Virginia Water Resources Research Center Bulletin 180

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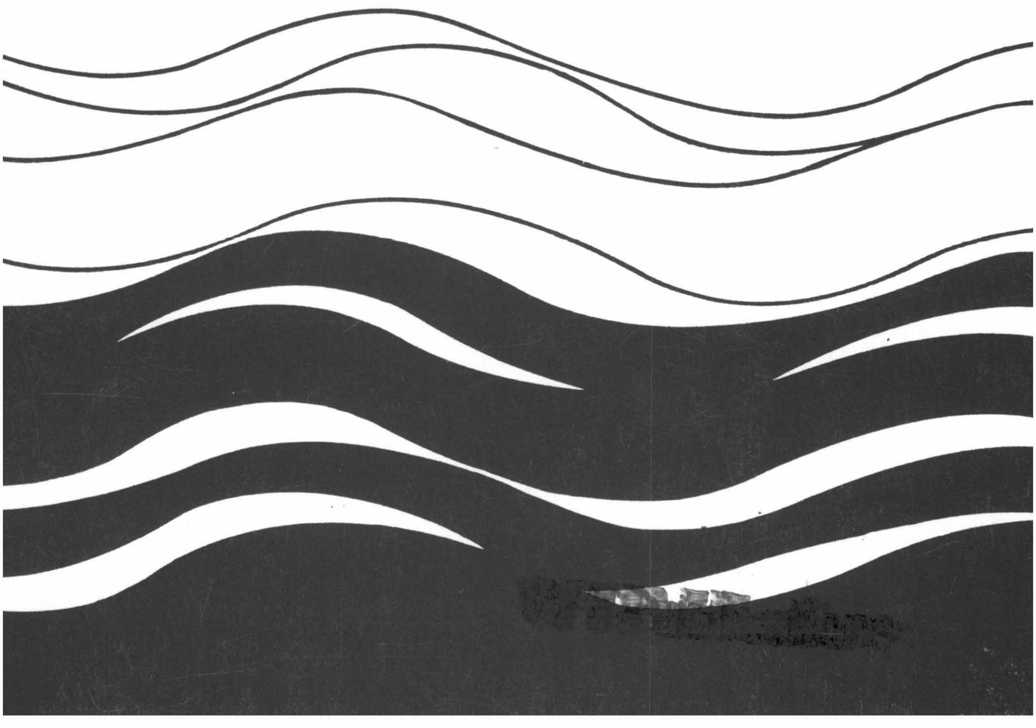

Bulletin 180
June 1993

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VPI-VWRRC-BULL 180
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Virginia Water Resources Research Center
Virginia Polytechnic Institute and State University
Blacksburg • 1993

VPI Publications

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This bulletin is published with funds provided in part by the
U.S. Geological Survey, Department of the Interior,
as authorized by Public Law 101-397

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Library of Congress Catalog Number:
93-60208

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Table of Contents

List of Tables

List of Figures

Acknowledgements

The authors would like to thank the Virginia Water Resources Research Center, U.S. Fish and Wildlife Service, Electric Power Research Institute, and Virginia Power for providing funding for this project. We also would like to thank Richard Neves and C. Andrew Dolloff for their constructive criticisms and technical advice. A special thanks goes out to Ian Jezoreck, our trusty technician, who braved tick- and leech-infested environments for the good of science. Finally, we would like to thank nine anonymous reviewers for their technical comments and our project advisory committee for advice throughout the project.

The members of the Project Advisory Committee: Tom Felvey, Jean Gregory, and Mike Shelor, Virginia Water Control Board; Tom Lee and Sarah Pugh, Virginia Department of Agriculture and Consumer Services; Judson White, Virginia Power; William Tanger, Friends of the Rivers of Virginia; John Kauffman, Department of Game and Inland Fisheries; R. Christian Jones, George Mason University; Greg Garman, Virginia Commonwealth University; Karen Mayne, Robert Kelsey, and Andy Moser, U.S. Fish and wildlife Service; and Jay Roberts, Virginia Council on the Environment, deserve special credit and thanks for providing suggestions and comments during this five-year research project. The successful completion of this investigation and the relevance of the Virginia Water Resources Research Center's total research program can be partially attributed to the guidance and participation of these knowledgeable and interested members of this committee.

