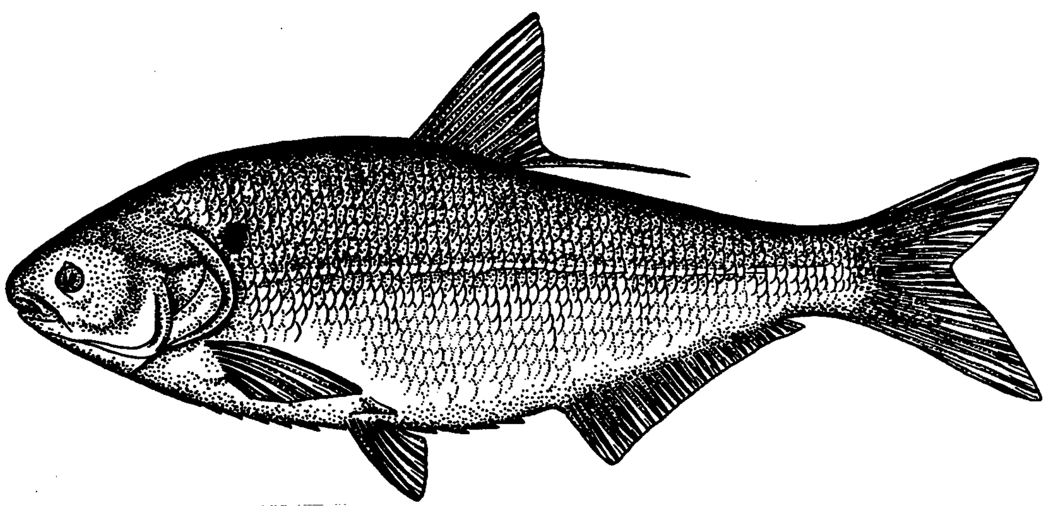
BIOLOGICAL REPORT 82(10.112)
SEPTEMBER 1985

HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: GIZZARD SHAD



Fish and Wildlife Service

U.S. Department of the Interior

This is one of the first reports to be published in the new "Biological Report" series. This technical report series, published by the Research and Development branch of the U.S. Fish and Wildlife Service, replaces the "FWS/OBS" series published from 1976 to September 1984. The Biological Report series is designed for the rapid publication of reports with an application orientation, and it continues the focus of the FWS/OBS series on resource management issues and fish and wildlife needs.

MODEL EVALUATION FORM

Habitat models are designed for a wide variety of planning applications where habitat information is an important consideration in the decision process. However, it is impossible to develop a model that performs equally well in all situations. Assistance from users and researchers is an important part of the model improvement process. Each model is published individually to facilitate updating and reprinting as new information becomes available. User feedback on model performance will assist in improving habitat models for future applications. Please complete this form following application or review of the model. Feel free to include additional information that may be of use to either a model developer or model user. We also would appreciate information on model testing, modification, and application, as well as copies of modified models or test results. Please return this form to:

Habitat Evaluation Procedures Group
or
Instream Flow Group
U.S. Fish and Wildlife Service
2627 Redwing Road, Creekside One
Fort Collins, CO 80526-2899

Thank you for your assistance.

Species ______________ Geographic Location ___________________________________

Habitat or Cover Type(s) ____

Type of Application: Impact Analysis ____ Management Action Analysis _____
Baseline _____ Other ____

Variables Measured or Evaluated ______________________________________
____
____
____

Was the species information useful and accurate? Yes ____ No ____

If not, what corrections or improvements are needed?____________________
____
____
____

Were the variables and curves clearly defined and useful? Yes ____ No ____

If not, how were or could they be improved? ______________________________

Were the techniques suggested for collection of field data:
- Appropriate? Yes ____ No ____
- Clearly defined? Yes ____ No ____
- Easily applied? Yes ____ No ____

If not, what other data collection techniques are needed? ______________

Were the model equations logical? Yes ____ No ____
Appropriate? Yes ____ No ____

How were or could they be improved? ______________________________

Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information) ______________

Additional references or information that should be included in the model:

Model Evaluator or Reviewer __________________________ Date ______________

Agency ____

Address ____

Telephone Number Comm: ______________________ FTS ______________

Biological Report 82(10.112)
September 1985

HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: GIZZARD SHAD

by

Kathryn L. Williamson
Habitat Evaluation Procedures Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Drake Creekside Building One
2627 Redwing Road
Fort Collins, CO 80526-2899

and

Patrick C. Nelson
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Drake Creekside Building One
2627 Redwing Road
Fort Collins, CO 80526-2899

Western Energy and Land Use Team
Division of Biological Services
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This report should be cited as:

Williamson, K. L., and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Gizzard shad. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.112). 33 pp.

PREFACE

The Habitat Suitability Index (HSI) models presented in this publication aid in identifying important habitat variables. Facts, ideas, and concepts obtained from the research literature and expert reviews are synthesized and presented in a format that can be used for impact assessment. Users should recognize that the models are hypotheses of species-habitat relationships, and that the degree of veracity of the HSI model, SI graphs, and assumptions is unknown and will vary according to geographical area and the extent of the data base for individual variables. The HSI model building techniques published by the U.S. Fish and Wildlife Service (1981), and the general guidelines for modifying HSI models (Terrell et al. 1982) and estimating model variables (Hamilton and Bergersen 1984) may be useful for simplifying and applying the models to specific impact assessment problems. Users of the SI curves for IFIM analyses should be familiar with the guide to stream habitat analysis (Bovee 1982) and the users guide to the physical habitat simulation system (Milhous et al. 1984). Simplified models should be tested with independent data sets, if possible.

Model reliability is likely to vary in different geographical areas and situations. The U.S. Fish and Wildlife Service encourages users to provide comments, suggestions, and test results that may help us increase the utility and effectiveness of this habitat-based approach to impact assessment. Please send comments to:

Habitat Evaluations Procedures Group or
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, CO 80526-2899

CONTENTS

ACKNOWLEDGMENTS

R. W. Drenner, Texas Christian University, Fort Worth, and L. R. Aggus, Aquatic Ecosystem Analysts, Fayetteville, AR, reviewed an earlier draft of this document and offered constructive suggestions. However, readers must not construe these reviews as an endorsement of the publication's content or the use of suitability index curves to evaluate habitat. The ADDITIONAL MODELS section of the report was written primarily by R. M. Jenkins, and L. R. Aggus, Aquatic Ecosystem Analysts, Fayetteville, AR. Word processing was done by E. Graf and P. Gillis, Western Energy and Land Use Team. J. Shoemaker, Western Energy and Land use Team, did the cover art. The U. S. Fish and Wildlife Service Office of Information Transfer furnished editorial assistance.

GIZZARD SHAD (*Dorosoma cepedianum*)

HABITAT USE INFORMATION

General

The gizzard shad (*Dorosoma cepedianum*) inhabits fresh and brackish waters in the United States. Its range extends from southeastern South Dakota and central Minnesota, throughout the Mississippi and Great Lakes drainages to about as far north as the St. Lawrence River, near Quebec; from southern New York (approximately 40° N latitude) along the Atlantic Coast to the Gulf of Mexico; and west through the Gulf Coast States to the portions of New Mexico and Colorado east of the Continental Divide (Miller 1960; Bodola 1965; Jester and Jensen 1972; Megrey 1980). Although most gizzard shad complete their entire life cycle in fresh water (Miller 1960), some enter brackish bays and estuaries along the Atlantic and Gulf Coasts and occasionally enter marine waters (Gunter 1945; Megrey 1980). Lake and reservoir populations use both the littoral and limnetic zones (Jester and Jensen 1972). The gizzard shad is essentially an open water species, living at or near the surface (Becker 1983; Trautman 1981; Pflieger 1971), however, they have been collected at depths of up to 33 m (Dendy 1945; Jester 1962). They hybridize with the threadfin shad, *D. petenense* (Minckley and Krumholz 1960; Shelton and Grinstead 1973).

Age, Growth, and Food

Growth rate characteristics of gizzard shad are extremely variable, both across the entire range of geographic locations and within relatively closely spaced populations (Table 1). Reproductive maturity normally is reached by age II or III (Berry 1958; Bodola 1965; Breder and Rosen 1966) at mean total lengths of 254 to 356 mm (Miller 1960). However, rapid growth rates are characteristic of some southern populations in shallow, fertile impoundments with abundant food and long growing seasons. Lengths attained are as much as 152 - 178 mm in 5 months in Georgia reservoirs (Zeller and Wyatt 1967) and 265 mm in 1 year in Florida reservoirs (Berry 1958). The largest gizzard shad reported in the literature was 521 mm long and weighed 1.56 kg (Trautman 1981).

The life span of gizzard shad is short in some portions of its range; few fish live past age III or IV in Lake Newnan, Florida (Berry 1958), or Beaver Dam Lake, Illinois (Lagler and Van Meter 1951). In general, short life spans are correlated with rapid growth rates in the first year of life (Table 1). In other, usually more northern parts of its range, gizzard shad typically

Table 1. Mean total lengths (mm) of gizzard shad from various locations in the United States at time of annulus formation (from Jester and Jensen 1972).

Location	Age										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Elephant Butte Lake, NM (Jester and Jensen 1972)	95	151	183	219	254	273	391	324	-	-	-
Conchas Lake, NM (Jester 1962)	76	154	225	284	320	343	360	371	379	387	412
Grand Lake, OK (Jenkins 1953)	100	203	260	318	350	383	395	-	-	-	-
Ft. Gibson Reservoir, OK (Jenkins 1953)	143	258	325	-	-	-	-	-	-	-	-
Lake Erie (Boloda 1965)	259	366	403	429	467	428	-	-	-	-	-
Foots Pond, IN (Lagler and Applegate 1942)	190	248	265	283	348	-	-	-	-	-	-
Beaver Dam Lake, IL (Lagler and Van Meter 1951)	240	278	330	375	-	-	-	-	-	-	-
Lake Wappapello, MO (Patriarche 1953)	103	170	208	230	245	258	273	293	300	293	-
Herrington Lake, KY (Turner 1953)	110	196	259	311	334	-	-	-	-	-	-
Lake Newnan, FL (Berry 1955)	254	317	338	-	-	-	-	-	-	-	-

live to ages V to VII and may live to ages X or XI (Miller 1960; Jester 1962). Sexual dimorphism in growth rate, length weight relationship, or external characteristics, is seldom, if ever, shown (Lagler and Van Meter 1951; Miller 1960; Jester and Jensen 1972); however, females usually are more abundant than males because of more extensive post-spawning mortality in males (Berry 1958; Breder and Rosen 1966; Jester and Jensen 1972).

Average fecundity of gizzard shad also is highly variable, and seemingly declines after peaking at age II or III. In Acton Lake, Ohio, mean fecundity of age II females (31.2 cm standard length) was 12,500 eggs per individual. Fecundity peaked at 380,000 eggs per individual (29.1 cm standard length) for age II gizzard shad from Lake Erie, declining thereafter in successively older age groups (Bodola 1965). Females older than age IV showed no sign of gonadal maturation (Pierce 1977). Mean fecundity of 27 age III female gizzard shad (19.0 cm total length) from Elephant Butte Reservoir, New Mexico, was 40,500 eggs; fecundity declined in older fish (Jester and Jensen 1972).

Total length at hatching is 3.25 to 5 mm (Berry 1958; Miller 1960). Larval gizzard shad subsist on yolk material for the first few days of life (Bodola 1965), then begin feeding at 4 to 5 days after hatching; for the first few weeks they eat mainly protozoans, rotifers and entomostracans (Warner 1940; Miller 1960; Bodola 1965). In lakes, young fish (< 35 mm total length) feed almost exclusively on zooplankton (Warner 1940; Kutkuhn 1958; Dalquest and Peters 1966; Cramer and Marzolf 1970; Barger and Kilambi 1980) while larger fish consume detritus, phytoplankton, zooplankton and insect larvae and exuviae (Tiffany 1921a, b; Kutkuhn 1958; Bodola 1965; Baker and Schmitz 1971; Jester and Jensen 1972; King et al. 1977; Hendricks and Noble 1979; Barger and Kilambi 1980; Pierce et al. 1981). Jude (1973) found gizzard shad to consume fingernail clams in a pool of the Mississippi River. In a Kentucky stream, gizzard shad ate principally tendipedids, oligochaetes, diatoms, and Spirogyra (Minckley 1963).

