL) (Leim 1924; Marcy 1976). Shad larvae absorb their yolk sacs when they reach 12.2 mm (0.48 inch) TL, in 4-7 days (Walburg and Nichols 1967). Initially, the larvae are planktonic and are carried passively from the spawning grounds (Marcy 1976).

American shad larvae grow rapidly and transform into juveniles about 4 to 5 weeks after hatching (approximately 25-28 mm or about an inch) (Leim 1924; Walburg and Nichols 1967). The juveniles form schools and gradually move downstream (Chittenden 1969). Their movement from spawning grounds to nursery areas is influenced by current, water temperature, and size (Watson 1968, 1970; Williams and Bruger 1972; Marcy 1976).

The literature contains discrepancies about juvenile utilization of estuaries. Little information exists describing the duration of time that juveniles spend in the estuary. Hildebrand (1963) indicated that juveniles may remain in estarine waters, such as the Chesapeake Bay, for the first year. Neves and Depres (1979), however, reported subadult shad (8 cm or 3.1 inches) taken with adults during bottom trawl sampling. The subadult size is comparable to the emigrating juvenile size, indicating that at least a portion of the emigrating juveniles pass through the estuaries and directly to the ocean. From the existing literature, it is difficult to predict whether a specific juvenile stock will remain in the estuary upon emigration from the home river. Further information concerning individual shad stocks will be necessary to determine precise residence time in estuaries.

Adults that survive spawning, together with subadults, migrate to the Gulf of Maine or to an area south of Nantucket Shoals and remain there through the summer and early fall. Most shad move out of the Gulf of Maine in fall when water temperature declines, and congregate offshore, between southern Long Island and Nantucket Shoals (lat. 39°-41° N), during the winter. Zooplankton abundance may be a factor in influencing shad distribution during the year (Neves and Depres 1979). Adults enter coastal waters in a broad front toward the Middle Atlantic coast, as far south as North Carolina during the winter and spring. Shad populations returning to southern U.S. rivers migrate south adjacent to the coast and within the 15° C (59° F) isotherm to reach natal rivers by winter and early spring. Northern U.S. and Canadian populations proceed north up the coast in the spring with the warming of coastal waters above 3° C (37.4° F) (Neves and Depres 1979). Nonspawning adults migrate up to 177 km (110 mi) from the coast (Hildebrand 1963) at a maximum depth of 160-230 m or 525-754 ft (Walburg and Nichols 1967). Nonspawning shad occur most frequently in offshore areas of intermediate depths (approximately 50-100 m or 160-328 ft) (Neves and Depres 1979).

Nonspawning adults have been recorded in brackish estuaries (Hildebrand 1963; Gabriel et al. 1976). The length of time each population spends inshore is not well documented.

SPECIFIC HABITAT REQUIREMENTS

Food

Adult. Adult shad are primarily plankton feeders and characteristically swim withtheir mouths open and gill covers extended, straining the water for food. Their diet consists principally of copepods and mysids, supplemented by small quantities of other planktonic crustaceans and some small fishes (Bigelow and Welsh 1925; Roy 1969; Scott and Crossman 1973). Little or no food has been found in American shad stomachs while they are migrating upriver (Leidy 1868; Clift 1874; Moss 1946; Nichols 1959) probably because the available food is too small to be retained by the gill rakers (Walburg and Nichols 1967). Atkinson (1951), however, reported that adult shad were observed feeding while maintained in a freshwater pond.

Larva and juvenile. The most critical time in the life cycle apparently occurs when the larvae have first absorbed the yolk sac and must find their own food (Hildebrand 1963). The food-limiting hypothesis has been offered to explain high larval mortality of Georges Bank herring (Graham and Chenoweth 1973) and Norwegian herring (Dragesund and Nakken 1971). May (1974), however, stated that available data cannot support the conclusion whether or not mortality is concentrated at the end of the yolk-sac stage in natural populations.

Larval and juvenile shad feed predominantly on aquatic insects and crustaceans. The dominance of aquatic insects and cladocerans in their diet has been observed by Mitchill et al. (1925) and Levesque and Reed (1972) in the Connecticut River and by Massman (1963), Maxfield (1953), Walburg (1956), Williams and Bruger (1972), Leim (1924), Davis and Cheek (1966), and Chittenden (1969) in other rivers along the Atlantic coast. The food variety suggests that shad are essentially opportunistic feeders, although they do appear to select food more from the water column than from the bottom or surface (Levesque and Reed 1972).

Temperature

Adult. Offshore movements are limited to areas and depths with near-bottom temperatures between 3° and 15° C (37.4° and 59.0° F) (Neves and Depres 1979). Shad occur most frequently in offshore areas of intermediate depths (approximately 50-100 m) (Talbot and Sykes 1958; Neves and Depres 1979). Estuarine temperatures from initial to peak arrival of shad at home rivers along the Atlantic coast range from 3° to 15° C with the lower values for northern populations and the higher values for southern populations (Talbot 1954; Massman and Pacheco 1957; Walburg and Nichols 1967; Leggett 1972; Leggett and Whitney 1972; Chittenden 1976). Peak numbers of shad enter the St. Johns River, Florida, in mid-January when water temperatures are at an annual low of 15° C; the peak in juvenile emigration occurs simultaneously (Leggett and Whitney 1972; Williams and Bruger 1972).

Although American shad have been reported spawning at water temperatures of 8°-26° C (46.4°-78.8° F), the peak of activity generally occurs from 14° to 21° C (57.2' to 69.8' F) (Walburg and Nichols 1967). The timing of the spawning run is highly correlated with water temperature, ensuring that the majority of adults arrives at the spawning grounds when temperature is optimum for egg and larval survival (Leggett and Whitney 1972). Peak movements into rivers occur at temperatures near 18.5° C (65.3° F) (Leggett and Whitney 1972). A review of investigations on shad migration by Watson (1968, 1970), Katz (1972, 1976), and Marcy (1972) revealed substantial evidence that shad normally discontinue upriver spawning migrations in the Connecticut River at water temperatures above 20° C (68° F) (Kuzmeskus 1977).

Egg and larva. The survival of eggs and larvae are closely related to water temperatures. Temperatures for maximum hatching and survival of eggs and larvae are 15.5°-26.0° C (59.9°-78.8° F) (Leim 1924; Massman 1952; Walburg 1960; Bradford et al. 1966; Marcy 1972). Leach (1925) reported that 11° C (51.8° F) is very near minimum temperature for successful incubation of eggs. Marcy (1976) was unable to find spawned eggs in abundance below 12° C (53.6' F). Water temperatures greater than 26.7° C (80.1' F) are definitely unsuitable for hatching of eggs and eventual development of larvae (Leim 1924; Carlson 1968).

Juvenile. Juveniles begin emigrating from streams and rivers when water temperatures drop below 15.5° C (59.9' F) (Leggett and Whitney 1972). Some remain in estuarine waters such as the Chesapeake Bay for the first year, and those in northern localities tend to remain inshore for at least the first year (Hildebrand 1963).

Water temperature is an important factor affecting growth and survival of juvenile American shad. The lower thermal tolerance limit is about 2.2° C (36.0° F), but sublethal effects suggest that prolonged exposure to 4°-6° C (39.2°-42.8° F), cannot be tolerated (Chittenden 1972). Juveniles were found in water temperatures ranging from 10° to 31° C (50.0' to 87.8' F), although only one fish was found at 31° C (Marcy et al. 1972).