Diana L. Weigmann
Interim Director

Abstract

The purpose of this study was to determine whether habitat suitability criteria developed in the summer months for smallmouth bass, *Micropterus dolomieu*, were transferable among streams representing different ecoregions.

Habitat suitability criteria were developed for depth, mean column velocity, cover, and substrate for two size classes of smallmouth bass, 100-199 mm and ≥200 mm, in the North Anna River and Craig Creek, Virginia. Criteria that accurately describe habitat selection by a species or guild in a system different from where the criteria were developed are said to be transferable to that system. The transferability of suitability criteria between the North Anna River and Craig Creek, as well as depth and mean column velocity criteria from Minnesota, the Huron River, Michigan, and the Upper James River, Virginia, to the North Anna River and Craig Creek were tested using a 2x2 contingency table analysis.

Depth criteria for the smaller sizes of smallmouth bass did not transfer well between regions; four of the eight transferability tests (50%) failed. Depth criteria for larger smallmouth bass transferred to the North Anna River and Craig Creek in all cases.

Velocity criteria developed for the smaller size classes did not transfer well among regions; only three of the eight transferability tests were positive. Likewise, velocity criteria for larger sizes of smallmouth bass did not transfer well; only one of eight tests were positive.

General criteria were developed for depth and mean column velocity by averaging the suitability values reported from this and three other studies. General depth and velocity criteria transferred well to the North Anna River and Craig Creek for both the larger and smaller size classes of smallmouth bass; all depth tests were positive, and three of four velocity tests were positive. The improved success of transferability warrants investigation of developing general criteria for smallmouth bass.

Cover criteria for both size classes of smallmouth bass were transferable from the North Anna River to Craig Creek, but not vice versa. Substrate heterogeneity criteria were not transferable between the North Anna River and Craig Creek for either size class of smallmouth bass. Criteria developed for the percentage of substrate particles ≥15 cm (smallmouth bass ≥200 mm only) were transferable from Craig Creek to the North Anna River but not vice versa.

The transferability of habitat suitability criteria among regions was inconsistent, and it is recommended that site-specific criteria be developed for each stream to which habitat assessments are applied. Additionally, nose (focal point) velocities of smallmouth bass were more consistent between the North Anna River and Craig Creek than were mean column velocities used. Hence, it is recommended that information on nose velocities be incorporated into habitat studies to more accurately describe smallmouth bass velocity requirements.

Keywords: Smallmouth bass, *Micropterus dolomieu*, habitat suitability, depth, mean column velocity, cover, substrate.

1 Introduction and Justification

The demand for water as a multiple-use resource continues to increase. Consequently, reliable decision-making tools are needed to assist in the allocation and regulation of water resources. The Instream Flow Incremental Methodology (IFIM), developed by the U.S. Fish and Wildlife Service, is one such habitat-based tool for evaluating the environmental consequences of land and water practices (Bovee, 1982). IFIM uses a series of mathematical, empirical, and conceptual models to calculate total instream habitat area for particular evaluation organisms as affected by various stream flows, channel characteristics, water quality, and temperature (Bovee, 1982). The resulting information can be used to evaluate the consequences of alternative flows.

Physical habitat simulation (PHABSIM), a component of IFIM, is a collection of computer programs used to relate changes in discharge or channel structures to changes in physical habitat availability (Bovee, 1982). The underlying principles of PHABSIM are that:

- each species exhibits preference within a range of habitat conditions that it can tolerate;

- these ranges can be defined for each species; and

- the area of stream providing these conditions can be quantified as a function of discharge and channel structure.

Habitat suitability criteria (HSC) are used in the PHABSIM model to convert simulated stream depths, velocities, substratum, and measured cover into indices of habitat quality. The output gives a relationship between stream discharge and usable habitat. Habitat preferences (or suitability) for a particular species are defined by curves in which the optimum range of a particular habitat variable for each particular species is given a weighting factor of 1. Other ranges of the variable considered less preferred are given values less than 1, with the least preferred (avoided) ranges having a value of zero.