Gizzard shad feed in both the limnetic zone and along bottom sediments as evidenced by the occurrence of both plankton and sand in their digestive tracts (Kutkuhn 1958; Pierce et al. 1981). In laboratory experiments, Drenner et al. (1982b) found that gizzard shad collected suspended food items as a pump filter feeder, capturing particles by a series of rapid suctions. The feeding selectivity of gizzard shad for plankton is determined by the size of the plankton relative to the gill raker spaces (Mummert 1983; Drenner et al. 1984) as well as the escape ability of the plankton (Drenner et al. 1978, 1982a). Abundance and diversity of items eaten may vary widely with season and locality (Bodola 1965) with apparent variability in food preferences among age groups and populations being the result of capture location or availability of prey items (Bodola 1965; Jester and Jensen 1972; Pierce 1977). Bodola (1965) found that digestive tract contents of adult gizzard shad captured in open waters consisted predominantly of free-floating phytoplankton, whereas shad captured in littoral vegetation contained Cladocera, Copepoda, Rotifera, and small aquatic insect larvae and those captured in very turbid waters contained mostly mud.

Reproduction

Gizzard shad spawn in spring and early summer; they have no obvious spawning migration patterns, except that fish in brackish or salt water return to fresh water (Breder and Rosen 1966). Spawning occurs principally in low gradient tributaries or ditches, where large spawning aggregations move upstream as far as water depth will allow, to spawn in shallow water (Trautman 1981; Shelton 1972; Pierce 1977; Becker 1983); spawning aggregations also may concentrate at the mouths of the main tributary streams of a lake (Jester 1962). Not all eggs ripen simultaneously; consequently spawning is frequently extended over a period of two weeks (Warner 1940) and sometimes up to two months (Berry 1958; Taber 1969). Spawning activity may begin as much as two weeks earlier in the upper end of a reservoir than in the lower end (Netsch et al. 1971).

Spawning activity has been associated with rapidly rising water levels and temperature: low water levels and low temperatures during spring and early summer adversely affect spawning success (Bross 1967; Walburg 1976; Pierce 1977; Downey and Toetz 1983). Water temperature of about 16°C apparently provides the stimulus for spawning (Warner 1940; Miller 1960; Minckley 1963; Bodola 1965; Taber 1969; Shelton 1972; Shelton and Grinstead 1973; Pierce 1977; Storck et al. 1978). Pierce (1977) found that the number of days in May with water temperatures > 15°C accounted for 34% of the variability associated with year class success. Spawning activity is greatest in the evening and early night, and declines markedly during daylight hours (Shelton 1972; Bodola 1965; Mayhew 1957). Although gizzard shad usually spawn in shallow water, less than 1.5 m deep, they have been observed spawning at the surface of water that is 15 m deep (Jester and Jensen 1972). In reservoirs with fluctuating surface elevations, spawning extended farther upstream in high water years than in low water years; the spawners appeared to prefer recently inundated habitat when it was available (Storck et al. 1978).

Specific Habitat Requirements

Gizzard shad of all ages are extremely fragile, and handling them or keeping them in captivity for controlled laboratory testing is difficult even under the best of circumstances (Shoemaker 1942; Bodola 1965; Reutter and Herdendorf 1974); consequently, many specific habitat requirements can only be assumed from field observations, and few or no quantitative data are available for most habitat variables. Comprehensive life history and habitat information was given by Bodola (1965), Jester and Jensen (1972), and Miller (1960).

Conditions for gizzard shad populations are optimal in warm, fertile, shallow bodies of water with soft mud bottoms, high turbidity, and relatively few predators (Miller 1960; Zeller and Wyatt 1967). In fact, lacustrine habitats with these characteristics are the most likely to become overpopulated with gizzard shad. Factors contributing to this problem are the gizzard shad's high reproductive capacity, rapid growth rate, and efficient and direct use of plankton (Hubbs 1934; Miller 1960; Bodola 1965). Moderate to heavy predation by large game species, fluctuating water levels, deep clear water, and steep shorelines (factors that are less than optimal for many species) tend to be associated with lower gizzard shad populations.

Gizzard shad are often abundant in large sluggish rivers, impoundments of all sizes (especially those connected with large river systems), lakes, swamps, bayous, and floodwater pools (Gerking 1945; Summerfelt 1967; Boschung 1961; Carlander 1969; Becker 1983). In smaller rivers they are highly associated with permanent, deep, sluggish pools with soft sand and silt bottoms (Larimore and Smith 1963; Pflieger 1971). Intermittent flows upstream and downstream from reservoirs in New Mexico have limited the gizzard shad's range and distribution in that state, and Jester and Jensen (1972) suggested that the species might be absent from New Mexico if reservoirs had not been impounded there. It seems likely that intermittent flows may limit the distribution of gizzard shad in the more arid western parts of the country where demands on water are high.

Gizzard shad have been captured over all types of substrate, including mud, sand, gravel, bedrock, and inundated vegetation (Pflieger 1971; Jester and Jensen 1972); however, they are most consistently found over bottoms of sand, silt, or mud (Hubbs and Lagler 1942; Gerking 1945; Larimore and Smith 1963; Dalquest and Peters 1966; Jester and Jensen 1972; Pierce 1977).

Temperature plays an important role in controlling populations of gizzard shad (Jester and Jensen 1972; Becker 1983). According to Miller (1957), gizzard shad populations increase in northern waters during a series of warm years and then are almost eliminated during cold years. The young-of-the-year are particularly susceptible to mortality caused by sudden or extreme changes of temperature, and massive winter kills frequently occur in northern or high-altitude lakes (Trautman 1981; Jester and Jensen 1972; Miller 1960). Gizzard shad in Elephant Butte, Caballo, and Conchas Reservoirs, New Mexico, normally become inactive and move into deeper water in fall as water temperatures dip below 14° C and become active again in spring as temperatures rise to 14° C or higher (Jester and Jensen 1972). Winter die-offs of gizzard shad have been observed in these reservoirs when temperatures fell below 3.3° C. Although the young-of-the-year are the most susceptible to death from these temperatures, older fish also die within a few days if the temperature is not abated or if it falls below 2.2° C. Death also occurs at high temperatures that are within the optimum range, if changes are relatively abrupt. Agersborg (1930) reported unbalanced movements of gizzard shad when the fish moved from 28 to 24°C water. Miller (1960) hypothesized that winter mortality also could be caused by sudden rises in temperature after prolonged periods of cold weather. In South Dakota, ice cover lasting longer than 103 days resulted in almost complete mortality of overwintering young shad, but some survived an ice cover of 88-103 days (Walburg 1964). The northern limits of the gizzard shad's range is the St. Croix River below Taylor Falls in Minnesota (Becker 1983; Eddy and Underhill 1974); none have been found in Lake Oahe, near the border of North Dakota and South Dakota (Gasaway 1970), or north of about 40°N latitude in New York (Bodola 1965; Megrey 1980). Although the species has become firmly established in Lake Michigan (Miller 1960), it is relatively scarce in upper Lake Huron, (Miller 1960), and virtually absent in Lake Superior, although one large speciman was reported captured in the southeastern end of the lake in 1961 (Scott and Crossman 1973).

Embryo. In lakes, gizzard shad prefer to spawn in protected shallow water coves and backwaters (Miller 1960), along the shoreline (Pierce 1977), and near the surface in water 0.3 to 1.6 m deep. The eggs, which are expelled from the body in ribbon-like masses, sink to the bottom or drift in the current and readily adhere to submerged vegetation, rocks, or any objects they contact (Mayhew 1957; Berry 1958; Taber 1969; Walburg 1976). There is no nest building or parental care. In riverine areas, or tributary streams, spawning aggregations collect in large deep pools, and a female, accompanied by several males, swims away from these aggregations to spawn in nearby shallow water (Shelton 1972; Minckley 1963). Optimal habitat for survival of the embryo in these tributary streams is a continuous flow of fresh clear water over shallow, rocky riffles in which the bottom is covered with periphyton, providing ample surface area for egg attachment (Pierce 1977).

Depending on local weather conditions, gonads begin to ripen from March to early April at water temperatures of 7 to 10° C. Initiation of spawning activity usually begins (in late March to late June) at temperatures of 15.5 to 16.5° C, peaks at 19 to 21° C (Bodola 1965; Jester 1962), and continues at 24 to 25° C (Carlander 1969; Jester and Jensen 1972; Storck et al. 1978). Maximum reported spawning temperatures for gizzard shad are 27° C (Mayhew 1957) to 29° C (Miller 1960). The recommended maximum temperature suitable for spawning and embryo development is 26.7° C (Brungs and Jones 1977).

The length of the incubation period is inversely related to temperature; modal hatching times are 32 hours at 23° C, 73 hours at 18° C, and 106 hours at 15° C (Shelton and Stephens 1980). Warner (1940) reported an incubation period of 95 hours at the minimum hatching temperature of 16.7° C and 36 hours at 26.7° C.

Larvae/fry. Average total length of gizzard shad larvae at hatching is 3.3 to 3.5 mm (Shelton and Stephens 1980; Warner 1940). After one day at 23° C the length is 4.5 to 5.0 mm. The yolk sac is nearly absorbed by the second or third day. Yolk-sac larvae have either a negative geotaxic or a positive phototaxic response (or both) that causes them to swim to the surface (Shelton and Stephens 1980). Their active upward swimming and passive downward sinking has the net effect of concentrating them away from the substrate and toward the surface. Netsch et al. (1971) found that gizzard shad prolarvae tended to be concentrated near the surface of Beaver Reservoir, Arkansas until they were 4 weeks old; they then gradually moved into deeper water.

Water temperature appeared to influence vertical distribution of larval gizzard shad in Lake Norman, North Carolina, but dissolved oxygen (DO) concentration did not (Lewis and Siler 1980). Netsch et al. (1971) found that larval shad concentrated closer to the surface in turbid areas of a reservoir (Secchi disc depth, 0.7 to 1.2 m) than in less turbid areas (Secchi disc depth 2.9 to 4.9 m), where they were at depths of about 5 m. Kashuba and Matthews (1984) and Matthews (1984) also found larval shad concentrated near the surface of Lake Texoma during episodes of high turbidity (Secchi disc depth 0.1 to 0.4 m), in contrast to their zooplankton prey, which were deeper in the water column; they correlated rapid declines in larval shad abundance with high turbidity and decreased zooplankton abundance. They proposed that turbidity, though not directly lethal to larval shad, could indirectly but severely reduce their abundance, particularly in mainstem reservoirs where spring and early summer floods commonly occur during the period of larval development. Barnes (1977) found that gizzard shad are poor swimmers until they reach a length of about 25 mm (corresponding to the transition to the juvenile age class 1.5 to 2.5 months). Median swimming speeds attained by gizzard shad < 25 mm long were 2 to 4 cm/s; maximum speed was 10 cm/s under optimum conditions. Juveniles 25 to 50 mm long attained speeds up to 23 cm/s. Barnes (1977) suggested that the high mortality in larval shad may be closely related to their reduced swimming ability during the "critical period" after yolk absorption, about 5 to 11 days after hatching. This view is consistent with that of Pierce (1977), who found that seasonal abundance and timing of peak densities of zooplankton play a critical role in the survival of young gizzard shad. That is, young shad with reduced swimming ability cannot actively forage for food and are therefore dependent on a large population density of zooplankton at this critical time.

Walburg (1976) correlated abundance of larval gizzard shad taken from backwater areas and coves of Lewis and Clark Reservoir, a Missouri River mainstem reservoir, with several environmental variables, including water temperature, water level fluctuation, water current, and abundance of plankton and bottom fauna. Three variables were common to areas with the greatest abundance of gizzard shad larvae: little or no water current (< 2.5 cm/s); water depth > 1 m; and little or no fluctuation in water level. Siltation of nearshore spawning and nursery areas and associated increased turbidities of up to 675 mg/l in the upper end of the reservoir had a negative effect on these habitats.

Larval abundance in the Lower Mississippi River was higher during high-water years and larvae preferred quiet vegetated areas along the river and inundated flood plain, rather than open water areas (Gallagher and Conner 1980). Bross (1967) correlated low abundance of young-of-the-year gizzard shad with low water levels and low water temperatures in the spring.

