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Library of Habitat Models to Evaluate Benefits of Aquatic Restoration Projects on Fishes

by K. Jack Killgore, Jan Jeffrey Hoover, and Catherine E. Murphy

INTRODUCTION: Habitat models are used to evaluate impacts of water resource development activities such as flood control and navigation projects, and environmental benefits of restoration or mitigation projects. These models generally take the form of an index ranging from 0.0 (poor habitat) to 1.0 (optimum habitat), referred to as a "Habitat Suitability Index" (HSI). HSI's are used to weight acres of affected habitat, a method compatible with the commonly used Habitat Evaluation Procedure (www.fws.gov/policy/hbindex.cfm) or Instream Flow Incremental Methodology (www.fort.usgs.gov/Products/Software/IFIM/). Both of these methods multiply quality (i.e., HSI) and quantity (e.g., acres) to determine habitat conditions. HSI's represent the biological components of the evaluation (e.g., number of species, relative abundance) and their responses to changes in habitat conditions. The multiplicative product of HSI and acres of habitat is a unit (e.g., Habitat Unit, Weighted Usable Area) that can be compared among project alternatives and averaged over the life of the project (e.g., Average Annual Habitat Unit).

The U.S. Army Engineer Research and Development Center (ERDC) continues to evaluate consequences of flood control, water supply, and navigation projects on fish assemblages, as well as benefits of aquatic restoration. Many of these projects have been completed through leveraged funds from Corps of Engineers Districts (primarily Vicksburg and Memphis Districts) and the Ecosystem Management and Restoration Research Program at ERDC. HSI models are based on field-derived correlations between biotic-abiotic variables, resulting in a library of regression equations developed over the past 10 years. The purpose of this technical note is to summarize the HSI models and describe their development and applicability as assessment tools in similar aquatic systems.

DEVELOPMENT OF MODELS: All models presented herein were developed from field studies that sampled fish populations and measured a suite of habitat variables concurrently. Depending on the objectives of the original study, the biotic response was either for a single species (e.g., largemouth bass), guild (e.g., riverine versus wetland assemblages), or the entire community (e.g., number of species). Fish were collected with seines, hoop nets, gill nets, and/or electrofishing. Standard methods were used to calculate total number of species and the mean and range of catch-per-unit-effort. Specific habitat variables (e.g., water quality, hydraulics and hydrology, depth, instream cover) were measured during or prior to fish collection activities so correlations between biotic and abiotic variables could be derived.

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Analyses of data included removing outliers, identifying correlations between biotic and abiotic variables using Pearson or Spearman correlation matrices, and in some cases, $\log_{10}$-transforming variables to improve correlation coefficients and meet assumptions of a normal distribution. Two types of models were developed. The Red River Navigation model evaluated tradeoffs between un-impounded and impounded (locks and dams) river reaches. Fish species were collected in the field and grouped into ecological guilds that consider preference and tolerance to riverine, lacustrine, and wetland habitats. Mean abundances of fish guilds were compared among three different macrohabitats: river, navigation pool, and oxbow lake. An HSI of 1.0 was assigned to the habitat with the highest mean abundance of a particular guild, and the mean abundances in the two remaining habitats were divided into the highest abundance value to calculate their respective HSI scores.

The second type of model was in the form of regression equations using linear or curvilinear functions. These models were based on microhabitat variables (e.g., depth, velocity, dissolved oxygen) rather than larger-scale macrohabitats considered in the Red River model. Predicted biotic value was divided by a measured or theoretical (i.e., professional opinion, comparison to regional values) maximum value to obtain the HSI score. The overall goal of the analysis was to maximize the coefficient of determination (r^2-value) for a univariate or multivariate regression model that has realistic biological predictions over a defined range of habitat conditions. The projects associated with model development are referenced in Appendix A. Some of the final models presented herein were modified from the original studies to maintain consistency in reporting variables and further improve the accuracy and precision of the output.

