Relations Between Two Darter Species and Their Respective Abiotic Environments

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Standing crops (kg/hectare) of slenderhead darters (*Percina phoxocephala*) and orangethroat darters (*Etheostoma spectabile*) were graphed separately against 23 abiotic variables measured for Kansas streams. The resulting habitat suitability curve for each variable allowed fish biomass to be normalized to index values (range, 0.0-1.0) that could be regressed linearly against abiotic variables. Stepwise multiple-regression techniques isolated variables that accounted for a large proportion of the variability in darter biomasses. Regression models failed to accurately predict darter biomass in Oklahoma streams, but assigning habitat suitability curves developed from Kansas data allowed different models to be constructed for Oklahoma streams that explained nearly all of the variation in biomass of each darter species. Regression models appear to provide little predictive power across geographic regions; however, habitat suitability curves do appear regionally consistent and variation in darter biomass can be explained largely in abiotic terms.

INTRODUCTION

Resource managers and biologists are often forced to evaluate projects impacting select species habitats with little quantitative information available on which to base project modification decisions. Much of the available literature describes fish habitats in general terms, and often these terms are of only local relevance.

In an effort to relate quality of habitat with fishery value, Layher and Maughan (1) evaluated channel catfish (*Ictalurus punctatus*) habitats by comparing standing stocks of the fish in streams with quantitative measures of physical and chemical stream descriptors. Achieving some degree of success with that species led to the evaluation of habitats of other fish species using identical approaches and methods.

The objectives of this paper are: (a) to determine whether orangethroat darter (*Etheostoma spectabile*) populations and slenderhead darter (*Percina phoxocephala*) populations are related to individual physical and chemical variables measured in streams; (b) to develop multivariate regression models explaining standing stocks of species evaluated based on habitat suitability; and (c) to determine the widespread applicability of both individual variable relations to habitat quality and multivariate models predictive applications.

STUDY AREA

One data set used in this study was collected throughout the sixteen major river basins in Kansas by the Kansas Fish and Game Commission during the summers of 1974 through 1978. Physical and chemical characteristics of streams and fish biomass were measured at each site.

A second data set was collected from 50 stream segments in Oklahoma during the summer of 1981. The sample sites in Oklahoma were limited to the northern part of the state. This data set has been previously described (1-4).

MATERIALS AND METHODS

The Kansas data set was used to develop habitat suitability curves separately for orangethroat darters and slenderhead darters by using a number of abiotic variables. Such curves have been recommended to evaluate fishery potentials in relation to project design parameters (4). The procedure used to develop these curves was identical to that used by Layher and

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Maughan (1) for channel catfish and was first proposed by Layher et al. (5).

Development of Habitat Suitability Curves and Biomass Models

Habitat suitability curves were developed in the following manner. We determined whether a relationship existed between biomass and variation in each physical or chemical variable by dividing the range of each variable into increments and calculating mean standing crop values within each increment. Curves were generally drawn to pass through these means. However, if an observation yielded a high estimate of biomass at a point where the major portion of the biomass data showed low values, and the biomass value was based on only a few samples, the curve was drawn according to the median value of the data.

To scale suitability to biomass, we generally assigned a suitability value of one to the highest mean standing crop value. Proportional habitat suitability values were then assigned to the data in each increment. The effect of this procedure was to linearize the relation between standing crop and the individual physical or chemical variables (1).

Curves showing the relation between individual variables and standing crop were developed for 23 variables for both darter species from the Kansas data. Each observation in the data set was then assigned suitability values ranging from 0 to 1 on the basis of habitat suitability curves for each variable. Stepwise multiple regression runs were then used (SAS PROC STEPWISE) to identify variables that explained the variation in standing crop values (6).

From these procedures, we developed models to estimate standing crop at a given location on the basis of physical habitat measurements. However, we emphasize that (a) the regressions were performed on suitability index values and not on empirical data; (b) coefficients from resulting equations cannot be used to evaluate importance or relations between variables because different measurement scales were used for each variable; and (c) because the model is a combined estimator of standing crop, the entire model must be used.

Testing the Models

Field Sampling

To test the validity of these models and to evaluate the relationship between abiotic factors and standing crops of the two darter species, we collected data at 50 stream sites in Oklahoma. Depletion techniques (7) and the maximum likelihood estimator (8) were used to make population estimates at each site. The procedures outlined by Raleigh and Short (9) were followed to meet the assumptions of this sampling technique.