Adult. Adult gizzard shad frequented areas with temperatures of 22 to 29° C (Gammon 1973); growth was satisfactory at a maximum temperature of 34° C (Clark 1969; Brungs and Jones 1977). Adults normally do not enter water above 35° C (Hubbs and Lagler 1942; Hart 1952; Gammon 1973), and lethal temperatures of 36.5° C have been reported, depending on acclimation temperature (Hart 1952; Strawn 1958). Adult gizzard shad have been found in thermal plumes at temperatures up to 37.5° C (Proffitt and Benda 1971).

Borges (1950), noting that gizzard shad avoided waters of low DO sandwiched between cold, well-aerated, spring-fed layers, proposed that DO depletion overshadows temperature as a factor in influencing distribution. Indeed, in Arbuckle Lake, Oklahoma, vertical depth distribution indicated that gizzard shad were generally absent from water with less than 2 mg/l DO, even though it comprised 50 to 60% of the total lake volume in some years (Gebhart and Summerfelt 1978). Jester (1972) captured large and small gizzard shad down to the oxygen limit in the thermocline during the warm summer months, and Becker (1983) reported that, if oxygen is adequate, the species may descend to a depth of 33 m.

Low temperatures appear to be more influential than high temperatures in determining gizzard shad distribution (Miller 1960). Velasquez (1939) reported that the fish hibernate in deep water in winter, and Jester (1972) captured them in the abyssal zone of Elephant Butte Reservoir during the coldwater overturn period. Gizzard shad in Lake McConaughy, Nebraska, overwintered in a few sheltered coves where spring-fed streams provided thermal refugia from the nearly freezing temperatures of the open windswept lake (Ellison, D. G., Nebraska Game and Parks Commission, Rural Route 2, Ogallala, NE; pers. comm.). October beach seine catches of young-of-the-year gizzard shad reported by Pahl and Willfahrt (1962) dropped to zero when water temperatures had declined to < 13° C. Jester and Jensen (1972) noted a decline in numbers when temperatures dropped below 14° C in fall, (activity resumed when temperatures rose to 14° C in spring). Hart (1952) determined that the lower lethal temperature for gizzard shad was 11° C for fish acclimated at 25° C. However, it is assumed that lower acclimation temperatures permit survival at much lower temperatures than 11° C, because gizzard shad are known to be able to overwinter successfully at temperatures of 4° C (Dalquest and Peters 1966). The lower temperature limit that decimates young-of-the-year gizzard shad and begins to adversely affect adults is about 3° C in several New Mexico lakes (Jester and Jensen 1972).

High turbidities do not appear to be detrimental to the well-being of adult gizzard shad; on the contrary, catch rates in experimental nets are usually lower in clear water than in more turbid water (Taber 1969; Jester and Jensen 1972). Adults are commonly captured in areas where Secchi disc depth is less than 0.5 m (Pahl and Willfahrt 1962; Dalquest and Peters 1966; Jester and Jensen 1972); however, Bodola (1965) indicated that gizzard shad from the more turbid areas of Sandusky Bay were smaller and spawned earlier than shad from less turbid portions of Lake Erie.

Gizzard shad are commonly found in large, brackish water bays along the Texas coast where salinity varies from 2.0 to 33.7 ppt. The smallest fish were in the freshest water and the larger ones at the higher salinities (Gunter 1945). Gizzard shad are also remarkably tolerant of high total dissolved solids (TDS) in inland waters, such as Lake Diversion, Texas, a saline lake where the TDS range in some years was as high as 1,224 to 3,185 ppm with sulfate and chloride ions exceeding biocarbonate ions. Shad began dying in Great Salt Plains Reservoir, Oklahoma, when chloride ion concentration reached approximately 7,000 ppm; a complete kill occurred when the concentration rose to approximately 11,000 ppm (Jenkins 1949).

Juvenile. Habitat requirements for juvenile gizzard shad seem to be similar to those for adults. No differentiation of adult and juvenile requirements was noted in the literature.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The model is applicable to lakes and reservoirs throughout the United States. Regression models by Aggus and Morais (1979) which are cited in the ADDITIONAL MODELS section, are derived from data sets subdivided by Administrative Regions of the U.S. Fish and Wildlife Service (FWS).

Season. The model is intended for general use throughout the year, although certain components are structured to handle the potentially limiting periods of reproduction and summer stratification.

Cover types. The model is applicable to permanent lakes and reservoirs. Many gizzard shad populations occupy the limnetic zone of a lake throughout the year, but undertake loosely organized spawning migrations to nearshore areas, mouths of tributary streams, or up tributary streams. Because little information is available on riverine spawning requirements, and gizzard shad can successfully spawn in lakes, a model of riverine reproductive requirements was not developed. To evaluate reproductive habitat, a definition of useable spawning habitat based upon either percent littoral area during spawning season or access to suitable spawning tributaries is developed.

Water quality. It is assumed that aquatic habitats to which the model is applied are not contaminated with toxic substances, overloaded with sewage or particulate matter, or significantly or extensively affected by thermal effluents (to the extent that the normal thermal regime is significantly altered). Extreme drawdowns, which can induce physiological stress, disease, or death in crowded populations, also are not considered in the model.

Minimum habitat area. The minimum area required for a self-sustaining population of gizzard shad is not known. Standing crops as large as 576 kg/ha have been reported in lakes as small as 6.6 ha (Jenkins 1957), and presumably many more examples such as this exist; however the model presented here was based on habitat information from larger lakes (generally > 200 ha) and is more representative of habitat requirements in relatively large lakes and reservoirs.

Verification level. This model represents the authors' interpretation of how specific environmental factors combine to determine the ability of a habitat to support a reproducing population of gizzard shad. It has not been field tested.

Model Logic and Description

The Habitat Suitability Index (HSI) model that follows represents an attempt to condense the preceding observations into a manageable set of measurable habitat characteristics. The model is structured to produce an index of gizzard shad habitat quality between 0.0 (unsuitable, shad survival unlikely) and 1.0 (optimum) for separate components of the entire life cycle. The index generated by the model is assumed to represent a limit to prespawning populations imposed by model variable values for the previous year, but this relationship has not been demonstrated. Habitat variables believed to be important in limiting distribution, abundance, or survival of gizzard shad are included in the model. An assumed functional relationship between each habitat variable and habitat suitability is represented in a variable suitability index (SI) graph. It is assumed that SI ratings for different habitat variables can be compared. This is one of the weakest model assumptions; it is likely to be violated for some ranges of the selected variables because the responses (e.g. changes in growth, survival, distribution, habitat selection, or abundance) used to subjectively derive the SI's are not directly comparable. However, the model is likely to provide the most accurate description of habitat imposed population limits when all of the variables have extreme SI values, that is, either near optimum or near unsuitable. Gizzard shad habitat quality is represented in this model by three components: Food, Water Quality, and Reproduction. Variables that are believed to be direct or indirect measures of the relative ability of a habitat to meet food, water quality, and reproductive requirements are included in the appropriate component.

Not all habitat-related variables that can potentially affect gizzard shad populations are included in the model. A variable was not included if it: (1) was adequately measured by another variable or variables; or (2) would be difficult to measure quantitatively. Modifications, such as redefinition of SI curves or inclusion of different or additional variables, will probably be necessary before the model can be expected to predict or describe limits to populations imposed by habitat related variables. The model is structurally simple and can therefore be easily modified.

Model Components

The structure of the lacustrine HSI model for gizzard shad is presented graphically in Figure 1.

Food component. Log_{10} TDS (V_1) is considered part of the food component because gizzard shad feed on plankton and detritus which are highly correlated with the fertility of the lake or reservoir. There are many indices of fertility; however TDS concentration is easily measured and is a fairly reliable indicator of fertility.

Water quality component. Temperature (V_3) and dissolved oxygen (V_4) seem to be the two most influential criteria in determining growth and survival of gizzard shad populations. Long growing seasons (V_2), in addition to optimum average summer temperatures, favor high standing crops.

Reproduction component. Water level fluctuation during the spawning season (V_5) can be a limiting factor to spawning activity as well as to the survival of embryo and larval stages. Mean weekly temperature during the spawning season (V_6) is important to initiation of spawning and survival of the embryo. Quantity of spawning habitat, as indicated by percent littoral area (V_7), can also be a limiting factor to successful reproduction, especially in smaller reservoirs.

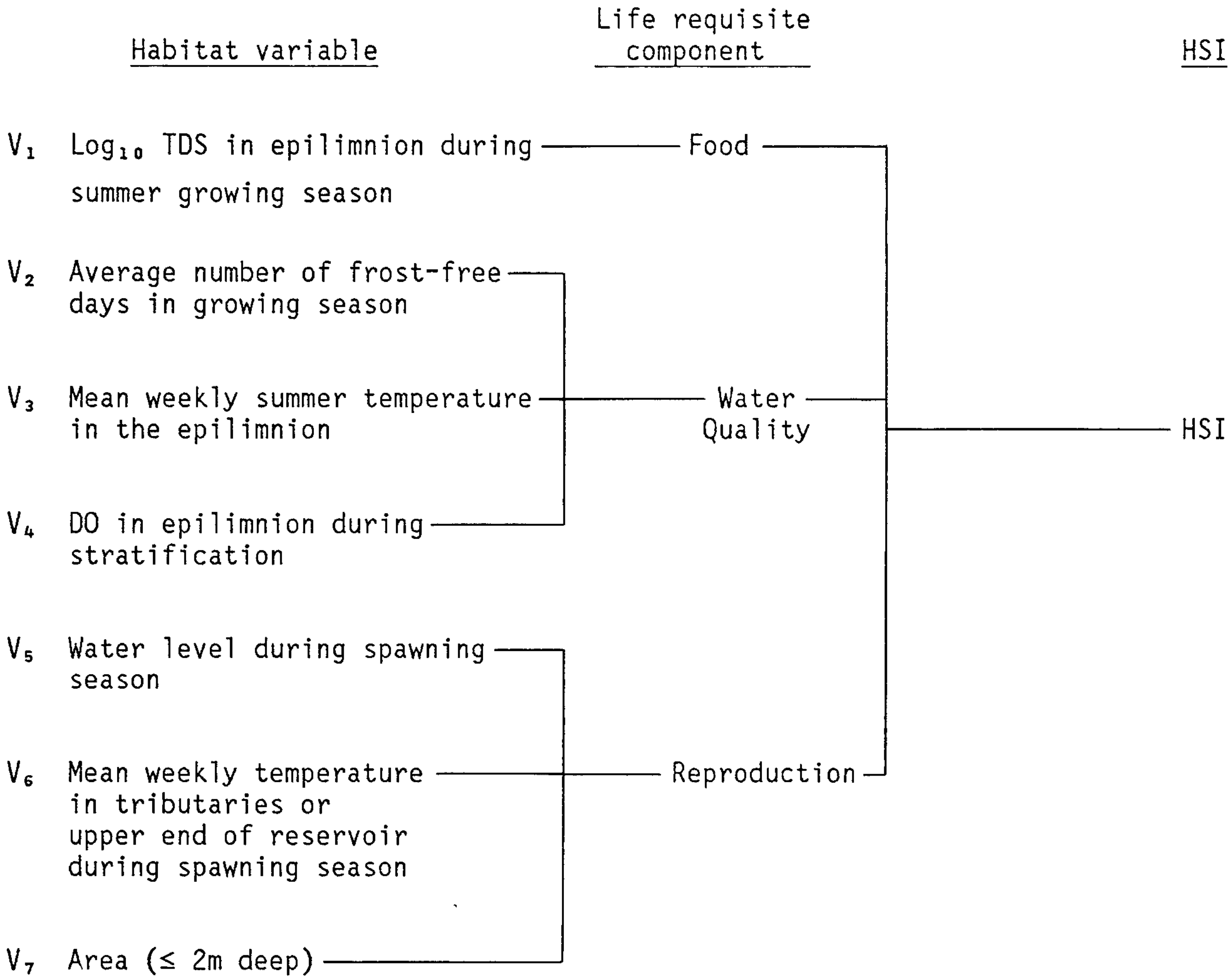


Figure 1. Diagram illustrating relationships between key habitat variables, components and the HSI for gizzard shad in lacustrine environments.

