Spotted Bass Habitat Evaluation Using an Unweighted Geometric Mean to Determine HSI Values

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Suitability Index (SI) curves developed by the U.S. Fish and Wildlife Service were used to evaluate habitat of adult spotted bass *(Micropterus punctulatus)* in riverine enviroments in northern Oklahoma. Reliability of suitability indices for individual variables appeared high. However, when the individual indices were aggregated into an overall habitat suitability index (HSI) by use of an unweighted geometric mean, correlations were low between HSI and species biomass. Accurate prediction of standing crop by aggregating individual suitability indices by an unweighted geometric mean appears to be unlikely. Rationale to explain failure of the geometric mean aggregation model is presented and an alternative procedure for predicting impacts is suggested.

INTRODUCTION

In the past, project impact assessment has often relied on a variety of methodologies, many of which lacked field verification. These procedures, having varing degrees of reliability, resulted in variable, sometimes conflicting, mitigation recommendations (1). Methodological diversity and lack of unanimity of approach resulted in low credibility (2). In recent years, the Congress has mandated standardized methods and charged the United States Fish and Wildlife Service (USFWS) to develop procedures to quantitatively predict the impact of development efforts. The USFWS, in response to these legislative mandates, developed Habitat Suitability Index (HSI) models to quantify habitat suitability for individual species of fish and wildlife. These models are currently being used with the Habitat Evaluation Procedures (HEP) to predict project impacts on fish and wildlife resources (3). These models have been extensively reviewed by fish and wildlife experts but most have not been adequately field tested. Use of untested models could result in further loss of credibility should the approach be proven unreliable (4,5,6,7).

The objective of this study was to apply one method of validating an HSI model: to test whether standing crops of spotted bass (*Micropterus punctulatus*) were correlated with HSI at given locations. The assumption that such a correlation exists is suggested in HEP, and field testing of HSI models prior to their use with HEP has been recommended (8).

MATERIALS AND METHODS

Eleven stream sites containing spotted bass were sampled in north-central and northeastern Oklahoma during summer 1981 (Table 1). Population estimates at each site were made by the depletion method (9) and the maximum likelihood estimator (10). Procedures were followed to meet the assumptions of this sampling technique as outlined by Raleigh and Short (11). A 30-m section of stream was blocked upstream and downstream with nets of 64-mm mesh. To ensure blockage, we drove metal fence posts through loops in the lead line in soft substrate and placed large rocks on the lead line in rocky substrate. We collected adult fishes from each site, using a boat-mounted DC electrofishing unit (cathode embedded in the boat's

TABLE 1. Locations, dates, and names of stream sites sampled in Oklahoma.

Site	Location	Date sampled 1981	Stream name[a]
1	SE¼,S29,T23N,R9E	6 Aug.	Hominy Creek
2	SE¼,S29,T23N,R9E	6 Aug.	Hominy Creek
3	NE¼,S4,T23N,R12E	4 Aug.	Candy Creek
4	NW¼,S5,T23N,R6E	7 July	Gray Horse Creek
5	SW¼,S19,T23N,R7E	14 July	Salt Creek
6	SE¼,S24,T28N,R6E	9 July	Elm Creek
7	NW¼,S2,T26N,R6E	13 July	Salt Creek
8	SW¼,S13,T26N,R5E	18 Aug.	Salt Creek
9	SW¼,S35,T24N,R20E	12 Aug.	Big Cabin Creek
10	NE¼,S35,T24N,R20E	12 Aug.	Big Cabin Creek
11	SE¼,S12,T23N,R11E	′4 Aug.	Bird Creek

[a]Big Cabin is in Craig County; all others listed are in Osage County.

keel) composed of a generator, variable-voltage pulsator (Coffelt Model VVP-2C), and two hand-held remote anodes. One complete pass (upstream and downstream) through the site constituted a single sampling effort. Passes continued for at least three efforts or until depletions were obtained. Fish collected were not returned to the stream until all sampling runs were completed.

Weights (± 2 g) were recorded for each fish collected. The number of spotted bass estimated to be in the sample area was multiplied by the average weight of those collected, to obtain an estimated biomass of fish. This estimated biomass was reported as kilograms per hectare.