Typically, HSC are developed individually for each particular stream in question. Models that are transferable from stream to stream are desirable to reduce the cost and time required to develop such models. A transferable model would reduce costs because an entirely new model would not have to be made for each stream. Minor adjustments in the transferable model would, undoubtedly, have to be made, but the cost of these adjustments would be much less than for developing a new model.

Habitat suitability criteria for a single species may take one year or more to develop (Bovee, 1986), and this time can be increased when events, such as flooding, prevent field data collection. This basic data requirement can, therefore, greatly increase the time required for the environmental studies needed for hydropower development, water withdrawal, and flow modifications. Transferable HSC can benefit both decision makers and those applying for licenses or permits by reducing the time required for management decisions.

Although transferable models are desirable from a management perspective, few studies have addressed this question. There are numerous examples demonstrating that abiotic factors such as temperature (Baltz et al., 1982; Todd and Rabeni, 1989; Taylor, 1988) and velocity (Matheson and Brooks, 1983), and biotic factors, such as predation (Mittelbach, 1981), food availability (Wilzbach, 1985), and competition (Baltz et al., 1982), can influence habitat choice by stream fish. Therefore, there is reason to believe HSC models will not be totally transferable. Furthermore, there is considerable debate about the best approach for developing habitat suitability curves. Parson and Hubert (1988) argued that habitat availability should not be used when constructing preference curves, whereas Moyle and Baltz (1985) concluded that the combination of habitat availability and use data provided for the most accurate habitat suitability models. It also has been suggested that perhaps more than habitat use and availability are needed to determine preference for a species (Bartholow and Slauson, 1990). Therefore, there is a need for multiple transferability studies to define the degree of generality in the HSC models.

Previous studies have compared site-specific criteria to general criteria developed by the U.S. Fish and Wildlife Service and found large enough differences to recommend that site-specific criteria be used for subyearling coho salmon, *Oncorhynchus kisutch*, (Sheppard and Johnson, 1985), juvenile fall chinook salmon, *Oncorhynchus tshawytscha*, (Campbell and Eddy, 1988) and spawning chinook salmon (Shirvell, 1989). Alternately, Belaud et al. (1989) developed site-specific criteria for brown trout, *Salmo trutta fario* L., on four streams in southern France and found them to be similar to the general criteria. Few studies have tested the general applicability of criteria developed in specific streams (as opposed to general models) in other systems. Preference criteria developed for juvenile Atlantic salmon, *Salmo salar*, differed significantly between two Newfoundland rivers (DeGraaf and Bain, 1986). Likewise, criteria for young Colorado River cutthroat trout, *Oncorhychus clarki pleuriticus*, differed among sites in Wyoming streams (Bozek and Rahel, 1992). Although the results of these studies strongly suggest that habitat suitability criteria should be developed on a site-specific basis for young salmonids in coldwater systems, few studies have used coolwater or warmwater species of fish.

The goal of this study was to assess the transferability of habitat suitability criteria developed for smallmouth bass, *Micropterus dolomieu*, between streams representative of two dissimilar ecoregions. The objectives were to:

- develop habitat suitability criteria for the North Anna River and Craig Creek, Virginia;
- assess the transferability of suitability criteria between the two study streams; and
- assess the transferability of suitability criteria developed in other regions of the United States to Virginia streams.

Smallmouth bass was chosen as a target species because it is a popular sportfish and is often the focus of IFIM studies. Also, smallmouth bass are either native or have been introduced into waters in almost every state in the United States. HSC have been developed for this species in different regions (Aadland et al., 1989; Orth et al., 1981; Edwards et al., 1983; Leonard et al., 1986; Monahan, 1991; Barrett, 1992), making transferability assessments of HSC among different regions possible. The streams chosen have abundant populations of smallmouth bass, which made it feasible to collect adequate data over a short period of time.