Lacustrine Model

This model attempts to describe life requisite requirements separately, and consists of three components: Food, Water Quality, and Reproduction.

1) Food (C_F)

$$C_F = V_1$$

2) Water Quality (C_{WQ})

$$C_{WQ} = (\text{lowest of } V_3,\ V_4) \times (V_2)$$

3) Reproduction (C_R)

$$C_R = \frac{V_5 + V_6 + V_7}{3}$$

4) HSI determination

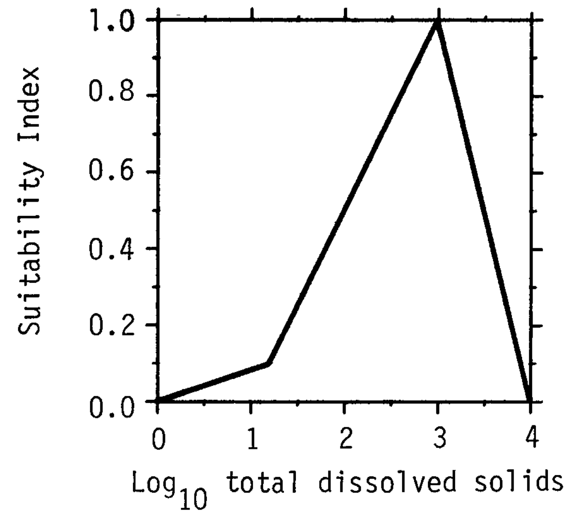
HSI = the lowest of C_F, C_{WQ}, or C_R

Suitability Index (SI) Graphs for Model Variables

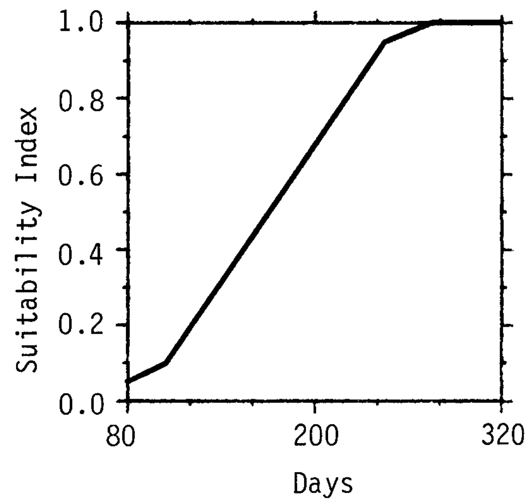
Suitability indices for variables in a lacustrine habitat are described by the following set of curves. Sources of data and the rationale and assumptions made in developing suitability indices are presented in the next section.

Variable | Suitability graph

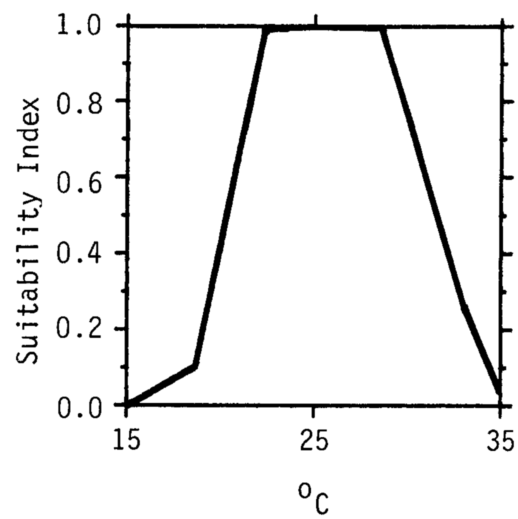
V_1 — Log_{10} Total Dissolved Solids (ppm) during summer growing season.



V_2 — Growing season (average number of days between last and first frost annually)

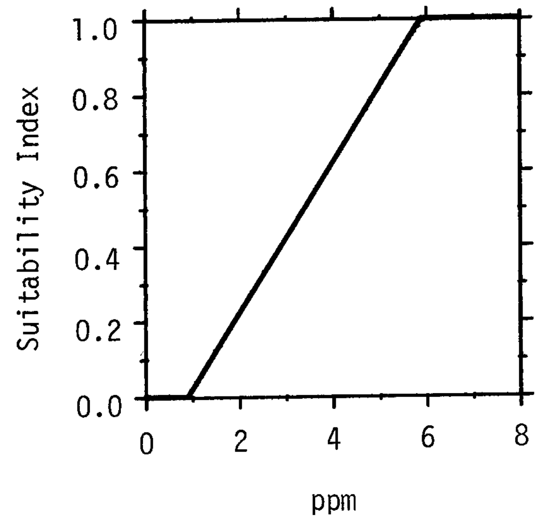


V_3 — Mean weekly summer temperature (epilimnion) (°C)



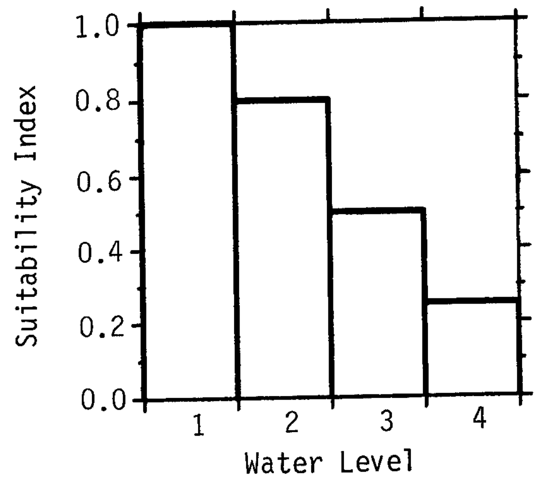
Variable

V_4 Maximum available dissolved oxygen in epilimnion during summer stratification (ppm)

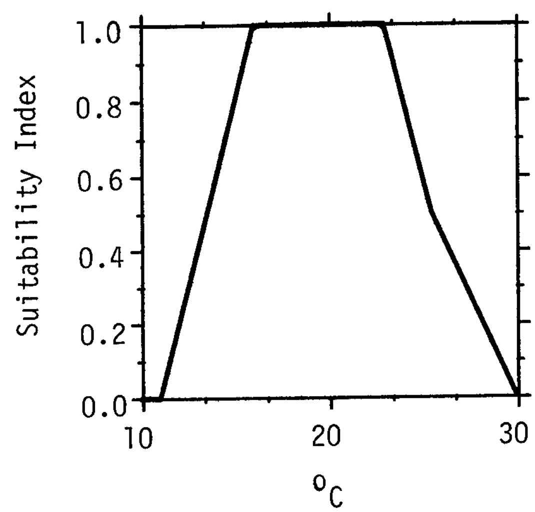


V_5 Water level during spawning season and embryo development

1 = rising water levels and inundated vegetation
2 = stable water levels or no inundated vegetation
3 = decline in water level ≤ 0.5 m
4 = decline in water level > 0.5 m

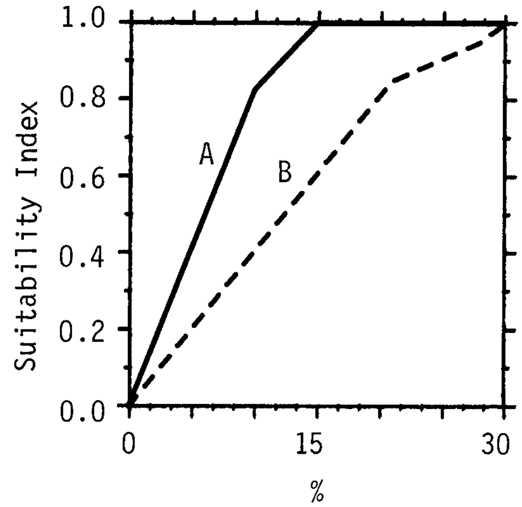


V_6 Mean weekly temperature in tributaries or upper end of lake or reservoir during spawning season (°C)



Variable

V_7 Area vegetated and ≤ 2 m deep during spawning season
A = accessible spawning tributaries with low gradients
B = spawning tributaries absent or not accessible



Development of Suitability Index Graphs: Rationale and Assumptions

The preceding suitability index graphs should be regarded as the authors' opinions. Modifications based on documentation of the user's experience or other data bases are encouraged. The prospective user should understand that the suitability index graphs are not products of extensive laboratory or field investigations. Rather, they reflect the authors' subjective interpretation and integration of the literature and reviewers' comments. We here document some of the thought processes that entered into the construction of each curve. Some curves are better documented than others. For most, there is some information about preferred and limiting or unsuitable conditions, but few data exist from which ratings of intermediate conditions can be based. No particular significance should be attributed to inflection points unless specifically noted in the text. The model is offered as a starting point; it is assumed that refinements will be made as additional information, including that resulting from tests of the model, becomes available.

Log_{10} TDS in epilimnion during the summer growing season (V_1). Gizzard shad are an efficient link in the aquatic food chain (Tiffany 1921a; Hubbs 1934); post yolk sac larvae feed predominantly on zooplankton (Kutkuhn 1958; Miller 1960; Bodola 1965; Cramer and Marzolf 1970; Matthews 1984) and adults on phytoplankton (Turner 1953; Kutkuhn 1958; Miller 1960; Bodola 1965) and organic detritus (Baker and Schmitz 1971; Drenner et al. 1978; Pierce et al. 1981). It is not surprising, then, that most descriptions of optimum or highly productive gizzard shad habitat include some reference to the fertility of the lake or reservoir (Kutkuhn 1958; Jenkins 1957; Miller 1960; Zeller and Wyatt 1967). Fertility and plankton production often are highly correlated with TDS; furthermore, this variable was among those highly correlated with clupeid standing crops in an analysis of 228 reservoirs made by Aggus and Morais (1979); therefore a positive relationship between TDS and gizzard shad food supply is assumed. Although few literature sources gave specific TDS concentrations or quantified standing crop information, a report by Leidy and Jenkins (1977) contained this type of information and was a useful aid in the construction of the curve. Impacts of very high TDS levels are not well documented. The highest TDS concentrations associated with viable gizzard shad populations were 3185 ppm (Dalquest and Peters 1966), 5755 ppm (Aggus and Morais 1979), and an unusually high 15,000 ppm in Great Salt Plains, OK (Jenkins 1949). Individual gizzard shad can withstand salinities up to 33.7 ppt (Gunter 1945), the approximate salinity of ocean water.

Length of agricultural growing season (V_2). Length of agricultural growing season (average number of days between last spring frost and first fall frost) appears to be a key variable affecting gizzard shad abundance (Berry 1958; Zeller and Wyatt 1967; Branson 1967). The northern distribution of the species is limited by severe winters (Miller 1960; Gasaway 1970; Jester and Jensen 1972; Becker 1983), ice cover > 103 days (Walburg 1964), or water temperatures of about 3° C or lower (Jester and Jensen 1972).

The suitability index curve is based largely on length of agricultural growing season days along the northern limits of the gizzard shad's native range, and on clupeid standing crop data from U.S. reservoirs (Leidy and Jenkins 1977; Aggus and Morais 1979).

Mean weekly summer temperature in the epilimnion (V_3). Water temperatures during the summer growing season affect growth, development, and survival of of gizzard shad of all ages; however, little information exists on the range of optimal or unsuitable temperatures for fry, and information on temperatures affecting juvenile gizzard shad is contradictory. Cvancara et al. (1977) found an apparent TL_{50} of 28.5° C for gizzard shad 43 mm long, and the lethal threshold for underyearlings in experiments by Hart (1952) was 34 to 36.5° C depending on acclimation temperature. Field temperature preferences of adults vary widely: 19 to 21° C (Reutter and Herdendorf 1974); 23 to 24° C (Clark 1969); and 22 to 29° C (Gammon 1973). Optimum temperatures for growth have not been reported, but maximum temperature for growth was reported as 34° C (Brungs and Jones 1977). The SI curve optimum is 22 to 29° C (mean weekly water temperatures), and allows maximum temperatures to be somewhat higher for short periods and still be within the optimum or acceptable range. Field temperature measurements should be taken in open water away from shore.

DO in epilimnion during stratification (V_4). Gebhart and Summerfelt (1978) found that gizzard shad were generally absent from water with < 2 mg/l DO, and that this reduction in available habitat was reflected in yearly variations in the growth rate of fish during the stratified period. Gizzard shad generally descend as far as the thermocline during the warmest weather if oxygen is not limiting (Borges 1950; Carter 1967; Jester 1972). Many shallow windswept lakes have no thermocline during summer; this variable can be omitted in these lakes, if oxygen is not a problem.