At each site a 30-m section of stream was blocked upstream and downstream with 0.25-inch mesh net. In soft substrates, metal fence posts were driven through loops in the lead line to ensure blockage. Large rocks were placed on the lead line at sites with hard substrates. At each site, fish were collected with a boat-mounted DC electrofishing unit composed of a generator, variable voltage pulsator (Coffelt Model VVP-2C), and two hand-held, remote electrodes. The cathode was embedded in the boat bottom. One complete pass through the site constituted a unit of sampling effort. The procedure was repeated until the species was depleted. The number of passes made through a site varied from three to seven. Total weight of each of the darter species, plus average weights of each individual collected, were then determined. Total biomass (B) (kg) at a site was estimated by the formula $B = W + I\,(E\text{-}N)$, where W is the weight of the fish captured, I is the average weight of the fish captured, N is the number of fish collected, and E is the number of fish estimated to be in the sample area. Biomass was expressed as kg/ha.

Chemical and physical factors were measured at each site. Depth (m) was measured with a metric wading rod, current velocity (m^3/s) was measured with a pygmy current meter at 0.6 of the depth from the water surface, and substrate was classified according to a modified Wentworth scale (10). These measurements were taken at 1-m intervals along each transect; at each end of the site and midway between the block nets. Average depth and velocity were reported as the mean of all transect measurements. Each substrate category was recorded as percent of total observations. The percent of the sample site composed of pool, riffle, and run habitats were estimated as follows: pool, percent of current readings at 0 cm/s; riffle, percent of the site with current readings greater than 0 cm/s and with projecting substrate above the water surface or with turbulent flow; and run, percent of the site with current readings greater than 0 cm/s but with no apparent turbulence. Maximum and minimum stream widths (m) within the sampling area were also measured.

Hach meters, approved by the Environmental Protection Agency (EPA), were used to measure water temperature (°C), conductivity (mS), total dissolved solids (mg/L), dissolved oxygen (mg/L), and pH. Additional water samples for laboratory analysis were taken in acid-washed polypropylene bottles, acidified to pH 2, and transported on ice. After raising the pH to about 7, we measured soluble reactive phosphorus (SRP) and nitrate (NO_3-N) as described by Strickland and Parsons (11). The EPA standard reference solutions were used to validate the methods each time samples were processed. Chlorides, sulfates, total hardness, calcium hardness, magnesium hardness, total alkalinity, and turbidity were determined with a Hach DR-EL/2 Direct Reading Engineers Laboratory Kit (12, 13, 14).

Gradients (m/km) for each site were determined for U.S. Geological Survey (15) topographic maps. Growing season (frost-free period in days) was determined from maps published by Hambridge and Drown (16). Runoff values (inches per year) were obtained from climatological maps (17).

Species Biomass Predictions

To determine whether the same variables werre correlated with slenderhead and orangethroat darter biomass within Oklahoma and Kansas streams, we used equations based on Kansas data to predict biomass at the Oklahoma sample sites and calculated Pearson and Spearman correlation coefficients between the observed and predicted values.

The habitat suitability curves developed from the Kansas stream survey data were used to assign index values for each variable measured at sites sampled in Oklahoma. Predictive equations were then developed for the Oklahoma data to determine whether the curves developed from the Kansas data would explain variation in standing crops of the two darters in Oklahoma streams.

RESULTS - SLENDERHEAD DARTER

Suitability Curves

Suitability curves for slenderhead darters were developed for the following variables: calcium hardness, chlorides, conductivity, dissolved oxygen, gradient, growing season, maximum width, mean depth, mean width, minimum width, nitrates, percent pool, percent riffle, pH, phosphates, percent run, runoff, sulfates, total alkalinity, total dissolved solids, turbidity, volume of flow, and water temperature (Table 1)‡.

Biomass Models

Although Layher (3) found that the sampling technique used biased population estimates for spotted bass (*Micropterus punctulatus*), Layher and Maughan (18) found no significant relation between average standing crops of slenderhead darters and sampling technique. However, most of the 13 sites where slenderhead darters occurred in Kansas were sampled by mark and recapture in which rotenone was used for recapture. Occurrence information obtained by other sampling techniques always involved five or fewer sites; therefore, only data from sites at which rotenone was used for recapture were used in development of that model. One variable, calcium hardness, explained 87.9% of the variation in standing crop. The model was significant at the 0.0001 level. Addition of another variable, percent riffle, increased the r^2 value to 0.915. The significance of the entire model remained the same. When the variable of maximum stream width was added, the r^2 increased to 0.943, but again significance of the model remained at 0.0001. Equations for the one-, two-, and three-variable models are given below:

(A) -0.65 + 8.19 (calcium hardness SI) = slenderhead darter standing crop
$r^2 = 0.879$ PROB F = 0.0001

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‡Graphs of suitability curves are available from the senior author.