Dissolved Oxygen

Adult. The spawning environment is generally characterized by well-oxygenated flowing water. Dissolved oxygen concentrations of 5.0 mg/l or more are required throughout the spawning area (Walburg and Nichols 1967).

Egg and larva The lethal dose necessary to kill 50% of a test population (LD_{50}) of shad eggs and larvae from Atlantic coast stocks was between 2.9 and 2.5 mg/l dissolved oxygen concentration (Bradford et al. 1966). Marcy (1976) found no shad eggs at dissolved oxygen levels less than 5.0 mg/l. Dissolved oxygen levels less than 1.0 mg/l caused total mortality to shad eggs (Carlson 1968).

Juvenile. Dissolved oxygen requirements of juveniles appear to be similar to those of adults. Chittenden (1969) found that at dissolved oxygen levels below 3.0 mg/l, equilibrium was lost; at levels below 2.0 mg/l, heavy mortality occurs; and at less than 0.6 mg/l, all immediately die. It should be emphasized that the last value refers to an immediate mortality of exposed fish. Ellis et al. (1947) performed studies on the oxygen requirements of juveniles. They reported that many fish died before dissolved oxygen levels of 5.0 mg/l were reached, and that water containing less than 5.0 mg/l dissolved oxygen constituted a lethal barrier to the passage of shad.

Salinitv

Adult. American shad adults have a wide range of salinity tolerances necessary for an anadromous species. Despite this tolerance Leggett and O'Boyle (1976) reported that transferred shad began experiencing'heavy mortality 5 h after the initial reduction in salinity associated with movement into freshwater. Adults require 2-3 days to adapt to freshwater as evidenced by their meanderings in estuaries before entering the rivers (Dodson et al. 1972; Leggett 1976).

Egg and larva. Leim (1924) reported that American shad eggs and larvae survived exposure to salinities of 7.5-15.0 parts per thousand (ppt) at 12° and 17° C (53.6' and 62.6° F), but survival at 15 ppt was less favorable at 12°C than at 17° C. Chittenden (1969) concluded that young shad are extremely tolerant of salinity and salinity changes and, based on Leim's work, salinity tolerance apparently begins at the earliest stage of life.

Other Requirements

Adult. American shad may spawn anywhere in rivers, but they prefer areas dominated by broad flats or shallow water (Smith 1907; Bigelow and Welsh 1925; Hildebrand and Schroeder 1928; Massman 1952; Marcy 1972). American shad have been observed to spawn over a variety of substrates (Mansueti and Kolb 1953; Walburg 1960; Leggett 1976), preferably over sand and gravel bottom with sufficient water velocity to eliminate silt deposits (Walburg and Nichols 1967). Active spawning occurs over a wide range of water velocities from 9.1 to 132.0 cm/sec (0.3 to 4.3 ft/sec) (Kuzmeskus 1977), although it generally occurs from 30.5 to 91.4 cm/sec (1.0 to 3.0 ft/sec) during normal flow (Walburg 1960; Walburg and Nichols 1967).

Spawning has been observed at all depths in rivers, specifically from 0.45 to 12.2 m (1.5 to 40 ft) (Mansueti and Kolb 1953; Walburg 1960; Walburg and Nichols 1967; Kuzmeskus 1977).

Egg and larva. It appears that larvae are much less tolerant of suspended sediments than eggs. Auld and Schubel (1978) reported that concentrations of suspended sediments greater than 100 parts per million (ppm) significantly reduced survival of shad larvae continuously exposed for 96 h.

Although predation may be a potentially significant cause of larval mortality, such data are lacking for most fish species (May 1974; Dahlberg 1979).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

These habitat suitability index (HSI) models are designed to apply to American shad habitat along the Atlantic coast of the United States. They may, however, have applications to other areas where this species is found because the models are generalized to reflect the life cycle and requirements of American shad throughout its coastal range. Few generalized statements concerning habitat requirements will be precisely applicable to all areas. Consequently, it is desirable that information pertaining to a particular habitat be evaluated with regard to model criteria.

In some cases, average values have been used for model variables. Sudden changes in one habitat variable may affect American shad tolerances to other habitat factors. Therefore, caution should be exercised in calculating average values in situations marked by extreme variability.

The use of these models is not appropriate in areas where extensive habitat deterioration due to toxic wastes has occurred.

Season. The habitat suitability index (HSI) models are designed to apply only during those seasons when freshwater and estuarine habitats are used by American shad.

Habitat types. For the purpose of these models, American shad utilize two habitats: the riverine and estuarine systems as described by Cowardin et al. (1979). At least 50% of estuarine habitat should be subtidal (substrate continuously submerged) for application of the estuarine model. No model was developed for the evaluation of marine habitat. Although subadult and adult shad use this habitat type, insufficient information was available for model development.

Minimum habitat area. The minimum habitat area is that area of contiguous suitable habitat required for American shad to live and reproduce. No minimum habitat size for this species has been established.

Verification level. The acceptable output of the HSI model is an index that is believed to have a positive relationship to carrying capacity. The index varies from 0 (unsuitable habitat) to 1.0 (optimal habitat). Hypothetical data sets were used to verify that HSI's determined with the American shad models were reasonable and acceptable. These data sets and their relationship to model verification are described later.

Two biologists outside of the U.S Fish and Wildlife Service reviewed and evaluated the riverine and estuarine HSI models: Michael Dadswell, Canada Department of Fisheries and Oceans, St. Andrews, New Brunswick, and William Richkus, Martin Marietta Corporation, Columbia, Maryland. Their comments were incorporated when possible, but David Stier is responsible for the final versions of the models.

Model Descriptions

Separate riverine and estuarine HSI models were developed for the American shad. The models consider the quality of habitat requirements (variables) for specific life stages of the species. It is assumed that habitat suitability is primarily associated with water quality (physicochemical conditions) during most life stages. A minimum dissolved oxygen level of 5.0 mg/l is assumed to be necessary before either of the models can be applied. The relationship of habitat variables to life stage components for the American shad in riverine and estuarine habitats is illustrated in Figures 1 and 2.

Riverine model. The riverine HSI model considers three habitat variables and two life stage components (Figure 1). The availability of zooplankton, the major food of larvae and juveniles, is difficult to quantify in riverine habitat. The model, therefore, assumes that food is not limiting for American shad in riverine areas. Temperature is the remaining variable that influences juvenile habitat suitability. Because juveniles in riverine habitat have a wide range of temperature tolerance, this life stage was not included in the riverine HSI model. The model only evaluates habitat for the spawning adult and for the combined egg and larval stages, which have similar habitat requirements. The assumptions involved in selection of variables are described below.

Habitat suitability for spawning adults is limited primarily by water quality. Mean water temperature (V_1) and current velocity (V_2) were considered to be the two most important variables for evaluating habitat. Because American shad spawn over a wide variety of substrates at many depths, these variables were excluded from the model.

Water temperature during spawning can range from 8° to 26° C (46.4° to 78.8' F), and optimal temperatures are assumed to be 14°-20° C (57.2°-68.0° F). Spawning occurs at water velocities of 9.1-132 cm/sec (0.3-4.3 ft/sec) with optimum velocities of 30.5 to 91.4 cm/sec (1.0 to 3.0 ft/sec). The model assumes that there is no compensatory relationship between these variables and that habitat quality is determined by the lower of the two values.