Water level during the spawning season (V_5). Because gizzard shad usually spawn in water less than 1 m deep and often in water as shallow as 15 cm, they are vulnerable to declining water levels. Storck et al. (1978) reported that annual variations in spawning activity were proportional to increases in reservoir water level. The first major spawning activity occurred during rising water levels in high water years; gizzard shad were able to move farther upstream, and they were especially attracted to recently inundated habitats, which resulted in increased larval abundance (Storck et al. 1978; Gallagher and Conner 1980). High spawning success during years of high water levels apparently can be partly attributed to the availability of inundated vegetation. Conversely, Walburg (1976) and Bross (1967) attributed low water levels in spring and early summer to low abundance of larval gizzard.

Mean weekly temperature in tributaries or in the upper end of the lake or reservoir during spawning season (V_6). The initial stimulus for spawning appears to be a water temperature of 15 to 16° C (Warner 1940; Shelton 1972; Bodola 1965; Miller 1960; Taber 1969; Pierce 1977), and the provisional maximum temperature for spawning and egg development is 27° C (Brungs and Jones 1977), although no available data confirm this limit. Temperatures between these two extremes were selected as optimum on the SI curve. Maximum field temperatures at which spawning has been observed are 27° C by Mayhew (1957) and 28 and 29° C by Dendy (1945). Higher temperatures are assumed to be unsuitable.

Percent area ≤ 2 m deep during the spawning season (V_7). Gizzard shad spawn in shallow water, either along the shoreline of coves and backwaters of the reservoir or in small tributary streams (Kersh 1970; Shelton 1972; Pierce 1977). Concentrated spawning activity has been reported at depths of 0.3 to 1.6 m (Miller 1960; Jester and Jensen; 1972), 0.15 to 0.3 m (Langlois 1954), 0.6 to 1.2 m (Bodola 1965), and 0.08 to 0.6 m (Mayhew 1957). Densities of spawning aggregations are not given, and the amount of spawning habitat needed per spawning female is unknown. Spawning may occur in tributaries, provided they have a low gradient (Trautman 1981; Taber 1969; Pflieger 1971; Becker 1983), and large, deep pools (Larimore and Smith 1963; Minckley 1963; Shelton and Grinstead 1973) in which the fish can congregate before spawning. It is assumed that the availability of suitable spawning streams lessens the requirement for shallow shoreline spawning habitat. Little information was available from which to derive optimum values for this curve (i.e. quantitative estimates of spawning success); it is simply an estimate based on our interpretations of subjective statements in the literature. However, the variable is believed to be important in determining the success of gizzard shad populations.

ADDITIONAL HABITAT MODELS

Developing empirical models to predict numbers and standing crops of fish (including gizzard shad) in reservoirs was an important objective of the former National Reservoir Research Program (NRRP). The following paragraphs summarize the approach used by NRRP, cite sources of models, and present three representative (and useable) models from the sources cited.

The NRRP assembled a large volume of information on the standing crop (biomass) and abundance of reservoir fishes in large reservoirs. Data were from cove rotenone samples conducted by state and Federal agencies, primarily in the central and southern U.S. Correlation and multiple regression analyses were used to identify and quantify relationships between physical or operational features of reservoirs and standing crops of important fishes, and to develop simple equations to predict standing crops of fish in reservoirs.

Multiple regression equations developed by the NRRP are used to relate important environmental (independent) variables to specific standing crop (dependent) variables. The environmental variables used in the equations are described by Leidy and Jenkins (1977) and include parameters that can be identified early in reservoir design and planning. Variation in environmental variables is used to explain variation in standing crops of fish. The predictive value of an environmental variable is determined by how well a unit change in that variable is related to a change in the selected standing crop variable. It is assumed that the environmental variables that provide the greatest predictive value are biologically important. Users should be aware, however, that other environmental variables of lower predictive value, or environmental variables not included in the analysis, may also have important biological significance. When applying the equations for habitat evaluation, the assumption is that higher abundances or standing crops of a species reflect improved habitat for that species.

The gizzard shad is one of the most ubiquitous fishes in lacustrine habitats. Therefore, the standing crop (biomass) of the species tends to be most easily related to broad nutrient characteristics. Jenkins (1968, 1970) explored relationships between nine physical and operational characteristics of large reservoirs and average standing crops of fish. He found that total dissolved solids and water exchange rates (reservoir volume divided by average annual discharge) were highly correlated with standing crops of clupeids (mostly gizzard and threadfin shad).

Subsequent analyses by personnel of the NRRP concentrated on improving predictive equations by grouping data within broad reservoir use and chemical classifications. Jenkins (1977) divided the National Reservior sample according to reservoir use (hydropower and nonhydropower) and the water exchange rate (mainstream, water exchange rate ≤ 0.165 year; and storage, water exchange > 0.165 year). He further separated reservoirs on the basis of predominant chemical ions (Ca-Mg or SO_4-Cl). Aggus and Morais (1979) grouped reservoirs within Fish and Wildlife Service administrative regions and developed regression equations relating standing crops of gizzard shad and other fish to environmental features. This analysis included development of cumulative frequency distribution plots for standing crops of gizzard shad in reservoirs. Aggus and Morais (1979) scaled these plots from zero to one to provide an alternate definition of an HSI.

Personnel from the NRRP also developed general regression equations for gizzard shad that were never published. Ploskey (Ploskey, G. R. Aquatic Ecosystem Analysts, P.O. Box 4188, Fayetteville, AR; unpublished) explored relationships between primary nutrient measures (nitrogen, phosphorus, chlorophyll _a_) obtained during the National Eutrophication Survey and standing crops of shad and other species. He found good correlations between standing crops of gizzard shad and concentrations of nitrogen and phosphorus. The NRRP also maintained and periodically updated a list of multiple regression equations for reservoir fishes that included predictions for gizzard shad. These

Table 2. Multiple regression formulas developed by the former National Reservoir Research Program for predicting standing crops (pounds/acre) of gizzard shad in reservoirs.

In hydropower mainstream reservoirs (hydropower produced, and water exchange rate ≤ 0.165 year):

Standing crop of gizzard shad = 48.5143 + 0.4347 (total dissolved solids in ppm)

N = 52 $R^2 = 0.58$ Prob > F = 0.0001

In hydropower storage reservoirs (hydropower produced, and water exchange rate > 0.165 year):

Log standing crop of gizzard shad = 0.0872 + 1.0663 (log total dissolved solids in ppm) - 0.0012 (total dissolved solids in ppm).

N = 49 $R^2 = 0.31$ Prob > F = 0.0002

In 101 reservoirs included in the National Eutrophication Survey:

Standing crop of gizzard shad = 167.7022 + 108.4697 (log total phosphorus in mg/l) + 74.9173 (total nitrogen in mg/l) + 0.90932 (mean depth in feet).

N = 101 $R^2 = 0.43$ Prob > F = 0.0001

---

formulas were last updated in 1980 (U. S. Fish and Wildlife Service 1981). Examples of predictive formulas for gizzard shad from these unpublished sources are presented in Table 2. The U. S. Fish and Wildlife Service is currently updating, expanding, and reanalyzing the databases developed by the NRRP. Information on the status of this updating effort may be obtained from Tom Edsall, Project Officer, U. S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, 1451 Green Road, Ann Arbor, MI 48105.

Predictive equations relating abundance of different size classes of fish (including gizzard shad) to short-term changes in reservoir water levels and surface areas have recently been developed. Ploskey et al. (1984) present equations that are derived from information on discrete size-classes and monthly changes in reservoir surface elevation and area to predict changes in the abundance of young shad in relation to changes in reservoir surface area during the period June through August. This preliminary modeling was based on information from only 11 reservoirs and 65 reservoir-years of record. The current update of the NRRP fishery databases has yielded about 950 reservoir-years of record wherein fish standing crop data are arrayed by discrete (2.5 cm) size classes. Reanalysis of these data is expected to permit greater resolution of relationships between short-term changes in reservoir water levels and standing crops of gizzard shad and other reservoir fishes.

Rabern (1984) presents regression equations for predicting gizzard shad standing crops in Georgia rivers.

INSTREAM FLOW INCREMENTAL METHODOLOGY

The Instream Flow Incremental Methodology (IFIM) was designed to quantify changes in the amount of habitat available to different species and life stages of fish (or macroinvertebrates) under various flow regimes (Bovee 1982). The IFIM can be used to help formulate instream flow recommendations, to assess the effects of altered streamflow regimes, habitat improvement projects, mitigation proposals, and fish stocking programs; and to assist in negotiating releases from existing water storage projects. The IFIM has a modular design, and consists of several autonomous models that are combined and linked as needed by the user. One major component of the IFIM is the Physical Habitat Simulation System (PHABSIM) model (Milhous et al. 1984). The output from PHABSIM is a measure of physical microhabitat availability as a function of discharge and channel structure for each set of habitat suitability criteria entered into the model. The output 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).

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

Suitability Index Curves as Used in the IFIM

Suitability Index (SI) curves used in PHABSIM 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 history stage of a given fish species (e.g., spawning, egg incubation, larvae, juvenile, and adult). The FWS's Western Energy and Land Use Team has designated four categories of curves and standardized the terminology pertaining to the curves (Armour et al. 1984). Category 1 curves are based on literature sources and professional opinion; category 2 (utilization) curves, based on frequency analyses of field data, are fit to frequency histograms; category 3 (preference) curves are utilization curves from which the environmental bias has been removed; and category 4 (conditional preference) curves describe habitat requirements as a function of interaction among variables. The designation of a curve as belonging to a particular category does not imply that the quality or accuracy of curves differs among the four categories. Measurements are presented in English units for compatibility with units normally used in hydraulic simulation and other components of the IFIM.

Availability of SI Curves for Use in the IFIM

Gizzard shad have no life stages that are obligate riverine. If the major objective of an IFIM analysis is to protect the indigenous biota in a given area, the gizzard shad may not be the best candidate for a target species. The gizzard shad is important as forage in many areas, however, and investigators may want to predict impacts on forage species resulting from alteration of the flow regime.

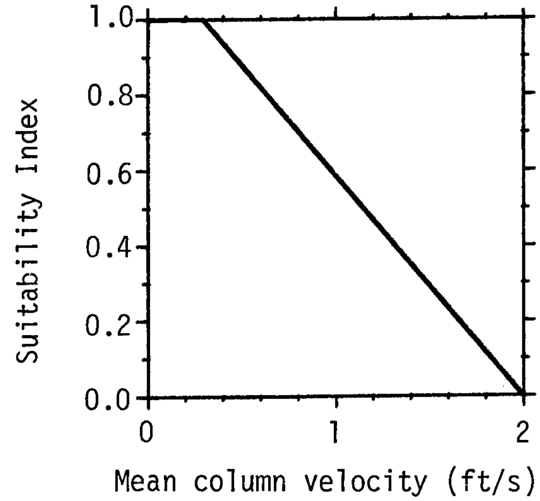
The SI curves available for IFIM analyses of gizzard shad habitat are in category 1, based on professional judgment, literature sources, and interpretation of varying amounts of field data. Users are encouraged to review the curves and verify them before use.

Spawning and egg incubation. Gizzard shad generally spawn during a 2 to 8 week period between mid-March and mid-August, depending on locale. Egg incubation requires 1.5 to 7 days, depending on water temperature. Investigators must determine the days and weeks of each year when habitat for spawning and egg incubation will be required in their study area.