APPLICATION OF MODELS: Models are presented by major water body types: navigable rivers, lowland streams, upland streams, wetlands, and oxbow lakes (Table 1). For each model, the location and a description of the water body size and other geomorphic conditions are provided. These descriptions will provide a basis to determine transferability of a particular model developed in one aquatic system to another. Although relationships between fishes and their habitats were developed from field studies of specific individual rivers (Table 1), they may be easily (and appropriately) applied in planning or assessment studies of other systems. This is because they predict responses for populations of wide-ranging taxa or for community-level metrics that are characteristic of many low-gradient aquatic ecosystems.

Except for the Red River model, each model calculates an HSI value for a given set of abiotic conditions by dividing the maximum observed value of the biotic, or dependent, variable by the predicted value. Models forecast HSI values over a specified range of habitat conditions (Table 2). Extrapolation beyond the range may result in erroneous values. Hydraulic variables (e.g., depth, velocity, discharge) were the primary correlates to diversity and abundance of the fish assemblage in most of the habitat models. Other factors, such as water temperature, dissolved oxygen, turbidity, and vegetative coverage were also important in describing biotic responses in some of the models. Models do not explain all of the variation in biotic responses to habitat changes, but do focus on those physical variables that can be predicted quantitatively by Corps of Engineers Districts and are known to influence the structure of fish assemblages.

Relationships between dependent (biotic) variables and independent (physical) variables may be evaluated (by planners, etc.) for reliability either "internally," based on descriptive statistics (e.g., reported measures of variance, magnitude of r^2), or "externally," based on comparisons with published information (e.g., previous studies, accounts in regional ichthyofaunal books). Transferability of these models to other systems will require independent field study but may be inferred *a priori* based on geographic proximity and/or habitat similarity. Models cannot be extrapolated beyond the ranges of data used in their development; computational limits and a worksheet for each model are provided (Table 2).

The models presented herein provide not only assessment tools for individual water bodies, but also a framework for system-wide or watershed-scale evaluations. Models represent large navigable rivers with both upland and lowland tributaries. In addition, wetlands and oxbow lakes that are characteristic of many alluvial river systems are represented. Comprehensive data, such as those used to derive these types of models, may be too labor-intensive or cost-prohibitive for large-scale assessments. However, several instream abiotic parameters such as channel dimensions, water chemistry, hydrology, and bathymetry may be available from Corps of Engineers Districts. Couple these physical data with strategically located fish collections and/or knowledge of local assemblages, and models such as these can be combined to estimate baseline conditions and reveal potential impacts or benefits of large-scale environmental modifications.

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Table 1
Habitat Suitability Index Models to Predict Biological Response of Fish Assemblages to Changes in Habitat Conditions.

Site Origin/Applicability	Model	Comments
Navigable Rivers		
White River, AR • Dependent Variable: Species richness based on 5 seine hauls (20-ft seine) per sample. • Applicability: Large, free-flowing tributaries of the lower MS River • Applicable range of abiotic variables: - Water temperature: 10–25 ºC - Discharge: 8,000–35,000 cfs	$HSI = \frac{0.542(a) + 0.00039(b) - 7.431}{20}$ where a= water temperature (ºC), b=mean discharge (cfs), R^2=0.85, p=0.0001, n=17.	• Predicted species richness was divided by maximum observed species richness (i.e., 20 species) to obtain an HSI value.
Red River, AR-LA • Dependent Variable - Discrete HSI values developed from mean abundance of guild members using multiple gears (seining, trotlines, gill nets). HIS = 1.0 was the habitat with the highest mean abundance of a particular guild, and the mean abundances in the two remaining habitats were divided into the highest value to calculate their respective HSI. • Applicability: Navigation system of the lower MS River that includes unimpounded river, impounded river (pool), and contiguous oxbow lakes.	See guild table below	• Sample size (n) is the sum of seines, gill nets, and trotlines used to determine means. • An asterisk indicates that mean value for a guild was significantly greater among habitats based on Student-Neumans-Keuls Multiple Range Test at p < 0.1. • Guilds were based on tolerance to anthropogenic impacts to rivers and preference to specific habitats.
Lowland Streams		
Mercer Bayou, AR • Dependent Variable – Species richness based on 10 seine hauls (10-ft seine) per sample. • Applicability: Large (average width = 200 ft) alluvial plain stream with extensive aquatic vegetation. • Applicable range of abiotic variables: - Channel wetted width: 50–300 ft	$HSI = \frac{5.226 + 0.0809(a)}{30}$ Where a=wetted channel width (ft), R^2=0.75, p<0.001, n=12	• Predicted species richness was divided by maximum observed species richness (i.e., 30 species) to obtain an HSI value.