(B) - 1.07 + 7.40 (calcium hardness SI) + 1.24 (% riffle SI) = slenderhead darter standing crop
r^2 = 0.915 PROB F = 0.0001
Calcium hardness PROB F = 0.0001
% Riffle PROB F = 0.0519

(C) - 1.44 + 6.88 (calcium hardness SI) + 0.83 (maximum width SI) + 1.34 (% riffle SI) = slenderhead darter standing crop
r^2 = 0.943 PROB F = 0.0001
Calcium hardness PROB F = 0.0001
Maximum width PROB F = 0.0519
% Riffle PROB F = 0.215

Addition of other variables increased the r^2 of the model but also resulted in minor decreases in significance. However, additional individual variables did not themselves meet the 0.05 level of significance arbitrarily set for model inclusion.

Testing the Models

We found no significant correlation between predicted standing crops based on Kansas data and observed standing crops at the 11 sites where slenderhead darters occurred in Oklahoma. However, when we assigned suitability index values for each variable for which curves had been drawn and conducted a stepwise regression analysis, we derived a significant explanation of Oklahoma standing crops for this species. Three variables, maximum width, mean depth, and phosphates, produced an r^2 of 0.79 with a significance level of 0.0197. The addition of total alkalinity increased the r^2 to 0.86 but the significance of the model changed to 0.0249. The addition of water temperature to the model increased the r^2 to 0.996 with a significance level of 0.0001.

The five-variable model explaining variation in slenderhead darter standing crops in Oklahoma streams follows: -1.12 + (2.25 × maximum width SI) + (1.67 × mean depth SI) + (-50.84 × phosphate SI) + (0.84 × total alkalinity SI) + (-5.42 × water temperature SI), where SI equals suitability index.

RESULTS - ORANGETHROAT DARTER

Suitability Curves

Suitability curves were developed for the orangethroat darter for the following variables: calcium hardness, conductivity, dissolved oxygen, gradient, growing season, magnesium hardness, maximum width, mean depth, mean width, minimum width, nitrates, percent pool, percent riffle, percent run, pH, phosphates, runoff, sulfates, total alkalinity, turbidity, velocity, volume of flow, and water temperature (Table 2)‡.

Biomass Models

Different models were developed for data collected by each capture technique. We used 16 sets of data collected by one sampling method (mark and recapture by seining and shocking) to develop the model. We obtained an r^2 of 0.64 when we used data from five independent variables (mean width, minimum width, percent pool, percent run, and total alkalinity). All variables were significant below the 0.0095 level. The entire model was significant at the 0.0269 level ($F = 3.95$). The addition of four variables, conductivity, magnesium hardness, riffle, and sulfates, to the model increased the r^2 value to 0.9490 ($F = 14.49$; $p > F = 0.001$). All nine variables were significantly correlated with biomass ($p < 0.008$). Values of F for individual variables ranged from 13.57 for total alkalinity (the lowest F value) to 73.32 (the highest) for percent run. Addition of two variables, dissolved oxygen and turbidity, to the model increased the r^2 to 0.98 ($F = 36.53$; $p > F = 0.0005$). Both variables were significant below the 0.05 level.

We used data from 63 stream sites sampled by marking followed by recapture with rotenone. A model based on five independent variables (magnesium hardness, nitrate, phosphates, dissolved oxygen, and maximum stream width) produced an r^2 of 0.3906 ($F = 7.44$; $p > F = 0.0001$) but only three of these variables (magnesium hardness, nitrates and phosphates) were significant at the 0.05 level. The addition of other variables resulted in an r^2 of 0.4993 ($F = 2.00$; $p > F = 0.0282$). However, only phosphates and magnesium hardness were significant at the 0.05 level.

Complete data for 23 sites sampled by the application of rotenone were available for model development. Four variables (conductivity, growing season, nitrates, and turbidity) produced an r^2 of 0.6259 ($F = 7.95$; $p > F = 0.0006$). The variables were all significant at the 0.05 level. The F

values for individual variables in the model ranged from 3.52 for turbidity to 28.40 for nitrates. Addition of three variables (mean depth, mean width, and total alkalinity) increased the r^2 of the model to 0.7230 ($F = 5.97$; $p > F = 0.0015$). Significance levels for the last three variables were 0.0736, 0.981, and 0.1025, respectively. The significance level of the four original variables was below 0.0303 in this model. An r^2 of 0.8830 was obtained by adding data on additional variables; however, the model was no longer significant at the 0.05 level. A model based on 15 variables did become significant at the 0.0356 level with an F of 3.63 and an r^2 of 0.8719.