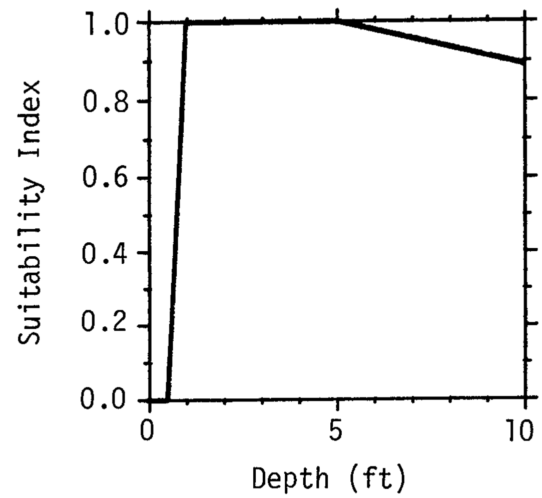
The SI curves for spawning and egg incubation velocity and depth suitability (Fig. 2) were based on information published by Jester and Jensen (1972), Scott and Crossman (1973), and Pierce (1977). Gizzard shad apparently spawn in water with little or no current in a wide range of depths. They spawn over a variety of substrate types, and the adhesive eggs adhere to whatever substrate they contact. Vegetation, gravel, and cobble were selected as the preferred substrate types (Fig. 2) by assuming that the eggs would be more likely to be protected from predation. The SI curve for suitability of spawning temperature is the same as V_6 from the HABITAT SUITABILITY INDEX MODELS section of this report.

Coordinates

x	y
0.0	1.0
0.3	1.0
2.0	0.0
100.0	0.0



x	y
0.0	0.0
0.5	0.0
1.0	1.0
5.0	1.0
50.0	0.0
100.0	0.0



x	Substrate type and size	y
1	Vegetation	1.0
2	Mud	0.0
3	Silt (< 0.062 mm)	0.2
4	Sand (0.062-2.0 mm)	0.5
5	Gravel (2-64 mm)	1.0
6	Cobble (64-250 mm)	1.0
7	Boulder (250-4000 mm)	0.5
8	Bedrock (solid rock)	0.1

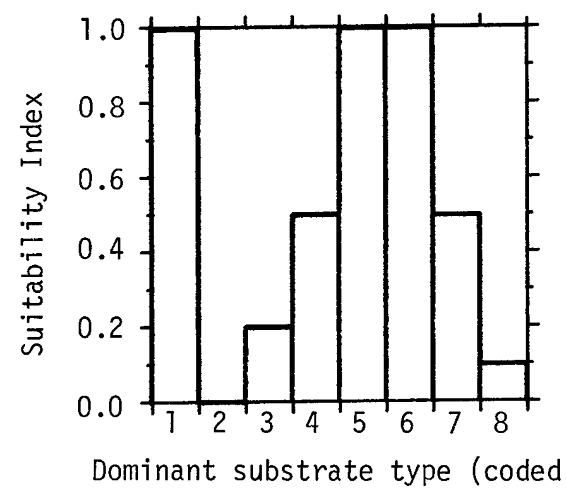


Figure 2. Category 1 SI curves for gizzard shad spawning and egg incubation velocity, depth, substrate, and temperature suitability.

Coordinates	
x	y
0.0	1.0
46.0	0.0
50.0	0.1
64.0	1.0
73.0	1.0
86.0	0.0
100.0	0.0

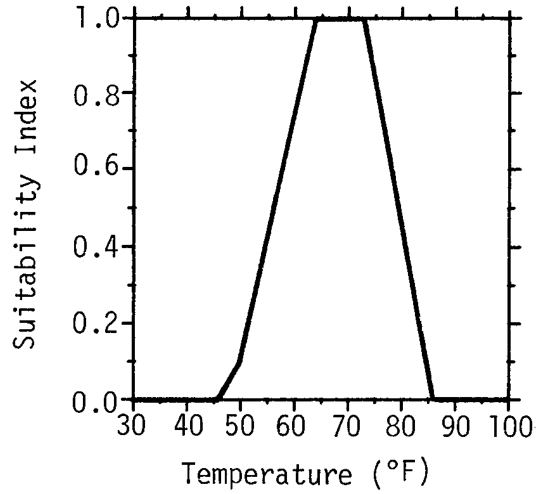


Figure 2. (concluded).

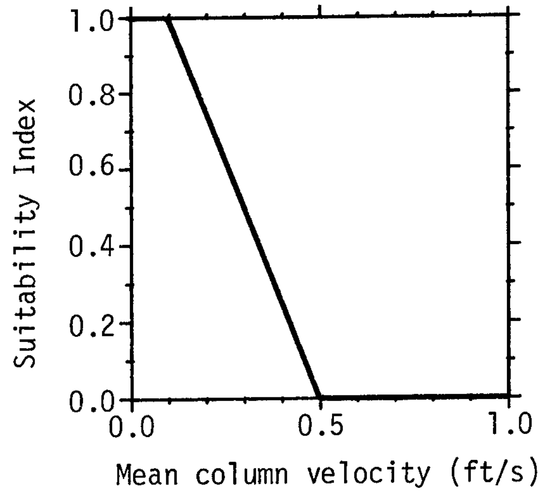
Fry. Gizzard shad fry are considered here to be fish less than 1.0 inch long, and require habitat from 2 days after the onset of spawning to about 2.5 months after the end of the spawning period, depending on locale. The SI curves depicting water velocities and depths suitable for fry (Fig. 3) were taken from information given by Walburg (1976), who found that gizzard shad fry were most abundant where current velocities were less than 0.08 ft/s and depths exceeded 3.3 ft. No information was found in the literature to suggest that fry prefer certain substrate types and no curve was developed. Although fry are often found over mud and silt, this is probably because these bottom types occur where water current is slow. There is some indication that fry use cover, but no quantitative information was available for developing a curve. The SI curve for suitability of temperature for fry was taken from the curve for juveniles and adults (Fig. 4), with the assumption that differences in relative suitabilities are insignificant.

Juveniles and adults. Juvenile gizzard shad are here considered to be fish from 1 to 10 inches in total length, and adults are longer than 10 inches. Habitat is required year-round for both life stages. The SI curves for juveniles and adults were combined (Fig. 4), with the assumption that differences in habitat requirements are not significant.

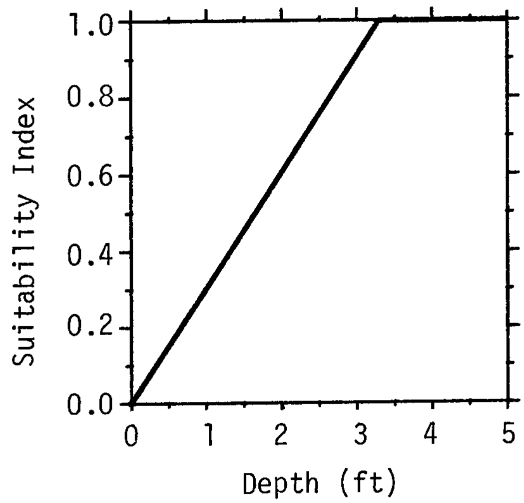
The SI curves for suitability of velocity and depth for juvenile and adult gizzard shad (Fig. 4) were derived from field data and modified by the use of professional judgment. Moss (1981), who collected data from 11 streams in Kansas from September 1980 to May 1981, electroshocked 118 gizzard shad 3.8 to 8.7 inches long and measured mean water velocity and water depth at each collection point. He collected 79 (67%) of the fish in the Neosho River, Allen and Lyon counties, in April 1981 when water temperatures were 62 to 85° F. Widths of the Neosho River at the study site were 40 to 100 ft, depths were 0.0 to 2.4 ft, velocities were 0.0 to 2.7 ft/s, substrate was predominantly gravel and silt, and the most numerous fish species included white bass (*Morone chrysops*) and red shiner (*Notropis lutrensis*). The depth curve was modified on the basis of information given by Becker (1983), who found gizzard shad at depths greater than 100 ft.

Coordinates

x	y
0.0	1.0
0.1	1.0
0.5	0.0
100.0	0.0



x	y
0.0	0.0
3.3	1.0
100.0	1.0



x	y
0.0	0.0
37.0	0.0
45.0	0.0
57.0	0.1
72.0	1.0
84.0	1.0
93.0	0.7
97.0	0.0
100.0	0.0

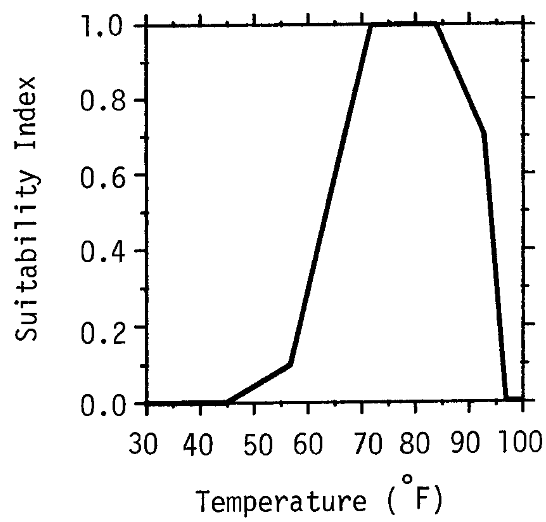


Figure 3. Category 1 SI curves for gizzard shad fry, velocity, depth, and temperature suitability.

Coordinates

x	y
0.0	1.0
0.7	1.0
1.0	0.9
1.5	0.7
2.0	0.4
2.8	0.1
4.0	0.0
100.0	0.0

x	y
0.0	0.0
1.0	0.1
3.0	0.2
4.0	1.0
100.0	1.0

x	y
0.0	0.0
37.0	0.0
39.0	0.1
52.0	0.4
57.0	0.5
72.0	1.0
84.0	1.0
93.0	0.7
97.0	0.0
100.0	0.0

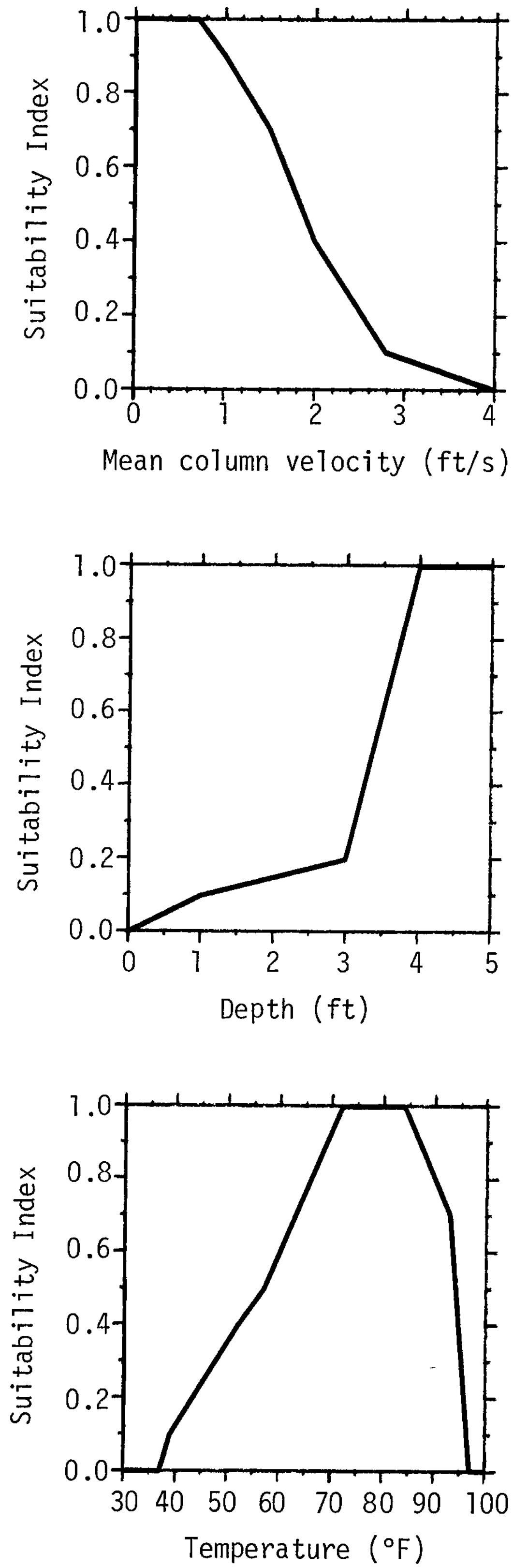


Figure 4. Category 1 SI curves for gizzard shad juvenile and adult velocity, depth, and temperature suitability.

No curve was developed for substrate, on the basis of the assumption that substrate is not an important variable for gizzard shad. No quantitative information was found for developing a curve for cover; users may wish to develop their own. The SI curve for temperature was based on information given by Hart (1952), Pahl and Willfahrt (1962), Dahlquest and Peters (1966), Jester and Jensen (1972), Gammon (1973), and Brungs and Jones (1977).