2 Study Streams

Study sites were located on the fall line of the North Anna River (latitude 37° 56′ 09″N, longitude 77° 33′ 00″E) and in Craig Creek (latitude 37° 32′ 30″N, longitude 80° 01′ 30″E), Virginia. These streams were chosen for two reasons: (1) they are from different ecoregions, and (2) they are morphologically dissimilar. That the two streams are dissimilar is important because, for HSC to be widely transferable, they must be accurate when used on different streams where a variety of habitats are available. If a single HSC model can be used to describe frequency of microhabitat use by fish in two different streams, it can be said that the HSC model is transferable. Each stream is representative of the streams associated with their respective ecoregions (table 1). The North Anna River is located within the Southeastern Plains ecoregion (Omernik, 1987), which encompasses the Upper Piedmont of Virginia. Craig Creek originates in Montgomery County in the Ridge and Valley province of Virginia, and is located within the Central Appalachian Ridge and Valley ecoregion (Omernik, 1987). The stream bed of the North Anna River is dominated by bedrock and sand, whereas Craig Creek is dominated by bedrock and cobble. The average water temperature from May 1991 through August 1991 for the North Anna River (27° C) was warmer than that of Craig Creek (23.2° C). In the vicinity of the study sites, the North Anna River is also a wider (.ca 35 m) and slower (gradient = 0.46 m/km) river than Craig Creek (.ca 25 m and gradient = 1.37 m/km). The North Anna River is impounded by the North Anna dam, which controls water levels, creating more stable base flows (minimum discharge = 1.13 m^3/s). There are no flow regulations on Craig Creek. Stream discharges during sampling ranged from 1.56 to 2.89 m^3/s (14-27% mean annual discharge) in Craig Creek, and from 1.16 to 1.96 m^3/s (11-18% mean annual discharge) in the North Anna River. Fish assemblages for Craig Creek and the North Anna River have similar families, but different genera and species (table 2).

3 Methods

Sampling was done from May 14 to August 15 1991 on the North Anna River, and from June 25 to August 12 1991 on Craig Creek. Sampling was alternated between streams during the overlapping period. Sampling was not done on Craig Creek from May 14 through June 25 because the water was too turbid and flows too high for snorkeling. Eight sites were sampled on the North Anna River (figure 1), and five sites were sampled on Craig Creek (figure 2). Sites in Craig Creek were, on average, longer ($\bar{x}=184.7$ m) and narrower ($\bar{x}=23.2$ m) than those in the North Anna River ($\bar{x}$ length = 149.6 m, $\bar{x}$ width = 34.6 m). The average area of a site in the North Anna River was larger than that in Craig Creek (0.541 ha and 0.43 ha, respectively).

3.1 Fish Observations

Smallmouth bass (SMB) habitat use information was collected only for individual fish $\geq$100 mm. Habitat use by smallmouth bass <100 mm is reported in Sabo (1993). At each sample site, water temperature, ambient air temperature, weather conditions, and other existing conditions (e.g., insect hatches) were recorded immediately before snorkeling. Underwater visibility was measured with a black disc (Davies-Colley, 1988); a 2-m minimum was required before snorkeling proceeded. Visibilities throughout the study period averaged 2.9 m in each stream, and ranged from 2.0 to 3.8 m in Craig Creek and 2.3 to 3.5 m in the North Anna River.

Study reaches were divided longitudinally into two sample areas, each representing one-half of the stream width, and were snorkeled sequentially. This was necessary because the study streams were too wide to thoroughly snorkel with one pass. Two observers snorkeled, starting at 0900 hrs at the lower end of a sample area and proceeding upstream. Observers swam slowly to avoid disturbing fish, and in a zig-zag pattern to thoroughly cover the sample area. When a smallmouth bass was sighted, the snorkeler stopped and measured the fish total length (calibrated mask-bar: Swenson et al., 1988) and the distance of the fish above the streambed. Two numbered markers were placed on the substrate—one directly below the mask-bar and one directly below the fish's position—to permit subsequent habitat measurements. Fourteen fish in the North Anna River and nine fish in Craig Creek were noticeably disturbed by the diver, as indicated by the fish swimming away upon seeing the diver, and were not recorded. Immediately after snorkeling was completed through a pool/riffle combination, microhabitat information (water depth, mean water column velocity, nose velocity (water velocity at a fish's position in the water column), substrate composition, and cover) was recorded at each fish location. Distances between mask-bar and fish positions were measured to the nearest centimeter, and used to estimate the total length of fish.