For the combined egg and larval component, mean water temperature (V_3) is the single variable used for rating habitat quality in riverine habitat. The temperature range for egg incubation and larval development is approximately 10°-30° C (50°-86° F). Maximum development is assumed to occur at temperatures from 15° to 25° C (59° to 77° F). Although little information exists on the tolerance of eggs and larvae to suspended sediment concentration, the HSI model assumes that habitats with sediment loads exceeding 100 ppm during the period of larval development are unsuitable.

Estuarine model. The estuarine HSI model considers two habitat variables and one life stage (juvenile) component (Figure 2). Adult shad use the estuary primarily to enter and exit their home rivers where spawning occurs. Meanderings at the interface of the river and coast do occur, but they are generally limited to a duration of several days. Therefore, adult habitat requirements in the estuary were not considered.

Mean near-bottom water temperature (V_4) and percentage of total study area supporting submerged and emergent vegetation (Vs), assumed to be an indirect measure of zooplankton abundance, were considered to be the two most important factors for assessing estuarine habitat quality for juvenile American shad. The model assumes no compensatory relationship between the variables. Habitat quality is, therefore, determined by the lower value.

Mean near-bottom temperatures of 10°-25° C (50°-77° F) are assumed to be optimal. Temperatures below 3° C (37.4' F) and above 35° C (95° F) are unsuitable.

Zooplankton abundance may be a factor influencing shad distribution in saltwater (Neves and Depres 1979). Although zooplankton abundance fluctuates widely over time in any estuary: the potential for an abundance of zooplankton appears to be related to estuarine productivity. The level of productivity in an estuary is a function of both freshwater nutrient (detritus) input to the estuary (Biggs and Flemer 1972; Hobbie et al. 1973; Saila 1973; Day et al.

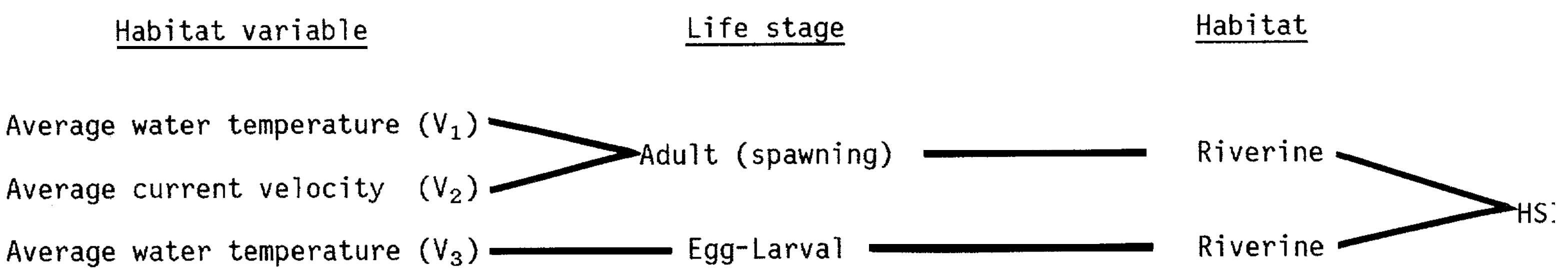


Figure 1. Tree diagram illustrating the relationships of habitat variables and life stages to the Habitat Suitability Index (HSI) for American shad in riverine habitat.

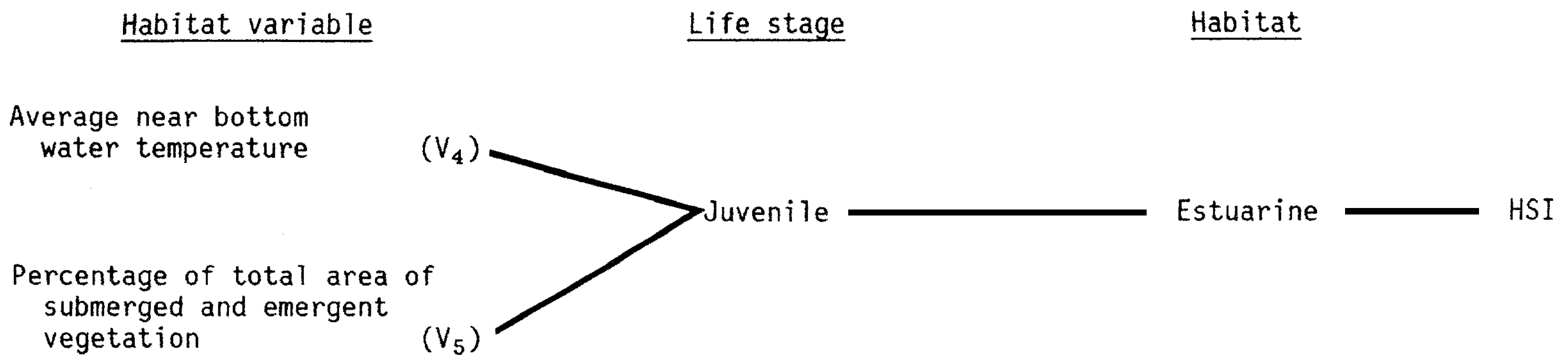


Figure 2. Tree diagram illustrating the relationships of habitat variables and life stage to the Habitat Suitability Index (HSI) for American shad in estuarine habitat.

1975; Polgar et al. 1975) and detritus production in the salt marsh (Teal 1962; Odum and Heald 1973; Reimhold et al. 1973; Stevenson et al. 1975). Detrital input to the estuary from freshwater inflow is typically greatest during the late winter and early spring. Seagrass beds also provide living space for a rich epifauna of both mobile and sessile organisms (Harlin 1980) in the estuary. Yokel (1975) has shown that a standing crop of crustaceans was 3.9 times larger in seagrass beds than on unvegetated bottoms.

While it is not possible to predict zooplankton abundance, indirect measures can be used to reflect the potential of the estuarine habitat to provide sufficient zooplankton prey. One method relates estuarine productivity to freshwater input during the spring and the extent of salt marsh (Bain and Bain 1982). This model assumes a positive relationship between primary and secondary productivity in an aquatic ecosystem. It assumes that the amount of submerged and emergent vegetation (Vs) will be a qualitative estimate of the estuary's secondary productivity and, therefore, food availability to juvenile shad. Estuarine habitat with 50% or more vegetation coverage is considered optimal.

Suitability Index (SI) Graphs for Model Variables

This section provides graphic representations of the relationships between different measures of each riverine (R) and estuarine (E) habitat variable and the corresponding SI value. The assumptions involved in developing the SI graphs are summarized in Table 1.