Physical measurements for use in the test of the model were also made. Stream width measurements were made near each end of each site and midway between the block nets. Depth (cm) was measured with a metric wading rod at 1-m intervals along each of the three transects. The average depth for each site was determined by finding the mean of depth measurements along all three transects.

Current velocity (cm/s) was measured with a Pygmy current meter at 1-m intervals at 0.6 of the depth from the water surface. A mean velocity was computed in a manner similar to that used to obtain mean depth. Depth and current velocity measurements were transformed to meters and meters per second, respectively. Substrate was classified at 1-m intervals according to a modified Wentworth scale (12). Substrate was recorded as the percent of each particle size found at the three transects. A Hach meter approved by the Enviromental Protection Agency was used to determine water temperature (°C) and dissolved oxygen (mg/L). Gradients (m/km) for each site were determined from U.S. Geological Survey topographic maps.

Variables used in the analysis were those reported to be important to riverine spotted bass populations by Maughan et al. (13). We assigned habitat suitability index values, ranging from zero to one, to each variable used at each site, using suitability curves provided by Maughan et al. (13). An overall habitat suitability index (HSI) for spotted bass at each site was computed by the geometric mean formula recommended for displaying compensatory relationships between individual suitability indices (8):

$$(I_1 \times I_2 \times I_3 \times I_4 \times I_5)^{1/n} = \text{HSI} \quad (1)$$

In our formula I_1 = suitability index (SI) for dissolved oxygen; I_2 = SI for gradient; I_3 = SI for substrate; I_4 = SI for water temperature; and I_5 = SI for velocity. Exponent values of 1 were used for all variables. The value of *n* equaled five. Spearman's rho, a nonparametric statistic (14), was used to evaluate the correlation between site rankings produced by habitat suitability indices and standing crops of spotted bass.

RESULTS

Total numbers of spotted bass collected at each site ranged from 1 to 11. Close agreement between depletion estimates and numbers caught indicated a high probability of capture of all spotted bass within an area. Usually most spotted bass collected were taken in the first pass through the sampling area (Table 2). Physical factors were variable (Tables 3-5). Dissolved oxygen ranged from 4.7 to 9.6 mg/L; gradients from 0.4972 to 9.6 m/km; water temperatures at locations yielding spotted bass from 25 to 35.5 ˚C; and average current velocities from 0 to 25 cm/s. There was no correlation (r_s 2 = -0.18; P > 0.10) between overall calculated site HSI values and standing crop (Table 6).

TABLE 2. Depletion of numbers of adult spotted bass collected per pass through each sample site.

Sample site	Run 1	Run 2	Run 3	Run 4[a]	Total
1	6	0	0	--	6
2	4	2	1	--	7
3	4	1	0	--	5
4	1	1	0	--	2
5	5	0	0	--	5
6	2	1	0	--	3
7	5	1	0	0	6
8	6	1	0	--	7
9	1	0	0	--	1
10	2	1	0	--	3
11	8	2	1	0	11

[a]A dash indicates that a 4th sampling effort was not made.

TABLE 3. Variable measurements and resulting suitability index (SI) values for stream sample sites. Index values from curves by Maughan et al. (13).

Stream	Oxygen V_1 (mg/L)	Gradient V_2 (m/km)	Temperature V_4 (°C)	Current speed V_5 (m/s)
1 (43)	7.6 (0.98)	0.5682 (1.0)	32.0 (0.67)	0.0 (1.0)
2 (42)	6.6 (0.94)	9.9681 (0.0)	28.0 (0.88)	0.0 (1.0)
3 (39	5.7 (0.85)	0.9040 (0.95)	27.5 (0.90)	0.06 (1.0)
4 (29)	5.0 (0.78)	1.4208 (0.85)	28.0 (0.88)	0.0 (1.0)
5 (26)	5.0 (0.78)	0.3857 (1.0)	27.2 (0.94)	0.04 (1.0)
6 (24)	9.0 (1.0)	1.9894 (0.75)	33.5 (0.42)	0.0 (1.0)
7 (25)	9.6 (1.0)	1.7140 (0.78)	30.0 (0.77)	0.0 (1.0)
8 (50)	7.1 (0.96)	1.2125 (0.89)	25.0 (1.0)	0.0 (1.0)
9 (48)	4.7 (0.75)	0.4972 (1.0)	25.0 (1.0)	0.25 (0.01)
10 (47)	5.2 (0.81)	0.4972 (1.0)	26.5 (1.0)	0.03 (1.0)
11 (40)	8.2 (1.0)	0.9040 (0.95)	33.5 (0.42)	0.14 (0.15)