Data from 11 sites sampled by seining and shocking were used to develop a standing crop model. Mean depth was the only variable that was significant to the 0.05 level ($F = 4.78$; $r^2 = 0.3236$).

Twenty sites were sampled by mark and recapture by seining. Nine variables, all significant at the 0.0019 level, produced an r^2 of 0.9254 ($F = 18.63$; $p > F = 0.0001$). Stepwise addition of these variables to the model produced the following results (r^2 for the entire model given in parentheses): phosphates (0.3065), percent pool (0.5381), minimum width (0.6394), conductivity (0.7202), growing season (0.7699), nitrates removed and replaced by turbidity (0.9158), and minimum width removed and replaced by mean width (0.9254).

Ten sites were sampled by seining alone. Five variables produced a model explaining standing crop with an r^2 of 0.9721 ($p > F = 0.0007$). All variables were significant below the 0.04 level. Stepwise addition of the variables produced the following model (r^2 for the entire model given in parentheses): water temperature (0.2234), sulfates (0.5941), percent pool (0.8790), total alkalinity (0.9323), and calcium hardness (0.9721).

Regression models are summarized in Table 3, and the equations are shown in Table 4.

Testing the Models

No significant correlations were found between predicted standing crops based on equations developed from Kansas data and observed standing crops in Oklahoma streams. However, when we assigned suitability index values to each Oklahoma site, we obtained significant regression models. In this analysis, three variables (percent run, gradient, and runoff) explained 75% of the variation in standing crop at 12 sample sites. The significance level for the regression model (Table 3) was 0.0090. The addition of mean depth increased the r^2 to 0.84 and the addition of conductivity increased the r^2 to 0.88. In both cases, the significance level was less than 0.01. Additional variables increased the r^2 value without reducing model significance.

DISCUSSION

Suitability Curves

Because curves have not previously been developed for either the slenderhead darter or the orangethroat darter, it is impossible to evaluate the reliability of the curves. However, curves developed with the same methods as those used in this study were in close agreement with curves reported for spotted bass (water temperature); green sunfish, *Lepomis cyanellus* (water temperature); largemouth bass, *Micropterus salmoides* (dissolved oxygen, water temperature, turbidity, velocity); white crappie, *Poxomis annularis* (water temperature) (19); and for channel catfish, *Ictalurus punctatus* (20).

Theoretically, if these curves are reliable and if the single habitat dimension modified was limiting, the effect on the fish population could be predicted from the suitability curve. This simple relation seldom occurs because of synergism between variables (21).

Biomass Models

Biomass equations developed from Kansas data had low predictive value at Oklahoma sites. However, when suitability index values based on Kansas data were assigned to Oklahoma stream variables at each site, highly significant multiple regressions of standing crop on habitat variables were obtained ($r^2 = 0.996$, slenderhead darters; and $r^2 = 0.88$, orangethroat darters). However, the variables that produced significant models differed between Kansas and Oklahoma data. These differences suggest that limiting factors may vary from one region to another and even possibly from one stream site to another within the same stream. However, the statistical analysis suggests that the factors controlling biomass in streams in both areas are abiotic, as suggested by USFWS (5, 22). In such areas, application of the curves to predict effects of physical habitat changes on fish may provide a useful tool for aquatic resource managers.

Probably some variables correlated with standing crop were not actually limiting, but were correlated with actual limiting factors. For example, calcium hardness, which seemed to explain much variation in standing crops of slenderhead darters in Kansas streams, was probably related to extent of groundwater recharge of streams, which is in turn related to permanence, of flow.

Use of the Models in Management

These data show a new approach to developing suitability curves but do not provide a general method for developing predictive models. Even without predictive models, quantitative suitability curves may be useful in predicting the effects of habitat changes for species that are limited by abiotic factors. However, since limiting factors vary from one location to another, some care must be taken in application. One approach would be to use previously developed suitability curves for as many variables as possible and subjectively predict the effects of changes. This approach may give more repeateable results than other subjective methods because of the existence of a common quantitative basis.

Another perhaps more satisfying approach would be to do as we have done and collect stream data and fish population data at a number of sites within the area of change. The higher the level of abiotic homogeneity, the fewer the limiting factors that would potentially affect the population. In these situations, identification of limiting factors or at least factors closely associated with those that are limiting factors would be enhanced. By using projected post-effect values, changes in fish populations could be predicted (i.e., 23). This approach would require intensive data collection for each project; however, the use of previously developed suitability curves to assign index values as we did would greatly reduce the number of sample sites needed to develop predictive models based on empirical data.