Red River, AR-LA model:

Guild	River (n=116)		Pool (n=84)		Oxbow Lakes (n=86)	
	Mean ±SD	HSI	Mean±SD	HSI	Mean±SD	HSI
Intolerant Riverine	5.9±19.6*	1.0	0.3±0.8	0.1	0.4±1.0	0.1
Tolerant Riverine	30.8±113.0*	1.0	11.3±30.5	0.4	6.1±8.3	0.2
Tolerant Lacustrine	120.7±327.3	0.8	84.0±288.2	0.6	154.1±312.4	1.0
Wetland/Backwater	0.3±0.8	0.1	0.4±0.8	0.1	7.3±20.2*	1.0
Catfish	1.9±2.5	0.4	5.3±6.0*	1.0	2.1±3.1	0.4
Crappie	0.1±0.4	0.3	0.3±0.7	0.8	0.4±1.3*	1.0
Largemouth bass	0.5±3.4	0.4	1.4±5.6	1.0	1.1±2.6	0.8

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Table 1. (Continued)

Site Origin/Applicability	Model	Comments
Lowland Streams (cont.)		
Bayou Macon, AR • Dependent Variable – Number of fish collected based on 10 seine hauls (10-ft seine) per sample. • Applicability: Medium-sized (average width = 125 ft, maximum depth = 10 ft) alluvial plain streams. • Applicable range of abiotic variables: - Depth: 1.5–10 ft. If depth >8 ft, then HSI = 1.0	$HSI = \frac{65.2(a) - 1.8(a^2)}{414}$ where a=maximum depth (ft), R^2=0.54, p<0.001, n=20	• Polynomial regression with a y-intercept of zero was used to obtain a functional relationship. • Predicted value was divided by maximum observed number of individuals (i.e., 414 individuals/ 10 seine hauls) to obtain an HSI value.
Upland Streams		
Black Creek, MS • Dependent Variable – Abundance of intolerant (to changes in physical habitat) stream fish collected in 10 seine hauls (10-ft seine) per sample. • Applicability: Small (average width = 40 ft, maximum depth = 2 ft) gravel riffles flowing into an alluvial plain. • Applicable range of abiotic variables: - Depth: 0.6–1.9 ft - Velocity: 0.25–1.00 ft/sec	$HSI_{Depth} = \frac{-110.6(a) + 217.3}{149}$, R^2=0.92, p<0.01, n=5 $HSI_{Velocity} = \frac{119.7(b) + 29.1}{149}$, R^2=0.68, p<0.10, n=5 where a=mean depth (ft) and b=mean velocity (ft/sec)	• The HSI equations for each hydraulic variable were divided by maximum abundance of intolerant fishes (149 individuals/10 seine hauls). • Intolerant fish species were mostly shiners, topminnows, and madtoms.
Upper Ouachita River, AR • Dependent Variable – Species richness based on 10 seine hauls (10-ft seine) per sample. • Applicability: Medium-sized (average width = 80 ft, maximum depth = 10 ft) upland, gravel-bottom tailwater streams with warm-water fish assemblages • Applicable range of abiotic variable: - Water temperature: 14–23 °C	$HSI = \frac{0.29(a^2) - 8.4(a) + 67.7}{25}$ where a=water temperature (°C), R^2=0.65, p=0.01, n=11	• Maximum species richness per sample, which is used as the divisor in the HSI equation, was estimated at 25 species. • Species richness was mostly comprised of minnows, sunfishes, and darters.