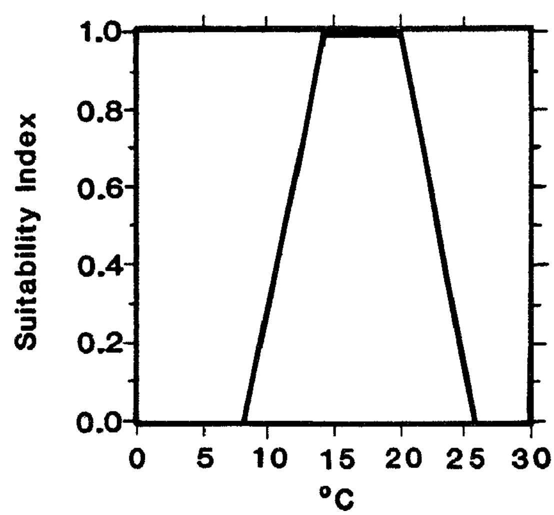
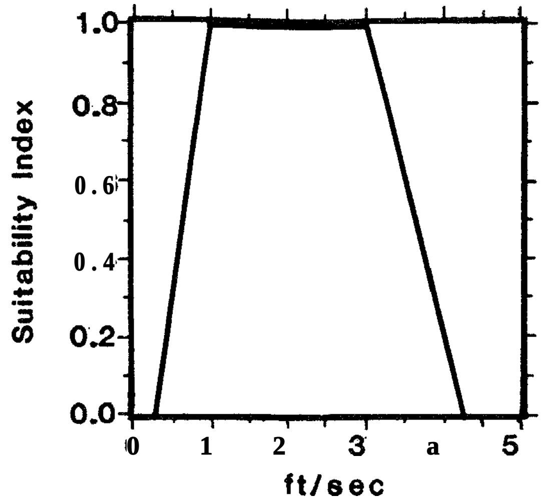
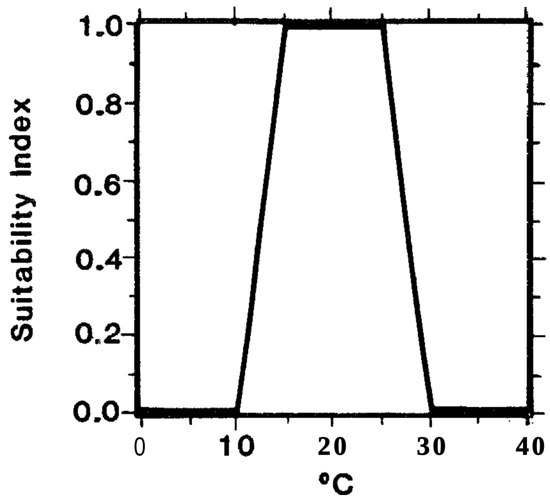
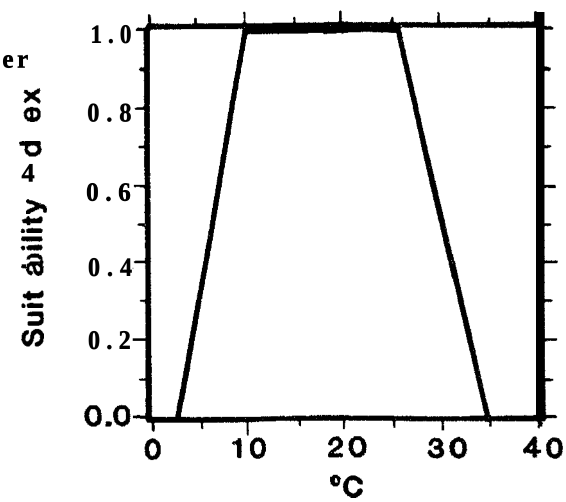
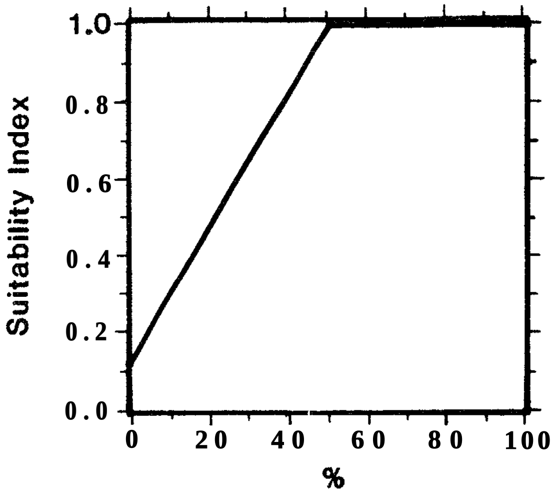
Habitat	Variable		Suitability Graph
R	V_1	Mean surface water temperature during spawning season.	

Table 1. Data sources and assumptions for American shad suitability indices.

Variable and source	Assumption
V_1 Walburg and Nichols 1967	Optimal water temperatures for American shad spawning range from 14° to 20° C. Temperatures below 8° C and above 26° C are unsuitable.
V_2 Walburg and Nichols 1967 Kuzmeskus 1977	Habitat quality for spawning American shad is related to water velocity. Optimal velocity during the spawning season ranges from 1 to 3 ft/sec.
V_3 Leim 1924 Massman 1952 Walburg 1960 Bradford et al. 1966 Carlson 1968 Marcy 1972	Optimal near-surface water temperature for American shad egg and larval development range from 15° to 25° C. Temperatures below 10° C and above 30° C are unsuitable.
V_4 Chittenden 1972 Leggett and Whitney 1972 Marcy et al. 1972	Mean near-bottom water temperatures of 10°-25° C are optimal for juvenile American shad. Temperatures below 3° C and above 35° C are unsuitable.
V_5	The percentage of an estuary supporting growth of submerged and/or emergent vegetation is an indirect indication of food availability to juvenile American shad.

Habitat	Variable		Suitability Graph
R	V_2	Mean water velocity during spawning season.	
R	V_3	Mean surface water temperature during egg and larval development.	
E	V_4	Mean near-bottom water temperature during winter and spring.	

Habitat	Variable		Suitability Graph
E	V_5	Percentage of area supporting emergent and/or submerged vegetation.	

Component Index (CI) Equations

To obtain life stage component indices for the adult (CI_a), egg plus larva (CI_{el}), and juvenile (CI_j), the SI values for appropriate variables must be combined. Suggested equations are:

Spawning adult (CI_a) = SIV_1 or SIV_2, whichever is lower

Egg plus larva (CI_{el}) = SIV_3

Juvenile (CI_j) = SIV_4 or SIV_5, whichever is lower.

HSI Determinations

The following steps must be taken to determine an HSI for any application of the models in riverine and/or estuarine habitats:

1. Review the section on model applicability for validity of the model(s) for the intended application(s). If dissolved oxygen falls below 5.0 mg/l for an extended period in any habitat, the HSI for American shad is set at 0. Similarly, the HSI for the combined egg and larval stage is set at 0 if mean sediment concentration at the middle of the water column exceeds 100 ppm. [Techniques for measuring sediment concentration are described in Auld and Schubel (1978) and American Public Health Assoc. (1976)]

2. Identify the boundaries of the elevation area(s) and obtain data for each model variable used in the model. Use the SI graphs and equations to calculate the component indices.

3. **Calculate the HSI as:**

Riverine HSI = CI_a or CI_{el}, whichever is lower

Estuarine HSI = CI_j.

Four sample data sets from which suitability indices, component indices, and habitat suitability index values have been generated using the model equations are presented in Table 2. If it is determined that juvenile American shad are absent from the estuary, the estuarine HSI model will not be used.

The data sets are not actual field measurements, but represent the kinds of values that one could expect to obtain in riverine and estuarine habitats used by American shad. The HSI's calculated from these hypothetical data sets reflect carrying capacity trends that the author believes are appropriate for water bodies with the characteristics listed in Table 2.