The identification of limiting factors or those correlated with limiting factors has long been intuitively practiced by fishery biologists. Emphasis on the quantitative relation between habitat and standing crop would give us better predictive abilities in references to changes in species management, habitat enhancement, and effects of development projects. The data reported here seem to indicate that the probability of developing information about such relations would be easier for species with restrictive habitat requirements.

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TABLE 1. Mean slenderhead darter standing stocks in Kansas streams related to increments of physical and chemical variables for which habitat suitability curves were drawn. The habitat suitability index value (HSI) is the mean height of the respective suitability curve within each interval, expessed as a proportion of the maximum curve height (1.0); the maximum curve height usually is associated with the greatest standing stock.

Range (a – b) of Variable X ($a \leq X < b$)	N	Mean standing stock (kg/hectare)	HSI
X = Calcium Hardness (mg/L)			
0- 100	2	0.50	.17
100- 200	7	0.25	.09
200- 300	3	2.65	1.00
300- 400	3	0.70	.26
400- 500	2	0.56	.18
500- 600	1	0.11	.12
600- 700	2	0.22	.07
1300-1400	1	0.11	.04
X = Chlorides (mg/L)			
0- 50	15	0.87	1.00
50- 100	6	0.33	.41
100- 150	1	0.33	.29
150- 200	2	0.16	.23
200- 250	1	0.78	.19
X = Conductivity (mS)			
0- 300	1	0.11	.12
300- 600	8	0.36	.42
600- 900	8	0.61	.73
900-1200	2	0.11	.86
1200-1500	1	0.11	.96
1500-1800	2	0.84	1.00
1800-2100	1	0.78	.91
2700-3000	1	0.33	.71
3900-4200	1	0.22	.25
X = Dissolved Oxygen (mg/L)			
4- 6	2	0.11	.13
6- 8	6	1.68	1.00
8- 10	12	0.55	1.00
10- 12	3	0.44	1.0
12- 14	3	0.37	1.0
16- 18	1	0.67	1.0
18- 20	2	0.72	1.0
X = Gradient (m/km)			
0.0- 0.5	10	0.51	.24
0.5- 1.0	11	0.58	.29
1.0- 1.5	5	2.15	1.0
1.5- 2.0	2	0.33	.16
3.0- 3.5	1	0.11	.05
X = Growing Season (frost-free days)			
175- 180	10	0.42	.32
185- 190	7	1.32	1.00
190- 200	15	0.66	.48
X = Maximum Stream Width (m)			
5- 10	4	0.50	.32
10- 15	9	1.59	1.00
15- 20	5	0.31	.71
20- 25	3	0.78	.48
25- 30	4	0.11	.19
30- 35	1	0.11	.08
35- 40	1	0.11	.05
45- 50	1	0.22	.02
X = Mean Depth (m)			
0.00- 0.25	2	0.44	.32
0.25- 0.50	16	0.74	.50
0.50- 0.75	6	1.49	1.00
0.75- 1.00	4	0.28	.19
1.00- 1.25	3	0.14	.11
1.25- 1.50	1	0.22	.06
X = Mean Width (m)			
0- 5	1	0.22	.14
5- 10	6	1.75	1.00
10- 15	11	0.70	.39
15- 20	8	0.42	.24
20- 25	3	0.22	.14
25- 30	1	0.22	.08
30- 35	2	0.39	.04
X = Minimum Stream Width (m)			
0- 5	5	2.08	1.00
5- 10	10	0.44	.20
10- 15	9	0.63	.10
15- 20	4	0.14	.05
X = Nitrates (mg/L)			
0.0- 3.0	2	0.16	.26
3.0- 6.0	5	0.40	.49
6.0- 9.0	15	0.87	1.00
9.0- 12.0	3	0.37	.42
X = pH			
6.5- 7.0	2	0.84	.05
7.0- 7.5	2	0.16	.14
7.5- 8.0	2	0.67	.47
8.0- 8.5	12	0.26	.87
8.5- 9.0	7	1.44	1.00
X = Pool (%)			
0- 20	8	1.26	1.00
20- 40	1	0.44	.88
40- 60	4	0.75	.60
60- 80	4	0.36	.28
80- 100	9	0.23	.20
100- 100	4	0.70	.02
X = Riffle (%)			
0- 10	14	1.08	1.00
10- 20	8	0.32	.32
20- 30	2	0.33	.28

TABLE 1. Continued.