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Table 1. (Continued)

Site Origin/Applicability	Model	Comments
	Upland Streams (cont.)	
Little Tallahatchie River, MS ● Dependent Variable – Abundance of lotic cyprinids (e. g., emerald shiner, mimic shiner, blacktail shiner, and Mississippi silvery minnow) collected in 10 seine hauls (10-ft seine) per sample. ● Applicability: Small (base flow <20 cfs) upland streams flowing into an alluvial plain. ● Applicable range of abiotic variables: - Maximum water depth: 2–10 ft - Average dissolved oxygen: 2–10 mg/l	$HSI = \frac{-1.047 + 2.924(a) + 1.056(b)}{3.0}$ where a=$\log_{10}$dissolved oxygen (mg/l), b=$\log_{10}$maximum depth (ft), $R^2 = 0.80$, $p<0.01$, n=17	● Predicted value was divided by $\log_{10}$ maximum observed abundance of the guild (3.0) to calculate HSI.
	Riverine Wetlands	
Bayou Desiard, LA ● Dependent Variable – Number of juvenile (<100 mm total length) largemouth bass in 10 seine hauls (10-ft seine) per sample. ● Applicability: Large, riverine back-water with cypress-tupelo wetlands (>1,000 acres, average width = 370 ft, average depth ranges from 5–15 ft, heavily vegetated in some areas). ● Applicable range of abiotic variable: - Dissolved oxygen: 2.3–9 mg/l during the afternoon	$HSI = \frac{5.5(a) - 12.4}{37}$ where a=dissolved oxygen (mg/l), $R^2 = 0.70$, df=9, $p=0.003$, n=10	● Model output was converted to an HSI value by dividing an esti-mated maximum abundance of largemouth bass per 10 seine hauls (mean + 1 standard deviation = 37 bass) into predicted abundance.
	Oxbow Lakes	
Lower Red River, LA ● Dependent Variable – Number of juvenile (<120 mm total length) black (largemouth and spotted) bass in 5 seine hauls (20-ft seine) per sample. ● Applicability: Mid-sized oxbow lakes (<600 acres, mean depth = 7 ft) either seasonally or permanently connected to the river. ● Applicable range of abiotic variable: - Average lake width: 150–700 ft	$HSI = \frac{0.0018(a) - 0.229}{0.903}$ where a=average lake width (ft), $R^2 = 0.66$, $p<0.004$, n=10	● Fish abundance was transformed as $\log_{10}[n + 1]$ in which n is the observed number of fish. ● Model output was converted to an HSI value by dividing the $\log_{10}$ transformed maximum observed number of black bass from a single collection (i.e., 7 bass = 0.903) into predicted abundance.
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Table 1. (Concluded)