All SI curves for IFIM analyses of gizzard shad habitat should be carefully reviewed before they are used. If any of the curves are believed not to be representative of local conditions or situations, modifications will be required. Field verification of all the curves is recommended.

REFERENCES

Agersborg, H. P. K. 1930. The influence of temperature on fish. Ecol. 11:136-144.

Aggus, L. R., and D. I. Morais. 1979. Habitat suitability index equations for reservoirs based on standing crop of fish. Natl. Reservoir Res. Prog. Rep. to U.S. Fish Wildl. Serv. Western Energy and Land Use Team. Fort Collins, CO. 120 pp.

Armour, C. L., R. J. Fisher, and J. W. Terrell. 1984. Comparison of the use of the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM) in aquatic analyses. U.S. Fish Wildl. Serv. FWS/OBS-84/11. 30 pp.

Baker, C. D., and E. H. Schmitz. 1971. Food habitats of adult gizzard and threadfin shad in two Ozark reservoirs. Pages 3-11 in G. E. Hall, ed. Reservoir fisheries and limnology. Am. Fish. Soc. Special Publ. 8. 511 pp.

Barger, L. E., and R. V. Kilambi. 1980. Feeding ecology of larval shad, *Dorosoma*, in Beaver Reservoir, Arkansas. Pages 136-145 in Lee A. Fuiman, ed. Proc. 4th Annu. Larval Fish Conf., U.S. Fish Wildl. Serv. FWS/OBS-80/43.

Barnes, J. 1977. The sustained swimming ability of larval and juvenile gizzard shad, *Dorosoma cepedianum* (LeSueur), and threadfin shad, *D. petenense* (Gunther), as related to entrainment and/or impingement by water intake structures of power stations. M.S. Thesis, Univ. Arkansas, Fayetteville, AR. 141 pp.

Becker, G. C. 1983. Fishes of Wisconsin. Univ. Wisconsin Press. Madison. 1052 pp.

Berry, F. H. 1958. Age and growth of the gizzard shad (*Dorosoma lacepedi*) (LeSueur), in Lake Newnan, Florida. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 11:318-331.

Bodola, A. 1965. Life history of the gizzard shad, Dorosoma cepedianum (LeSueur), in western Lake Erie. U.S. Fish Wildl. Serv. Fish. Bull. 65:391-425.

Borges, H. M. 1950. Fish distribution studies, Niangua Arm of the Lake of the Ozarks, Missouri. J. Wildl. Manage. 14(1):16-33.

Boschung, H. T., Jr. 1961. An annotated list of fishes from the Coosa River System of Alabama. Am. Midl. Nat. 66(2):257-285.

Bovee, K. D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Inf. Pap. 12. U.S. Fish Wildl. Serv. FWS/OBS-82/26. 248 pp.

Branson, B. A. 1967. Fishes of the Neosho River System in Oklahoma. Am. Midl. Nat. 78(1):126-154.

Bross, M. C. 1967. Fish samples and year-class strength (1965-1967) from Canton Reservoir, Oklahoma. Proc. Oklahoma Acad. Sci. 48:194-199.

Brungs, W. A., and B. R. Jones. 1977. Temperature criteria for freshwater fish: protocol and procedures. U.S. Environ. Protection Agency. Natl. Environ. Res. Cent. Ecol. Res. Ser. EPA-600/3-77-061. 130 pp.

Breder, C. M., and D. E. Rosen. 1966. Modes of reproduction in fishes. Am. Mus. Nat. Hist. Press, New York. 941 pp.

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Vol. 1. Life history data on freshwater fishes of the United States and Canada, exclusive of the Perciformes. Iowa State Univ. Press, Ames. viii + 752 pp.

Carter, N. E. 1967. Fish distribution in Keystone Reservoir in relation to physicochemical stratification. M.S. Thesis, Oklahoma State Univ., Stillwater. 38 pp.

Clark, J. R. 1969. Thermal pollution and aquatic life. Sci. Am. 220(3):19-27.

Cramer, J. D., and G. R. Marzolf. 1970. Selective predation on zooplankton by gizzard shad. Trans. Am. Fish. Soc. 99:320-332.

Cvancara, V. A., S. F. Stieber, and B. A. Cvancara. 1977. Summer temperature tolerance of selected species of Mississippi River acclimated young of the year fishes. Comp. Biochem. Physiol. 56A: 81-85.

Dalquest, W. W., and L. T. Peters. 1966. A life history study of four problematic fish in Lake Diversion, Archer and Baylor Counties, Texas. Texas Parks Wildl. Dept., Inland Fish. Rep. 6. 86 pp.

Dendy, J. S. 1945. Fish distribution, Norris Reservoir, Tennessee, 1943. II Depth distribution of fish in relation to environmental factors, Norris Reservoir. Rep. Reelfoot Biol. Sta. 9:114-135.

Downey, P., and D. Toetz. 1983. Distribution of larval gizzard shad (Dorosoma cepedianum) in Lake Carl Blackwell, OK. Am. Midl. Nat. 109:23-33.

Drenner, R. W. 1977. The feeding mechanics of the gizzard shad (Dorosoma cepedianum). Ph.D. dissertation. Univ. Kansas, Lawrence. 100 pp.

Drenner, R. W., J. R. Strickler, and W. J. O'Brien. 1978. Capture probability: the role of zooplankter escape in the selective feeding of planktivorous fish. J. Fish. Res. Board Can. 35:1370-1373.

Drenner, R. W., F. deNouyelles, Jr., and D. Kettle. 1982a. Selective impact of filter-feeding gizzard shad on zooplankton community structure. Limnol. Oceanogr. 27:965-968.

Drenner, R. W., W. John O'Brien, and J. R. Mummert. 1982b. Filter-feeding rates of gizzard shad. Trans. Am. Fish. Soc. 111:210-215.

Drenner R. W., J. R. Mummert, F. deNoyelles, Jr., and D. Kettle. 1984. Selective particle ingestion by a filter-feeding fish and its impact on phytoplankton community structure. Limnol. Oceanogr. 29(5):941-948.

Eddy, S. and J. C. Underhill. 1974. Northern fishes. Univ. Minnesota Press, Minneapolis. 414 pp.

Gallagher, R. P., and J. V. Conner. 1980. Spatio-temporal distribution of ichthyoplankton in the lower Mississippi River, Louisiana. Pages 101-115 in Lee A. Fuiman, ed. Proc. 4th Annu. Larval Fish Conf., U.S. Fish Wildl. Serv. FWS/OBS-80/43.

Gammon, J. R. 1973. The effect of thermal inputs on the populations of fish and macroinvertebrates in the Wabash River. Purdue Univ. Water Resources. Research Center, Tech. Rep. 32. West Lafayette, IN. 160 pp.

Gasaway, C. R. 1970. Changes in the fish population in Lake Francis Case in South Dakota in the first 16 years of impoundment. U.S. Fish Wildl. Serv. Tech. Pap. 56.

Gebhart, G. E., and R. C. Summerfelt. 1978. Seasonal growth rates of fishes in relation to conditions of lake stratification. Proc. Oklahoma Acad. Sci. 58:6-10.

Gerking, S. D. 1945. The distribution of the fishes of Indiana. Invest. Indiana Lakes Streams 3:1-137.

Gunter, G. 1945. Studies on marine fishes of Texas. Publ. Inst. Mar. Sci. 1:1-190.

Hamilton, K., and E. P. Bergersen. 1984. Methods to estimate aquatic habitat variables. U.S. Bur. Reclamation, Eng. Res. Cent., Denver, CO. n.p.

Hart, J. S. 1952. Geographic variations of some physiological and morphological characters in certain freshwater fish. Univ. Toronto, Biol. Ser. 60, Publ. Ontario Fish. Res. Lab. 72. 79 pp.

Hendricks, M. K., and R. L. Noble. 1979. Feeding interactions of three planktivorous fishes in Trinidad Lake, TX. Proc. Annu. Conf. Southeastern Assoc. Fish Wildl. Agencies 33:324-330.

Hubbs, C. L. 1934. Some experiences and suggestions on forage fish culture. Trans. Am. Fish. Soc. 63:53-63.

Hubbs, C. L., and K. F. Lagler. 1942. Annotated list of the fishes of Foots Pond, Gibson County Indiana. Invest. Indiana Lakes Streams 2:73-83.

Jenkins, R. M. 1949. A biological fishery survey of the Great Salt Plains Reservoir. Mimeo. U.S. Army Corps Eng., Tulsa District. (Masters Thesis). 92 pp.

____________. 1957. The effect of gizzard shad on the fish population of a small Oklahoma lake. Trans. Am. Fish. Soc. 85: 58-74.

____________. 1968. The influence of some environmental factors on standing crop and harvest of fishes in U. S. reservoirs. Proc. Reservoir Fish. Resour. Symp. (1967):298-321.

____________. 1970. The influence of engineering design and operation and other environmental factors on reservoir fishery resources. Water Resour. Bull. 6(1):110-119.

____________. 1977. Prediction of fish biomass, harvest, and prey-predator relations in reservoirs. Pages 282-293 in W. Van Winkle, ed. Proc. Conf. on Assessing effects of Power-Plant Induced Mortality of Fish Populations. Pergamon Press, New York.

Jester, D. B. 1962. Fisheries study of Conchas Lake. Fed. Aid Proj. F-22, R-3, Work Plan 2, Job B-1(3). Job Completion Rep., New Mexico Dept. Game Fish. 102 pp.

Jester, D. B., and B. L. Jensen. 1972. Life history and ecology of the gizzard shad, Dorosoma cepedianum (LeSueur) with reference to Elephant Butte Lake. New Mexico State Univ. Agric. Exp. Sta. Res. Rep. 218. 56 pp.

Jude, D. J. 1973. Food and feeding habits of gizzard shad in Pool 19, Mississippi River. Trans. Am. Fish. Soc. 102:378-383.

Kashuba, S. A., and W. J. Matthews. 1984. Physical condition of larval shad during spring-summer in a southwestern reservoir. Trans. Am. Fish. Soc. 113:199-204.

Kersh, G. M., Jr. 1970. Growth and distribution of larval and early juvenile gizzard shad and threadfin shad in Beaver and Bull Shoals Reservoirs. M.S. Thesis, Univ. Arkansas, Fayetteville. 77 pp.

King, P. A., T. E. Wissing, E. J. DeVillez, M. J. Chimney, and W. B. Randall, Jr. 1977. Nutritional implications of surface feeding by gizzard shad (Dorosoma cepedianum) on insect remains in an Ohio reservoir. J. Fish. Res. Board Can. 34:269-273.

Kutkuhn, J. H. 1958. Utilization of plankton by juvenile gizzard shad in a shallow prairie lake. Trans. Am. Fish. Soc. 87:80-103.

Lagler, K. F., and H. Van Meter. 1951. Abundance and growth of gizzard shad, Dorosoma cepedianum (LeSueur), in a small Illinois Lake. J. Wildl. Manage. 15:357-360.

Langlois, T. F. 1954. The western end of Lake Erie and its ecology. J. W. Edwards, Inc. Ann Arbor, MI. 479 pp.

Larimore, R. W., and P. W. Smith. 1963. The fishes of Champaign County, IL. Bull. Illinois Nat. Hist. Surv. 28:295-382.

Leidy, G. R., and R. M. Jenkins. 1977. The development of fishery compartments and population rate coefficients for use in reservoir ecosystem modeling. Contract Report Y-77-1, prepared for Office, Chief Eng., U.S. Army, Washington, DC. 72 pp. + appendices.

Lewis, R. E., and J. R. Siler. 1980. Determination of the vertical distribution of ichthyoplankton on Lake Norman, North Carolina, using a discrete-depth sampling design. Pages 91-100 in L. A. Fuiman, ed. Proc. 4th Annu. Larval Fish Conf. FWS/OBS-80/43.

Matthews, W. J. 1984. Influence of turbid inflows on vertical distribution of larval shad and freshwater drum. Trans. Am. Fish. Soc. 113:192-198.

Mayhew, J. 1957. Notes on the observations of the reproductive habits of the gizzard shad in two Iowa Lakes. Iowa Conserv. Comm. Q. Biol. Rep. 10:20-22.