Range (a – b) of Variable *X* (a ≤ *X* < b)	*N*	Mean standing stock (kg/hectare)	HSI
X = Riffle (%)			
30- 40	5	0.35	.25
40- 50	2	1.34	.24
X = Run (%)			
0- 20	18	0.48	.11
20- 40	4	0.28	.13
60- 80	2	0.39	.16
80- 100	2	0.33	.51
100- 100	4	2.15	1.00
X = Runoff (in/yr)			
0.0- 1.5	6	0.97	.70
1.5- 3.0	9	1.38	1.00
3.0- 4.5	8	0.14	.29
6.0- 7.5	1	0.22	.13
7.5- 9.0	4	0.19	.11
9.0- 10.5	4	0.78	.10
X = Sulfates (mg/L)			
0- 200	13	0.91	1.00
200- 400	7	0.44	.50
400- 600	2	0.16	.19
800-1000	2	0.50	.07
X = Total Alkalinity (mg/L)			
50- 100	3	0.78	1.00
100- 150	3	0.33	.44
150- 200	7	0.19	.27
200- 250	8	1.24	.20
250- 300	3	0.14	.18
550- 600	1	1.45	.17
X = Total Dissolved Solids (mg/L)			
0- 200	8	0.36	.43
200- 400	8	0.61	.75
400- 600	3	0.11	.93
600- 800	3	0.82	1.00
1200-1400	1	0.33	.41
1600-1800	1	0.22	.27
X = Total Phosphates (mg/L)			
0.0- 0.3	17	0.31	.04
0.3- 0.6	7	0.35	.05
0.9- 1.2	1	7.73	1.00
1.2- 1.5	2	0.61	.09
3.3- 3.6	1	0.78	.01
X = Turbidity (Jackson turbidity units)			
0- 25	10	0.42	.79
25- 50	5	0.53	1.00
50- 75	1	0.11	.23
100- 125	1	0.11	.18
X = Volume of Flow (m^3/s)			
0.0- 0.5	14	0.86	.90
0.5- 1.0	6	1.00	1.00
1.0- 1.5	2	0.44	.39
1.5- 2.0	1	0.11	.15
2.0- 2.5	1	0.11	.10
4.0- 4.5	1	0.56	.10
6.5- 7.0	1	0.67	.10
X = Water Temperature (°C)			
12- 16	1	2.91	1.00
16- 20	3	0.63	.83
20- 24	5	1.88	.57
24- 28	20	0.38	.17
28- 32	2	0.28	.09

TABLE 2. Mean orangethroat darter standing stocks in Kansas streams related to increment of physical and chemical variables for which habitat suitability curves were drawn. The habitat suitability index value (HSI) is the mean height of the respective suitability curve within each interval, expressed as a proportion of the maximum curve height (1.0); the maximum curve height usually is associated with the greatest standing stock.