Site Origin/Applicability	Model	Comments
	Oxbow Lakes (cont.)	
<u>Lake Whittington, MS</u> ● Dependent Variable – Number of juvenile (<50 mm) sunfish (primarily bluegill) and adult silversides (primarily inland) caught in light traps. ● Applicability: Littoral zone of large oxbow lakes (>300 acres), seasonally or permanently connected to the Mississippi River. ● Applicable range of abiotic variable: - Mean depth of littoral zone: 2 to 40 ft	$HSI_{\text{Sunfish} > 4\text{ ft}} = \frac{21.699 - 0.516(a)}{19.6}$ $HSI_{\text{Sunfish} < 4\text{ ft}} = \frac{-31.608 + 14.528(a)}{26.5}$ where a=mean depth (ft), R^2=0.309, p=0.0001, n=83 $HSI_{\text{Silversides} > 20\text{ ft}} = \frac{122.724 - 2.467(a)}{73.4}$ $HSI_{\text{Silversides} < 20\text{ ft}} = - 0.250 + 0.062(a)$ where a=mean depth (ft), R^2=0.243, p=0.0006, n=83	● No silversides were collected where mean depths were less than 4 ft (HSI=0). ● Sunfish represent recently spawned sport fishes and silversides represent a forage species. ● No silversides were collected at depths <4 ft so an HSI of 0.00 was assumed for depths <4 ft and a positive linear relationship for the depth interval of 4 to 20 ft.
<u>Dump Lake, MS</u> ● Dependent Variable – Depending on model, species diversity, abundance, and species richness of fish assemblage based on boat-mounted electrofishing per 5 minutes of sampling. ● Applicability: Large to medium-sized oxbow lakes (200–500 acres, mean depth ranging from 5–7 ft) permanently isolated from the river in alluvial plain landscapes. ● Applicable range of abiotic variables: - Sediment depth (ft): 0.5–6.0 - Maximum water depth (ft): 1–12 - Vegetative Cover (%): 0–85	$HSI = \frac{1.87 - 0.31a}{1.7}$ where a=soft sediment depth (ft), R^2=0.69, p<0.02, n=7 $HSI = \frac{82.4x - 3.5a^2}{525}$ where a=maximum water depth (ft), R^2=0.65, p<0.001, n=10 $HSI = \frac{7.6288a + 3.9816}{13}$ where a=% vegetative cover, R^2=0.41, p<0.001, n=25	● For sediment depth and vegetative cover, model output was converted to an HSI value by dividing the predicted by the maximum value (1.7 species diversity, species richness of 13, respectively). ● For depth, a y-intercept of zero was used to obtain a relationship between number of individuals and maximum depth. Model output was converted to an HSI value by dividing maximum observed number in reference lakes minus 1 SD (525 individuals).
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Table 2
Worksheet to Calculate HSI Values for Models Presented in Table 1.

Location	Biotic-response	Abiotic-predictor (a,b)	amin	amax	bmin	bmax	HSImin	HSImax
White River, AR	species richness	temperature (°C), discharge (cfs)	10	25	8000	35000	0.0555	0.9885
Mercer Bayou, AR	species richness	wetted width (ft)	50	300	--	--	0.3090	0.9832
Bayou Macon, AR	total individuals	water depth (ft)	1.5	8	--	--	0.2264	0.9816
Black Creek, MS	intolerant individuals	water depth (ft)	0.6	1.9	--	--	1.0130	0.0481
Black Creek, MS	intolerant individuals	water velocity (ft/s)	0.25	1	--	--	0.3961	0.9987
Upper Ouachita River, AR	species richness	temperature (°C)	14	23	--	--	0.2776	1.1164
Little Tallahatchie River, MS	lotic cyprinid individuals	log10DO (mg/L), log10max-depth (ft)	2	10	2	10	0.0504	0.9777
Bayou Desiard, LA	juv-bass individuals	dissolved oxygen (mg/L)	2.3	9	--	--	0.0068	1.0027
Lower Red River, LA	juv-bass individuals	width (ft)	150	700	--	--	0.045404	1.14175
Lake Whittington, MS - Sunfish	juv-sunfish individuals	mean depth (>4 ft)	4	40	--	--	1.0018	0.0540
Lake Whittington, MS - Sunfish	juv-sunfish individuals	mean depth (<4 ft)	2.2	4	--	--	0.0133	1.0002
Lake Whittington, MS - Silversides	adult-silverside individuals	mean depth (>20 ft)	20	40	--	--	0.9998	0.3276
Lake Whittington, MS - Silversides	adult-silverside individuals	mean depth (<20 ft)	4.1	20	--	--	0.0042	0.9900
Dump Lake, MS	species diversity	sediment depth (ft)	6	0.5	--	--	0.0059	1.0088
Dump Lake, MS	total individuals (ref. condition)	max water depth (ft)	1	12	--	--	0.1503	0.9234
Dump Lake, MS	species richness	vegetative cover (%)	0	85	--	--	0.3063	0.9947

APPENDIX A: LIST OF CIVIL REIMBURSABLE PROJECTS ASSOCIATED WITH HABITAT MODEL DEVELOPMENT

Hoover, J. J., and K.J. Killgore. 1995. Fish Habitat Benefits of a Weir at Lake Whittington, MS-AR, U.S. Army Engineer District, Vicksburg.

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