Table 2. Calculations of suitability indices (SI), component indices (CI), and habitat suitability indices (HSI) for four sample data sets, using the American shad habitat variables (V) and model equations.

Model	Data set 1		Data set 2		Data set 3		Data set 4	
component	Data	SI	Data	SI	Data	SI	Data	SI
V_1	12.5	0.75	17.5	1.00	10.0	0.33	22.5	0.58
V_2	0.9	0.86	3.5	0.62	1.00	1.00	2.5	1.00
V_3	15.0	1.00	13.0	0.60	20.0	1.00	26.5	0.70
V_4	17.5	1.00	10.0	1.00	5.0	0.29	20.0	1.00
V_5	50.0	1.00	25.0	0.55	75.0	1.00	20.0	0.46
CI_a	0.75		0.62		0.33		0.58	
CI_{el}	1.00		0.60		1.00		0.70	
CI_j	1.00		0.55		0.29		0.46	
HSI (Riverine)	0.75		0.60		0.33		0.58	
HSI (Estuarine)	1.00		0.55		0.29		0.46	

Field Use of Models

The level of detail needed for a particular application of these models will vary depending on time, money, and accuracy constraints. Detailed evaluation of all variables will produce the most reliable and repeatable HSI values. Use of previously collected data for any or all variables may produce a satisfactory application of the model with minimal expense. Data required by the models are frequently available from publications or resource agencies. Table 3 presents suggested techniques for measuring model variables and notes references to consult for more detailed guidance.

Table 3. Suggested techniques for measuring variables in estuarine and riverine habitats for application of the American shad HSI models.

Variable	Technique
V_1	Consult existing data and literature, or field-sample by using a thermometer or thermistor probe (Strickland and Parsons 1968; American Public Health Assoc. 1976).
V_2	Consult existing data and literature, or take field measurements (Buchanan and Somers 1976; Stalnaker and Arnette 1976).
V_3	Consult existing data and literature, or field-sample by using a thermometer or thermistor probe (Strickland and Parsons 1968; American Public Health Assoc. 1976).
V_4	Consult existing data and literature, or field-sample by using a thermometer or thermistor probe (Strickland and Parsons 1968; American Public Health Assoc. 1976).
V_5	Consult historical maps and information, current topographical maps, data, and aerial photographs and combine with field observations (Map Information Office, Geological Survey Department, Department of Interior, Washington, D.C.).

Any or all variables can be estimated for preliminary applications of the model. Subjective estimates will decrease model reliability and repeatability. When subjective estimates are used, they should be made by experienced professionals, if possible, and accompanied by full documentation.

Interpreting Model Outputs

An American shad HSI determined by field application of these models may not reflect the population density of the species in the study area, since factors other than habitat-related ones may be significant in determining population size. In coastal areas, however, where American shad populations are primarily regulated by habitat-based factors, the models presented here should yield HSI's that are positively correlated with long-term average population levels.

INSTREAM FLOW INCREMENTAL METHODOLOGY

Instream Flow Incremental Methodology (IFIM) is a process of stepwise analyses used to assess instream flow problems (Bovee 1982). The Physical Habitat Simulation System (PHABSIM) model (Mifhous et al. 1984), a component of IFIM, is used to compute the amount of available instream habitat for life stages of a species as a function of streamflow.

The output generated by the PHABSIM component of IFIM can be used for several IFIM habitat display and interpretation techniques, including:

1. Habitat Time Series. Determination of impact of a project on a species' life stage habitat by imposing project operation curves over baseline flow time series conditions and integrating the difference between the corresponding time series;

2. Effective Habitat Time Series. Calculation of the habitat requirements of each life stage of a single species at a given time by using habitat ratios (relative spatial requirements of various life stages); and

3. Optimization. Determination of flows (daily, weekly, and monthly) that minimize habitat reductions for a complex of species and life stages of interest.

Suitability Index Curves Used in IFIM

PHABSIM utilizes Suitability Index (SI) curves that describe the instream suitability of the habitat variables most closely related to stream hydraulics and channel structure (e.g., velocity, depth, substrate, cover, and temperature) for each major life stage of a given fish species (e.g., spawning, egg incubation, larval, juvenile, and adult). The Western Energy and Land Use Team (WELUT) has designated four categories of curves and standardized the terminology pertaining to the curves (Armour et al. 1984). The designation of a curve as belonging to a particular category does not imply that there are differences in the quality or accuracy of curves among the four categories.

Category one curves are the most common type presently available for use with IFIM. Category one curves have, as their basis, one or more literature sources. Some may be derived from general statements made in the literature about fishes (e.g., rainbow trout spawn in gravel; fry prefer shallow water). Others may come from literature sources which include variable amounts of field data (e.g., from a sample size of 300, fry were observed in velocities ranging from 0 to 0.9 m (0 to 3.0 ft/s), and 80% were found in velocities less than 30.5 cm/s (1.0 ft/s). Other category one curves may be based entirely or partially on professional opinion obtained by using the Delphi technique

(Crance 1984). Most category one curves are the result of a combination of sources; an individual curve may include information from the literature, combined with field data, and smoothed or modified using professional judgment. Category one curves usually are intended to reflect general habitat suitability throughout the entire geographic range of the species and throughout the year, unless they are identified as being applicable only to a given area or season. In the latter case, curves developed for a specific area or stream may not accurately reflect habitat utilization in other areas. Curves meant to describe the general habitat suitability of a variable throughout the entire range of a species may not be sensitive to small changes of the variable within a specific stream (e.g., rainbow trout generally utilize silt, sand, gravel, and cobble for spawning substrate, but utilize only cobble in Willow Creek, Colorado).

Category two curves are derived from frequency analyses of field data and basically are curves fit to a frequency histogram. Each curve describes the observed utilization of a habitat variable by a life stage of the evaluation species. Category two curves, unaltered by professional judgment or other sources of information, are referred to as utilization curves. When modified by judgment, they are considered category one curves. Utilization curves from one set of data are not applicable for all streams and situations (e.g., a depth utilization curve from a shallow stream cannot be used for the Missouri River). Category two curves, therefore, are usually biased because of limited habitat availability. An ideal study stream would have all substrate and cover types present in equal amounts; all depth, velocity, and percent cover intervals available in equal proportions; and all combinations of all variables in equal proportions. Utilization curves from such a perfectly designed study theoretically should be transferable to any stream within the geographical range of the species. Curves from streams with high habitat diversity are generally more transferable than curves from streams with low habitat diversity. Users of category two curves should first review the stream description to see if conditions are similar to those present in the stream segment to be investigated. Some variables to consider include stream width, depth, discharge, gradient, elevation, latitude and longitude, temperature, water quality, substrate and cover diversity, fish species associations, and data collection descriptors (e.g., time of day, season of year, sample size, and sampling methods). If one or more factors deviate significantly from those of the proposed study site, curve transference is not advised, and the investigator should develop his or her own curves.