Megrey, B. A. 1980. Dorosoma cepedianum (LeSueur). Page 69 in D. S. Lee et al., eds. Atlas of North American Freshwater Fishes. North Carolina Biol. Surv. Publ. 1980-12. 867 pp.

Milhous, R. T., D. L. Wegner, and T. Waddle. 1984. User's guide to the Physical Habitat Simulation System. Instream Flow Inf. Pap. 11. U.S. Fish Wildl. Serv. FWS/OBS-81/43. Revised.

Miller, R. R. 1957. Origin and dispersal of the alewife, Alosa pseudoharengus and the gizzard shad, Dorosoma cepedianum, in the Great Lakes. Trans. Am. Fish. Soc. 86:97-111.

________. 1960. Systematics and biology of the gizzard shad (Dorosoma cepedianum) and related fishes. U.S. Fish Wildl. Serv. Fish. Bull. V. 60:371-392.

Minckley, W. L. 1963. The ecology of a spring stream, Doe Run, Meade County, Kentucky. Wildl. Monogr. 11. 124 pp.

Minckley, W. L., and L. A. Krumholz. 1960. Natural hybridization between the clupeid genera Dorosoma and Signalosa, with a report on the distribution of S. petenensis. Zool. 44:171-182.

Moss, R. E. 1981. Unpublished field data. Kansas Dept. Fish Game, Pratt.

Mummert, J. R. 1983. Gill raker morphology and the filtering efficiency of the gizzard shad (Dorosoma cepedianum). M.S. Thesis, Texas Christian Univ., Ft. Worth. 44 pp.

Netsch, N. F., G. M. Kersh, Jr., A. Houser, and R. V. Kilambi. 1971. Distribution of young gizzard and threadfin shad in Beaver Reservoir. Pages 95-105 in G. E. Hall, ed. Reservoir Fish. Limnol. Am. Fish. Soc. Special Publ. 8.

Pahl, G., and G. Willfahrt. 1962. Growth study of young gizzard shad. Minnesota Acad. Sci. Proc. 30:22-25.

Pflieger, W. L. 1971. A distributional study of Missouri fishes. Univ. Kansas Mus. Nat. Hist. Publ. 20:225-570.

Pierce, R. J. 1977. Life history and ecological energetics of the gizzard shad (Dorosoma cepedianum) in Acton Lake, OH. Ph.D. Dissertation, Miami Univ., Oxford, OH. 214 pp.

Pierce, R. J., T. E. Wissing, and B. A. Megrey. 1981. Aspects of the feeding ecology of gizzard shad in Acton Lake, OH. Trans. Am. Fish. Soc. 110:391-395.

Ploskey, G. R., J. M. Nestler, and L. R. Aggus. 1984. Effects of water levels and hydrology on fisheries in hydropower storage, hydropower mainstream, and flood control reservoirs. Tech. Rep. E-84-8, prepared by the U.S. Fish Wildl. Serv., U.S. Dept. Int., and Environ. Lab., U.S. Army Eng. Waterways Exp. Stn., Vicksburg, MS.

Proffit, M. A., and R. S. Benda. 1971. Growth and movement of fishes, and distribution of invertebrates, related to a heated discharge into the White River at Petersburg, Indiana. Indiana Univ. Water Resour. Invest. Rep. 5. 94 pp.

Rabern, D. A. 1984. Development of habitat based models for predicting standing crops of nine species of riverine fishes in Georgia. M.S. Thesis. Univ. Georgia, Athens. 127 pp.

Reuter, J. M., and C. E. Herdendorf. 1974. Laboratory estimates of the seasonal final temperature preferenda of some Lake Erie Fish. Proc. 17th Conf. Great Lakes Res. (Int. Assoc. Great Lakes Res.) 17:59-67.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184, Ottawa, Canada. 966 pp.

Shelton, W. L. 1972. Comparative reproductive biology of the gizzard shad, Dorosoma cepedianum (LeSueur), and the threadfin shad, D. petenense (Gunther), in Lake Texoma, OK. Ph.D. Dissertation, Univ. Oklahoma, Norman. 241 pp.

Shelton, W. L., and B. G. Grinstead. 1973. Hybridization between Dorosoma cepedianum and D. petenense in Lake Texoma, OK. Proc. Annu. Conf. Southeastern Assoc. Game Fish Comm. 26:506-510.

Shelton, W. L., and R. R. Stephens. 1980. Comparative embryogeny and early development of threadfin and gizzard shad. Prog. Fish-Cult. 42: 34-41.

Shoemaker, H. H. 1942. The fishes of Wayne County, Indiana. Invest. Indiana Lakes Streams 2:267-296.

Storck, T. W., D. W. Dufford, and K. T. Clement. 1978. The distribution of limnetic fish larvae in a flood control reservoir in central Illinois. Trans. Am. Fish. Soc. 107:419-424.

Strawn, K. 1958. Optimum and extreme temperatures for growth and survival of various fishes. For handbook of biological data. Cited in K. D. Carlander, 1969. Handb. Freshwater Fish. Biol. Iowa State Univ. Press, Ames. 752 pp.

Summerfelt, R. C. 1967. Fishes of the Smokey Hill River, Kansas. Trans. Kansas Acad. Sci. 70:102-139.

Taber, C. A. 1969. The distribution and identification of larval fishes in the Buncombe Creek Arm of Lake Texoma with observations on spawning habits and relative abundance. Ph.D. Dissertation, Univ. Oklahoma, Norman. 119 pp.

Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Fish Wildl. Serv. FWS/OBS-82/10.A. 54 pp.

Tiffany, L. H. 1921a. The gizzard shad in relation to plants and game fishes. Trans. Am. Fish. Soc. 50:381-386.

________. 1921b. Algal food of the young gizzard shad. Ohio J. Sci. 21(4):113.

Trautman, M. B. 1981. The fishes of Ohio. Ohio State Univ. Press. 782 pp.

Turner, W. R. 1953. The age and growth of the gizzard shad Dorosoma cepedianum (LeSueur) in Herrington Lake, KY. Kentucky Dept. Fish Wildl. Resour., Fish. Bull. 13. 15 pp.

U. S. Fish and Wildlife Service. 1981. Multiple regression formulas for use in estimating fish standing crop, sport fish harvest and angler effort in U.S. reservoirs. Natl. Reservoir Res. Program. 18 pp. mimeo.

______________________________. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n. p.

Velasquez, G. T. 1939. On the viability of algae obtained from the digestive tract of the gizzard shad, Dorosoma cepedianum (LeSueur). Am. Midl. Nat. 22:376-412.

Walburg, C. H. 1964. Summary of fish population studies, Lewis and Clark Lake, during the first seven years of impoundment, 1956-1962. U.S. Fish Wildl. Serv., Special Sci. Rep., Fish. 482. 27 pp.

________. 1976. Changes in the fish population of Lewis and Clark Lake, 1956-74, and their relation to water management and the environment. U.S. Fish Wildl. Serv., Res. Rep. 79. 33 pp.

Warner, E. N. 1940. Studies on the embryology and early life history of the gizzard shad, Dorosoma cepedianum LeSueur. Ph.D. Dissertation, Ohio State Univ. 28 pp.

Zeller, H. D., and H. N. Wyatt. 1967. Selective shad removal in southern reservoirs. Pages 405-414 in C. E. Lane, Chairman. Reservoir Fish. Resour. Symp. Athens, GA. 569 pp.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(10.112)	2.	3. Recipient's Accession No.
4. Title and Subtitle Habitat Suitability Index Models and Instream Flow Suitability Curves: Gizzard Shad			5. Report Date September 1985
			6.
7. Author(s) K. L. Williamson and P. C. Nelson			8. Performing Organization Rept. No.
9. Performing Organization Name and Address	Western Energy and Land Use Team U.S. Fish and Wildlife Service Drake Creekside Building One 2627 Redwing Road Fort Collins, CO 80526-2899		10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address	Western Energy and Land Use Team Division of Biological Services Research and Development Fish and Wildlife Service Department of the Interior, Washington, DC 20240		13. Type of Report & Period Covered 14.

15. Supplementary Notes The Biological Report series was initiated in October 1984 to replace the FWS/OBS series published since 1976. The report number assigned to this model follows consecutively from the Habitat Suitability Index models published as FWS/OBS 81/10._, now numbered as Biological Report 82(10._).

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model and instream flow suitability curves for gizzard shad (Dorosoma cepedianum). The model consolidates habitat use information into a framework appropriate for field application, and is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

Fishes
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

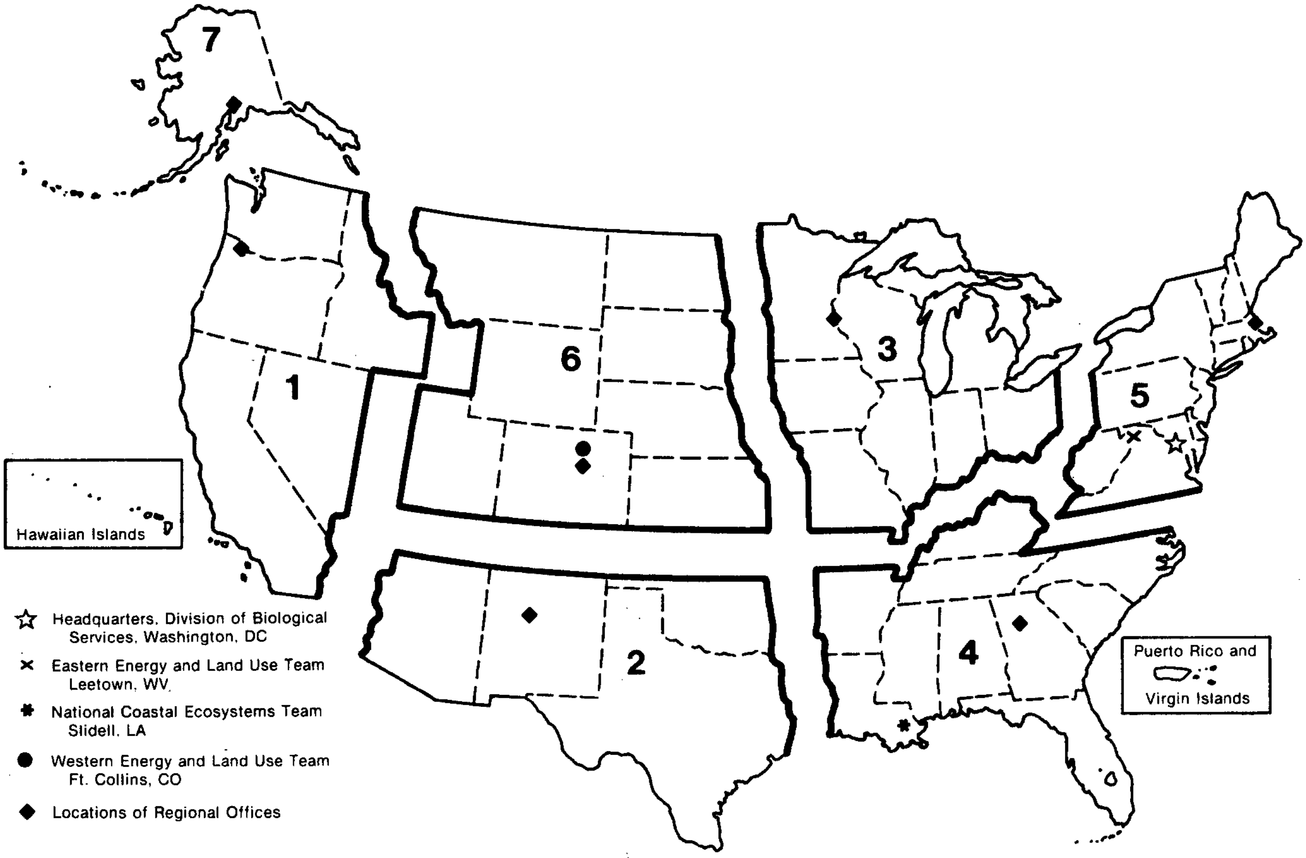
Gizzard shad
Dorosoma cepedianum
Habitat suitability

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	33
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988—574-485/85,076 REGION NO. 8



REGION 1
Regional Director
U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

REGION 3
Regional Director
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111

REGION 4
Regional Director
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

REGION 5
Regional Director
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts 02158

REGION 6
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

REGION 7
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.