Range (a–b) of Variable X ($a \leq X < b$)	N	Mean standing stock (kg/hectare)	HSI
X = Calcium (mg/L)			
0– 100	8	0.15	.09
100– 200	48	3.18	.51
200– 300	41	1.84	.73
300– 400	16	6.33	1.00
400– 500	5	0.13	.73
500– 600	2	3.08	.41
600– 700	4	0.39	.19
700– 800	2	0.39	.09
900–1000	2	0.84	.06
1300–1400	1	0.22	.03
X = Conductivity (mS)			
– 200	2	0.22	.11
200– 400	12	1.92	.54
400– 600	26	3.45	1.00
600– 800	17	0.71	.29
800–1000	5	0.94	.22
1000–1200	5	0.53	.14
1200–1400	1	0.11	.06
1400–1600	2	0.11	.06
1600–1800	2	0.16	.06
1800–2000	1	0.11	.06
2200–2400	1	6.05	.06
2600–2800	1	0.11	.06
4000–4200	2	0.33	.06
X = Dissolved Oxygen (mg/L)			
3– 6	9	0.17	.08
6– 9	51	2.49	1.00
9– 12	41	2.02	1.00
12– 15	25	1.41	1.00
15– 18	9	5.39	1.00
18– 20	4	0.61	1.00
X = Gradient (m/km)			
0.00– 0.75	27	1.57	.36
0.75– 1.50	44	1.29	.47
1.50– 2.25	24	4.24	1.00
2.25– 3.00	15	0.62	.88
3.00– 3.75	12	1.97	.59
3.75– 4.50	8	2.28	.53
4.50– 5.23	4	8.77	.52
X = Growing Season (frost-free days)			
80– 90	1	0.67	.29
160– 170	22	2.63	.98
170– 180	36	2.70	1.00
180– 190	61	2.37	.81
190– 200	30	1.77	.65
X = Magnesium Hardness (mg/L)			
0– 50	57	3.00	.86
50– 100	33	3.52	1.00
100– 150	17	2.51	.63
200– 250	8	0.33	.09
250– 300	2	0.16	.05
350– 400	1	0.11	.05
400– 450	1	6.05	.05
450– 500	1	0.33	.05
500– 550	1	0.56	.05
X = Maximum Stream Width (m)			
0– 5	27	5.03	1.00
5– 10	44	3.32	.66
10– 15	33	0.55	.28
15– 20	22	0.78	.14
20– 25	7	4.78	.06
25– 30	5	0.12	.04
30– 35	2	0.11	.04
35– 40	2	0.11	.04
45– 50	1	0.11	.04
X = Mean Depth (m)			
0.0– 0.5	91	1.97	.28
0.5– 1.0	45	2.06	.32
1.0– 1.5	11	6.89	1.00
1.5– 2.0	3	1.86	.28
0– 5	44	4.18	1.00
5– 10	59	2.08	.48
10– 15	26	0.41	.10
15– 20	13	2.67	.05
20– 25	3	0.11	.33
25– 30	2	0.11	.33
30– 35	1	0.11	.33
X = Minimum Stream Width (m)			
0– 5	8	3.72	1.00
5– 10	43	0.68	.19
10– 15	10	0.25	.08
15– 20	4	0.11	.04
20– 25	1	0.11	.03
X = Nitrates (mg/L)			
0– 5	27	0.87	.10
5– 10	89	3.10	.28
10– 15	11	1.70	.44
15– 20	3	2.27	.66
20– 25	2	9.86	1.00
25– 30	2	2.07	.20
35– 40	2	0.11	.03

TABLE 2. Continued.

Range (a–b) of Variable X $(a \le X < b)$	N	Mean standing stock (kg/hectare)	HSI
X = Nitrates (mg/L) contd.			
65– 70	1	0.33	.03
90– --	1	0.33	.03
X = pH			
6.0– 6.5	1	6.05	.17
6.5– 7.0	4	0.16	.17
7.0– 7.5	15	1.70	.59
X = Pool (%)			
0– 15	41	1.29	.42
15– 30	8	3.08	1.00
30– 45	22	2.66	.92
45– 60	18	2.56	.81
60– 75	10	7.64	.70
75– 90	16	1.75	.64
90– 100	34	1.96	.61
X = Riffle (%)			
0– 15	99	1.91	.37
15– 30	31	4.33	.74
30– 45	11	1.00	.89
45– 60	5	1.45	.96
60– 75	2	5.43	1.00
75– 90	1	0.22	.04
X = Run (%)			
0– 15	60	3.23	.71
15– 30	10	0.49	.75
30– 45	20	1.32	.88
45– 60	12	4.52	1.00
60– 75	8	1.24	.62
75– 90	7	1.90	.42
90– 100	31	1.59	.33
X = Runoff (in/yr)			
0– 1	19	3.03	.42
1– 2	19	1.40	.47
2– 3	48	2.38	.75
5– 6	43	3.18	.17
6– 7	10	1.01	.08
8– 9	8	0.93	.03
10– 11	3	0.18	.03
X = Sulfates (mg/L)			
0– 75	82	2.82	.86
75– 150	11	2.80	1.00
150– 225	14	2.01	.71
225– 300	15	1.49	.46
300– 375	3	0.26	.18
375– 450	2	0.22	.09
450– 525	2	0.16	.07
675– 750	1	0.22	.07
825– 900	1	0.11	.07
900– 975	1	0.22	.07
X = Total Alkalinity (mg/L)			
50– 100	5	1.86	.51
100– 150	14	1.85	.58
150– 200	25	2.91	.81
200– 250	52	3.44	1.00
250– 300	37	1.14	.93
300– 350	5	2.80	.78
350– 400	3	2.24	.64
550– 600	1	0.11	.04
X = Total Phosphates (mg/L)			
0.00– 0.75	116	2.08	.12
0.75– 1.50	14	1.81	.15
1.50– 2.25	6	13.46	1.00
2.25– 3.00	1	0.11	.09
3.75– 4.50	1	0.78	.03
4.50– 5.25	1	0.11	.01
X = Turbidity (Jackson Turbidity units)			
0– 25	76	3.39	1.00
25– 50	23	2.12	.61
50– 75	8	1.35	.35
75--100	2	0.39	.13
100– 125	2	0.16	.06
275– 300	1	0.22	.06
500– 525	1	0.22	.06
X = Velocity (m/s)			
0.0– 0.5	128	2.33	.42
0.5– 1.0	3	6.12	1.00
1.0– 1.5	2	0.11	.03
5.5– 5.0	1	0.22	.03
X = Volume of Flow (m^3/s)			
0– 2	128	2.47	1.00
2– 4	2	0.11	.24
4– 6	2	0.28	.08
6– 8	1	0.11	.04
24– 26	1	0.22	.04
X = Water Temperature (°C)			
5– 10	8	1.98	.64
10– 15	15	3.30	1.00
20– 25	55	2.53	.76
25– 30	55	2.27	.62
30– 35	3	0.63	.21
35– 40	1	0.11	.06