TABLE 4. Substrate types (%) and suitability index values (SI) for substrate (V_3) at sample sites. Index values from curves developed by Maughan et al. (13).

	Substrate type[a]								
Site No.[b]	1	2	3	4	5	6	7	8	V_3
1 (43)		1	12					87	0.20
2 (42)			23	2	2	16	18	39	0.28
3 (39)			3	10	39	48			0.45
4 (29)	3	18	34		13	24	5	3	0.85
5 (26)					90	10			0.45
6 (24)			16		42	19	23		0.45
7 (25)	3	4	6		9	72	6		0.29
8 (50)			3			11	16	70	0.20
9 (48)					76	21	3		0.45
10 (47)					26	59	10	3	0.45
11 (40)		2	2		2	38	16	40	0.29

[a]Substrate type: 1 = detritus; 2 = mud; 3 = silt; 4 = sand; 5 = gravel; 6 = rubble; 7 = boulder; 8 = bedrock.
[b]Numbers in parentheses refer to sample site code given by Layher (15).

TABLE 5. Width and Depth of Stream at Sites Sampled.

Site	Mean width,	Depth, m	
No.	m	Mean	Maximum
1	26.83	0.58	1.02
2	14.77	0.35	0.74
3	10.67	0.55	0.98
4	13.17	0.56	1.05
5	7.42	0.33	0.54
6	11.33	0.47	1.00
7	19.75	0.50	0.95
8	22.77	0.71	0.97
9	13.50	0.20	0.36
10	30.33	0.52	1.04
11	16.17	0.17	0.36

TABLE 6. Calculated habitat suitability index (HSI) values and spotted bass standing crops (kg/ha) for stream sites sampled.

Sample site[a]	HSI [from Eq. 1; see text]	Rank	Crop, kg/ha	Rank
1 (43)	0.666	4	8.2868	6
2 (42)	0	1	10.7483	8
3 (39)	0.800	9	31.2714	11
4 (29)	0.869	11	2.6829	2
5 (26)	0.801	10	8.6253	7
6 (24)	0.677	5	4.5000	4
7 (25)	0.705	7	5.2827	5
8 (50)	0.702	6	22.6171	9
9 (48)	0.320	2	3.4074	3
10 (47)	0.748	8	2.5816	1
11 (40)	0.445	3	25.4245	10

[a]Numbers in parentheses refer to sample site codes given by Layher (1983).

DISCUSSION

Only a few studies have been designed to allow field testing of the HSI models based on individual suitability index curves. The studies have generally supported the validity of the individual curves. For example, Layher and Maughan (6) concluded that suitability curves presented in USFWS models were generally valid and required little adjustment for use in Oklahoma and Kansas streams.

No previous attempts to correlate overall HSI's, based on aggregated suitability indices, with standing crops have been published and our failure to obtain significant relations would indicate that these types of HSI models need further study and evaluation. There are three possible explanations of our failure to obtain a significant correlation between HSI and standing crops. The first possibility is that there is no correlation between physical factors in the environment and standing crop. However, Layher (15) and Orth and Maughan (7) presented data showing high correlations between fish standing crops and individual physical factors in the environment. It is clear from these lines of evidence that individual physical or biological factors can and do limit populations, and therefore we are forced to conclude that some correlation between standing crops and environmental factors does exist.