Category three curves are derived from utilization curves that have been corrected for environmental bias and, therefore, represent the preference of the species. Habitat utilization data and habitat availability data must simultaneously be collected from the same area in order to generate a preference curve. Habitat availability information should reflect the relative amount of different habitat types in the same proportions as they exist throughout the stream study area. A curve is then developed for the habitat frequency distribution in the same way as for fish utilization observations. The equation coefficients of the availability curve are subtracted from the equation coefficients of the utilization curve, resulting in preference curve coefficients. Theoretically, category three curves should be Unconditionally transferable to any stream although this has not been validated. At present, very few category three curves exist because most habitat utilization data sets are without concomitant habitat availability data sets. In the future, investigators will be encouraged to collect habitat availability data,

Category four curves (conditional preference curves) describe habitat preferences as a function of interaction among variables. For example, fish depth utilization may depend on the presence or absence of cover, or velocity utilization may depend on time of day or season of year. Category four cuvres are just beginning to be developed and are still largely conceptual.

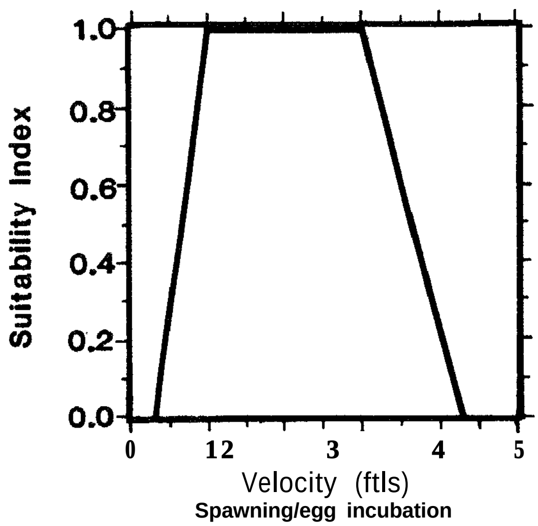
IFIM analyses may utilize any or all categories of curves, but category three and four curves would yield the most precise results. Category two curves yield accurate results if they are transferable to the stream segment under investigation. If no category three or four curves are available and category two curves are not transferable for a particular application, category one curves may be the better choice. A basic assumption of the IFIM is that the evaluation species exhibits a describable preference/avoidance behavior for one or more of the microhabitat variables of depth, velocity, substrate, and cover.

Availability of American Shad SI Curves for Use With IFIM

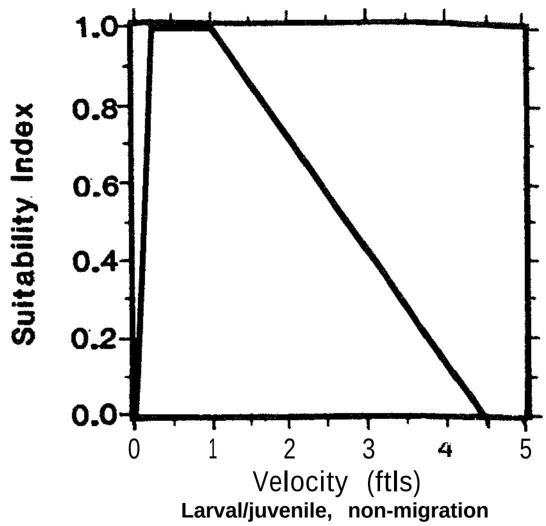
The Instream Flow and Aquatic Systems Group, WELUT, maintains a library of SI curves for riverine species of fish. Each curve is accompanied by information giving the basis for the curve and x, y coordinate pairs for the curve. The x coordinate values are reported in English units (e.g., ft/s and °F) which need not be converted to metric units when used with the PHABSIM model to compute weighted useable area of habitat. Curves in the library are available upon request for use in IFIM analyses.

SI curves available for use with IFIM analyses of American shad riverine habitat. SI curves available for use with IFIM analyses of American shad riverine habitat are presented in Figure 3 through Figure 6. They are each category one curves based on information in the literature and/or a four-round Delphi exercise conducted by mail during August 1984 to May 1985. Twelve fishery biologists served as panelists for the Delphi exercise. Each panelist had a substantial amount of experience and knowledge related to American shad. Eleven of the panelists responded to the final round of the exercise. Details of the results of the American shad Delphi exercise are being completed (Crance, in prep.) and will be available upon request.

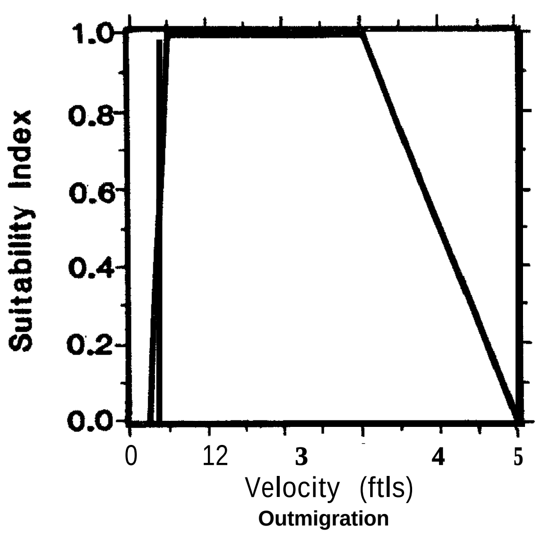
Velocity/spawning and/or egg incubation. The spawning and/or egg incubation velocity SI curve (Figure 3) is based on information in the literature (Walburg 1960; Walburg and Nichols 1967; Kuzmeskus 1977), which is summarized in the HSI section of this report and was used as the basis for the velocity suitability graph (V_2) included in the riverine HSI model. A spawning velocity SI curve also resulted from the American shad Delphi exercise. The curve had coordinates ($x = 0.2$ ft/s, $y = 0$; $x = 1.0$ to 2.5 ft/s, $y = 1$; $x = 4.5$ ft/s, $y = 0$) very similar to coordinates for the literature-based spawning velocity SI curve presented in Figure 3.



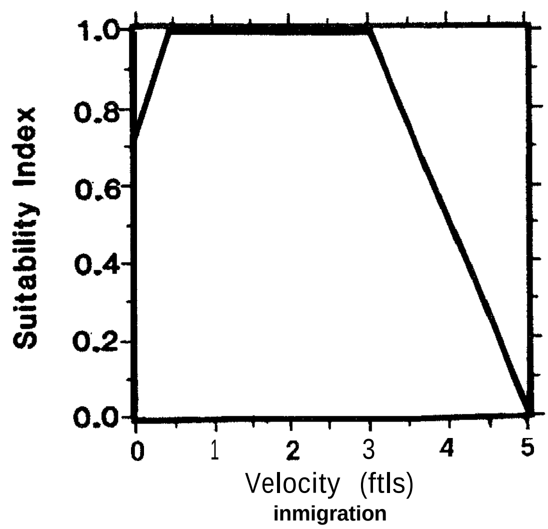
x ft/s	y SI
0.3	0.0
1.0	1.0
3.0	1.0
4.3	0.0