TABLE 3. Results of stepwise multiple regressions relating orangethroat darter standing crops by collection method.

Method of collection	*N*	r^2	*F*	PROB *F*	Variables	Partial *F*	PROB *F*
Mark and recapture shocking	16	0.64	3.95	.0269	Mean Width	12.68	.0045
					Minimum Width	10.63	.0076
					Percent Pool	9.81	.0075
					Percent Run	14.61	.0028
					Total Alkalinity	1.49	.2484
Kill technique with mark and recapture	63	0.39	7.44	.0001	Magnesium Hardness	3.82	.0555
					Nitrates	6.72	.0120
					Phosphates	30.90	.0001
					Dissolved Oxygen	2.25	.1394
					Mean Width	1.68	.1996
Kill technique without mark and recapture	23	0.62	7.95	.0006	Conductivity	5.90	.0252
					Growing Season	9.02	.0073
					Nitrates	28.40	.0001
					Turbidity	3.52	.0761
Seining and shocking	11	0.32	4.78	.0536	Mean Depth		
Mark and recapture seining	20	0.92	18.63	.0001	Phosphates	62.92	.0001
					Percent Pool	71.29	.0001
					Conductivity	23.12	.0004
					Growing Season	18.19	.0011
					Percent Riffle	21.60	.0006
					Magnesium Hardness	29.92	.0001
					Turbidity	23.37	.0004
					Mean Width	15.60	.0019
Seining	10	.97	34.90	.0007	Water Temperature	138.26	.0001
					Sulfates	113.50	.0001
					Percent Pool	40.58	.0014
					Total Alkalinity	10.97	.0212
					Calcium Hardness	7.15	.0441

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TABLE 4. Regression models explaining standing crop (kg/ha) of orangethroat darters. All models were significant at the .05 level.

Sample Method	Regression equation explaining standing crop based on suitability index (SI) values
Mark and recapture using seining followed by shocking (Kansas data)	(−0.06) + (1.83 × mean width SI) + (0.86 × minimum width SI) + (3.20 × pool SI) + (3.86 × run SI) + (−0.38 × total alkalinity SI)
Mark and recapture; recapture by rotenone (Kansas data)	(−11.18) + (−6.49 × dissolved oxygen SI) + (4.46 × maximum (Kansas width SI)) + (8.22 × magnesium hardness SI) + (28.19 × nitrates SI) + (33.02 × phosphates SI)
Rotenone (Kansas data)	(−18.36) + (3.09 × conductivity SI) + (−12.45 × growing season SI) + (−2.67 × mean width SI) + (4.04 × magnesium hardness SI) + (165.31 × phosphate SI) + (11.50 × pool SI) + (−9.14 × riffle SI) + (4.66 × turbidity SI)
Seining and shocking (Kansas data)	(+ 0.08) + (0.15 × mean depth SI)
Mark and recapture using seining (Kansas data)	(−18.36) + (3.09 × conductivity SI) + (−12.45 × growing season SI) + (−2.67 × mean width SI) + (4.04 × magnesium hardness SI) + (165.31 × phosphate SI) + (11.50 × pool SI) + (−9.14 × riffle SI) + (4.66 × turbidity SI)
Seining (Kansas data)	(−13.40) + (−2.75 × calcium hardness) + (−7.04 × pool SI) + (10.37 × sulfate SI) + (−4.47 × total alkalinity SI) + (20.64 × water temperature SI)
Depletion estimates using shocking (Oklahoma data)	(−0.15) + (1.63 × run SI) + (−0.40 × gradient SI) + (−2.03 × runoff SI) + (−0.47 × mean depth SI) + (0.26 × conductivity SI)

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