The second possibility is that the models did not include the factors that limited populations, or incorrectly weighted the importance of each factor. Streams in the Great Plains are highly variable physically and some data indicate that factors associated with low flow may limit populations in some streams (7). Many of the factors used in the models are related to flow, and it seems likely that limiting factors are included in the models. However, some data indicate high correlations between standing crops and variables that are not included in the models tested. For example Layher (15) obtained an R^2 value of 0.84 between standing crop of spotted bass and turbidity, mean depth, mean width, and pH suitability indices. None of these variables were included on the HSI model for spotted bass that we tested. Stream factors correlated with biomass production or standing crops of fishes were not always identical, even for the same species from site to site, and the problem increased in complexity across large geographic areas (16). Therefore, selection of variables for inclusion in the models is a critical issue and rationale for selection needs further study. Models restricted to a few stream characteristics have the inherent disadvantage that severe limiting factors may be omitted in habitat evaluations. Other life stage requirements at sample sites may also have limited the production of biomass of adults. However, if a fish community is somewhat sedentary, modeling of the adult life stage may represent a summation of their critical life stage requisites.

The final possible explanation of our data is that the numerous variables limiting a population act instantaneously and the chances of finding correlations of biomass and individual physical factors at any one time are low. This interpretation is strengthened by the fact that variables which were correlated with spotted bass biomass were different between Kansas and Oklahoma streams (6, 17, 16). Further support for this explanation was given by Orth and Maughan (7), who found populations at carrying capacity (as measured by available habitat) only during periods of severe flow reduction, and Wien's hypothesis (18) on populations reaching carrying capacity only during periods of ecological bottlenecks. If this interpretation is correct, large long-term data sets would be useful to evaluate the hypothesis that HSI as used in HEP is an index of carrying capacity.

The problem of correctly weighting each factor in the HSI formula is perhaps the most difficult one to address since weighting assumes *a priori* knowledge of the importance of limiting factors. In our study we assumed equal weighting of each factor. However, such an approach does not generally reflect reality. Trial *et al.* (19) proposed a methodology for unequal weighting, but further evaluation of how to weight factors and combine SI values is needed.

Much of the existing information strongly supports the reliability of most of the process of the current suitability index curve and model development process. Layher (15) found that habitat suitability curves developed from Kansas field data and based on measurements of spotted bass standing stocks produced a multiple regression model that explained most of the variation (R^2 = 0.84) in Oklahoma spotted bass standing stocks and was highly significant ($P > F = 0.0001$). It appears from these data that habitat suitability curves developed from field data correctly define population response along a unidimensional axis. In addition, Layher et al. (16, 17) reported that curves based on fish population data and macrohabitat measurements closely approximated those based on information collected for other purposes. However, there is a problem in integrating individual suitability index curve data to obtain an overall prediction model.

An alternative approach for weighting suitability index curve information where pre- and post-project physical habitat predictions are available might better be used. Variables that will be changed by project are scaled for pre- and post-project conditions based on suitability curves. From these variables the biologist then selects those that seem most likely to be limiting, based on the nature of the impending project, and predicts the impact on a target species based on this information. For example, if the pre-project water temperature habitat suitability index for a river stretch, for a species of importance, has a value of 0.4 and value of 0.8 post-project, the model would predict that the post-project habitat could support twice the population of the pre-project habitat. Of course, such an interpretation disregards synergistic effects of habitat variables and assumes correct identification of the limiting factors. However, such an approach should predict direction of change in a fishery resource being impacted.

The identification of probable limiting factors seems a reasonable prerequisite to predicting project impacts. Layher (15) emphasized that almost all habitat variables have the potential to be limiting at individual sites. Therefore models that are specific to sites or project areas would seem to have a better chance for sucess than those which are not specific.

Suitability index curves used in this way may prove to be a tremendous aid in developing project impact analyses on fish habitats. The variables selected for use in a model are determined by site conditions and are specifically those that will change with the project.

Suitability index curves for individual variables have widespread applicability, and are usually valid (6). In fact, most aspects of suitability index curve development are soundly supported by data or based on accepted ecological theory. However, the use of an HSI defined as an unweighted geometric mean of a standard set of habitat variables to predict standing stocks for all species at all locations has given poor results in our analysis.

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