x ft/s	y SI
0.0	0.0
0.2	1.0
1.0	1.0
4.5	0.0

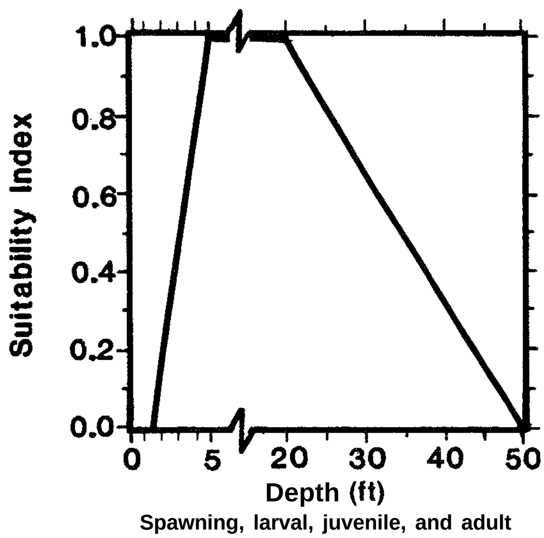


x ft/s	y SI
0.2	0.0
0.5	1.0
3.0	1.0
5.0	0.0

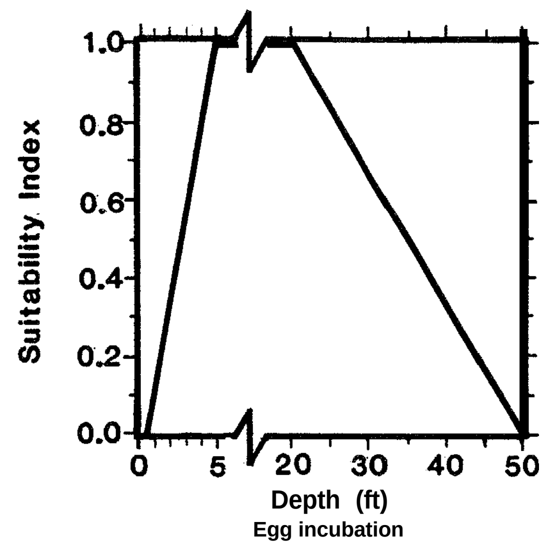


x ft/s	y SI
0.0	b.7
0.5	1.0
3.0	1.0
5.0	0.0

Figure 3. Velocity SI curves for IFIM analyses of American shad riverine habitat.



x ft	y SI
1.5	0.0
5.0	1.0
20.0	1.0
50.0	0.0



x ft	y SI
0.5	0.0
5.0	1.0
20.0	1.0
50.0	0.0

Figure 4. Depth SI curves for IFIM analyses of American shad riverine habitat.

Coordinates

x Code	Particle size	y SI
1	Plant detritus/organic material	0.0
2	Mud/soft clay	0.1
3	Silt (<0.062 mm)	0.2
4	Sand (0.062 to 2 mm)	1.0
5	Gravel (2 to 64 mm)	1.0
6	Cobble/rubble (64 to 250 mm)	1.0
7	Boulder (250 to 4,000 mm)	0.6
8	Bedrock (solid rock)	0.4

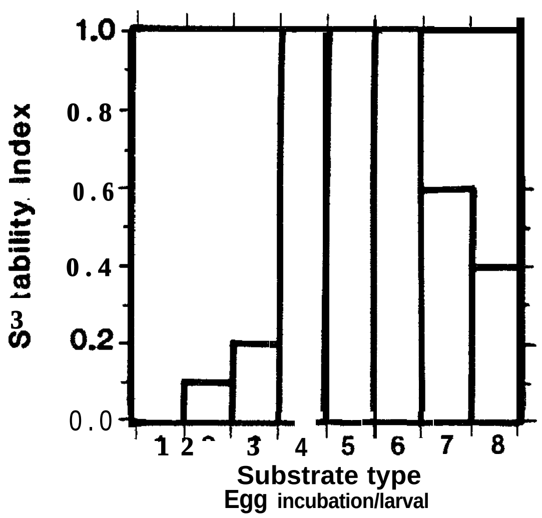
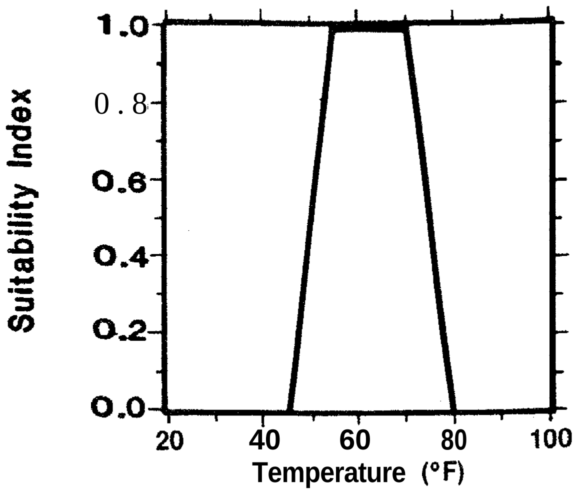
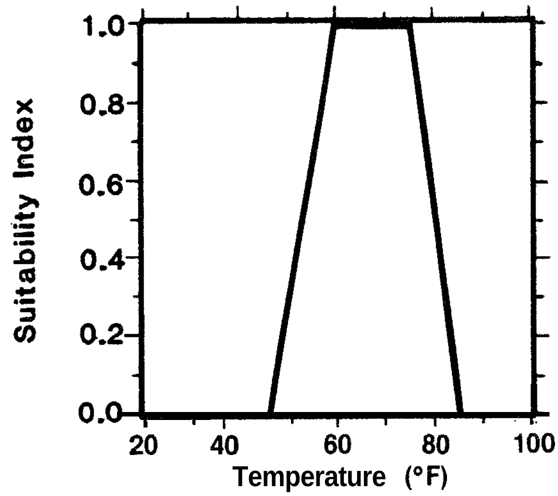


Figure 5. Substrate SI graph for IFIM analyses of American shad riverine habitat.



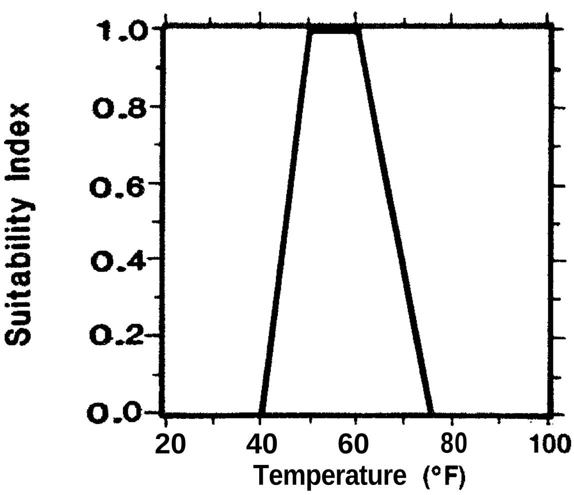
Spawning/egg incubation

x °F	y SI
45	0.0
55	1.0
70	1.0
80	0.0



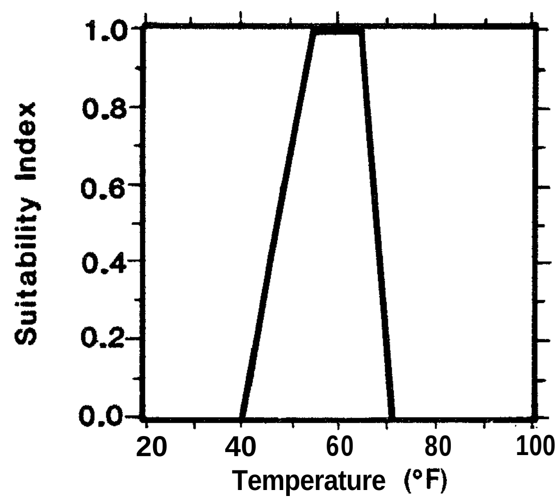
Larval/juvenile, non-migration

x °F	y SI
45	0.0
60	1.0
75	1.0
85	0.0



Outmigration

x °F	y SI
40	0.0
50	1.0
60	1.0
75	0.0



inmigration

x °F	y SI
40	0.0
55	1.0
65	1.0
71	0.0

Figure 6. Temperature SI curves for IFIM analyses of American shad habitat.

Insufficient information was found in the literature to develop a velocity SI curve for American shad egg incubation. A majority of the American shad Delphi exercise panelists indicated that some flow is needed for eggs to develop and hatch successfully. Fertilized eggs are slightly heavier than water, and they will settle to the bottom and possibly suffocate if there is no flow. Most of the panelists indicated that a velocity SI curve for egg incubation would be the same as the spawning velocity SI curve. Therefore, it is assumed that the spawning and/or egg incubation velocity SI curve (Figure 3) can be used when incubation habitat is of concern, and that a separate incubation velocity SI curve is not needed. One Delphi panelist reported that American shad eggs hatched with very high success rates in an aquarium with little or no water current, indicating that some eggs may survive and hatch in habitat where water velocity is less than 0.2 ft/s and substrate and water quality conditions are suitable.

Velocity/larval and/or juvenile nonmigration. Insufficient information was found in the literature to develop velocity SI curves for larval or juvenile (nonmigration) American shad. Some current is probably needed for successful larval development and survival. Initially, larvae are planktonic and are carried passively from their hatching site. Larvae and young juveniles tend to aggregate in eddies and backwaters. The larval and/or juvenile velocity SI curve (Figure 3) is based on results of the American shad Delphi exercise. There was unanimous agreement by the panelists on the curve. Also, most panelists believed that a larval velocity SI curve is suitable for use for juvenile nonmigration habitat. Some panelists, however, felt that the optimum velocity range for juvenile nonmigration habitat should be 0.2 to 2.5 ft/s, or somewhat higher than the optimum velocity range of 0.2 to 1.0 ft/s for larvae.

Velocity/outmigration. The velocity SI curve for outmigration (Figure 3) is based on results of the American shad Delphi exercise. The Delphi panelists unanimously agreed on the curve. The curve is intended for riverine habitat used by American shad (primarily juveniles) during migration from their natal stream seaward.

Velocity/inmigration. The velocity SI curve for inmigration (Figure 3) is based on results of the American shad Delphi exercise. There was unanimous agreement by the panelists on the curve. The curve is intended for riverine habitat used by adults during upstream migration to spawning grounds.

Depth. Insufficient information was found in the literature to develop depth SI curves for each of the life stages/activities of American shad. Depth selection by the species is probably influenced by velocity, food abundance, light intensity, size of fish, and other factors. Reports indicate that spawning may occur at depths ranging from 1.5 to 40 ft (Mansueti and Kolb 1953; Walburg 1960; Walburg and Nichols 1967; Kuzmeskus 1977). This depth range is included in the spawning range of the SI curve for spawning, larval, juvenile, and/or adult (Figure 4) that resulted from the American shad Delphi exercise. Ten of 11 Delphi panelists agreed on the curve. One panelist felt that this curve is also suitable for egg incubation. However, 10 of 11 panelists agreed that the shallowest depth where SI = 0 for egg incubation is 0.5 ft, not 1.5 ft. Therefore, the egg incubation depth SI curve (Figure 4) is based on the results of the American shad Delphi exercise and is intended for use where depth of egg incubation habitat is of concern.

Substrate. The suitability of various types of substrate for life stages/activities of American shad is unclear. Spawning has been reported to occur over a variety of substrates (Mansueti and Kolb 1953; Walburg 1960; Leggett 1976). The species probably prefers to spawn over sand and gravel substrate where there is sufficient water velocity to eliminate silt deposits (Walburg and Nichols 1967). Results of the American shad Delphi exercise indicated that substrate type is probably not an important factor for most life stages/activities of the species. Most of- the Delphi panelists agreed on the substrate SI graph (Figure 5) on the assumption that some eggs will suffocate if they settle on substrate having a high percentage of silt or clay, and that some larvae use substrate for resting, escape cover, or feeding. Panelists that disagreed believed that code 1 (plant detritus/organic material) should be given an SI value of 0.1 instead of 0.

Cover. No cover SI curves for American shad are available. Cover types used by the species have not been adequately defined or quantified. The description of most cover factors is quite subjective and most cover variables are difficult to quantify and assign SI values representative of relative use or preference. Most of the Delphi panelists agreed that an increase in light intensity reduces American shad spawning habitat suitability, and that adult shad use resting areas during upstream spawning migration. Spawning may occur at night in clear water (Leim 1924; Whitney 1961) or all day in turbid water (Chittenden 1976). Light intensity/penetration is influenced by water depth, turbidity, time of day, weather conditions, and other factors. Resting areas are probably selected on the basis of velocity and depth preferences, but such areas have not been adequately described.

Temperature/spawning and/or egg incubation. The temperature SI curve for spawning and/or egg incubation (Figure 6) is based on scanty information in the literature (Liem 1924; Walburg and Nichols 1967; Carlson 1968) and on results of the American shad Delphi exercise. The Delphi panelists reached a consensus that the curve for spawning will also serve for egg incubation. One panelist, however, believed that the upper temperature of the optimum range and the upper temperature where SI = 0, should be slightly lower than 70° and 80° F, respectively.

Temperature/larval and/or juvenile nonmigration. This SI curve (Figure 6) is based on results of the American shad Delphi exercise. Eight of II panelists agreed that it is appropriate for juveniles (nonmigration). Three panelists felt that the optimum temperature range for larvae is 55° to 75° F (instead of 60° to 75° F) and that the upper temperature where SI = 0 is 80° F (instead of 85° F). One panelist felt that the optimum temperature range for the juvenile (nonmigration) is 60° to 82° F (instead of 60° to 75° F) and that the upper temperature where SI = 0 for this life stage is about 95° F (instead of 85° F).

Temperature/outmigration. The outmigration temperature SI curve (Figure 6) is for riverine habitat used by American shad (primarily juveniles) during emigration from their natal stream. The curve is based on results Of the

Delphi exercise. Nine of 11 panelists agreed on the curve. Two panelists believed that the lower temperature where SI = 0 should be 30° F and that the lower end of optimum range should be 45° F. Information on the relationship between water temperature and the movement of young shad is given by Walburg and Nichols (1967), Chittenden (1969, 1972), and Leggett and Whitney (1972).

Temperature/inmigration. The inmigration temperature SI curve (Figure 6) is for riverine habitat used by American shad during upstream migration to spawning grounds. The curve is based on the American shad Delphi exercise. There was unanimous agreement on the curve. Information on temperatures related to upriver movements of American shad in specific rivers is available (Leach 1925; Talbot 1954; Watson 1968, 1970; Chittenden 1969; Katz 1972, 1976; Leggett and Whitney 1972; Marcy 1972; Williams and Bruger 1972; Kuzmeskus 1977).

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop habitat suitability index models and instream flow suitability curves for the American shad. The models produce an index from 0 (unsuitable habitat) to 1.0 (optimally unsuitable habitat) for riverine and estuarine habitats along the Atlantic coast of the United States. They are designed for use with the habitat evaluation procedures developed by the U.S. Fish and Wildlife Service. The instream flow suitability curves are intended for use with the Instream Flow Incremental Methodology.

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