3.2 Habitat Availability

After snorkeling was completed, the habitat available in each site was described by sampling along a series of transects laid perpendicular to the stream flow. The first transect was positioned at the upstream end; other transects were positioned downstream by randomly choosing a distance to the next transect from a range of distances (18-22 m for the North Anna River and 9-11 m for Craig Creek) until the last transect, positioned at the bottom of a study site, was reached. The number of transects for each site was proportional to the length of the site. Habitat measurements of depth, velocity, substrate composition, and cover were taken at 3-m intervals along each transect and 1 m from each stream margin.

3.3 Protocol for Habitat Measurements

Water depths were recorded with a top-setting graduated wading rod. Water velocities were measured with either a Marsh-McBirney or a pygmy-Gurley current velocity meter. Nose velocities were recorded by measuring water velocity at the recorded fish distance above the streambed. Mean water column velocity was measured at 0.6 of the total water depth for water <1 m; for water >1 m, the average at 0.2 and 0.8 of total water depth was used.

Substrate compositions were measured using a modified version of a substrate sampling technique by Bain et al. (1985). Two 1-m rods marked at 10-cm increments were attached perpendicular to each other at the midpoint. The cross was placed on the stream bottom at each sample point, with one of the rods parallel to the stream flow. The dominant substrate (modified Wentworth scale, Bovee, 1982) in each 10-cm increment was recorded as (1) sand/silt, (2) small gravel = $>$0.5-2.5 cm, (3) large gravel = $>$2.5-5 cm, (4) small cobble = $>$5-15 cm, (5) large cobble = $>$15-30 cm, (6) small boulder = $>$30-60 cm, (7) large boulder = $>$60 cm, and (8) bedrock, resulting in 20 substrate observations for each sample location.

Any object that a smallmouth bass used or potentially could have used to escape current, to provide a sight barrier (hiding), to forage around, or to escape sunlight that was within 1 m of marked fish locations or habitat availability sampling points was considered a potential cover object. Cover objects included: single logs, log complexes, rootwads, undercut banks, overhead cover (objects within 1 m above the water surface), overhanging bedrock ledges, overhanging boulders, vegetation, brushpiles, and velocity shelters. The dimensions (length, width, and height) of each cover object were recorded, as well as comments on any peculiarities of that cover object that separated it from the general classification.

3.4 Data Analysis

To determine whether habitat use varied by fish length, scatter plots were developed of fish total length versus depth used, and fish total length versus velocity used. Six cover categories were used for analysis: no cover, woody debris, rock ledge, velocity shelter, aquatic vegetation, and overhead cover. Some cover types described during data collection were combined to produce categories of similar functions. Single log, log complex, rootwad, and brushpile cover types were combined to form the woody debris category. Boulder or bedrock structures that provided pockets for fish to hide in (under) that were classified as overhanging bedrock ledge and overhanging boulder during data collection were combined to form the rock-ledge category. Velocity shelters consisted of objects embedded in the stream bottom (e.g., rocks), where the only function was to provide a position where fish could escape flowing water. It is possible that objects placed in other categories (e.g., logs, boulders) also could have been used as velocity shelters; however, because use as a velocity shelter was determined a secondary, rather than primary, function (based on water velocity), these objects were not categorized as velocity shelters. Undercut banks made up less than 1% of available cover types, and no fish were found using them; therefore, there was insufficient information to describe the relative preference smallmouth bass had for an undercut bank, and this cover type was omitted from the analysis. Each cover category was used as a separate interval for analysis.

Habitat suitability criteria for substrate composition were based on two aspects of the stream substrate particles: heterogeneity and particle size. To describe substrate heterogeneity, the standard deviation of the 20 substrate codes assigned to each sample location (i.e., each location of fish use and availability measurements) was calculated (Bain et al., 1985). A low standard deviation indicates a relatively homogeneous substrate, with the substrate becoming increasingly heterogeneous as the value increases.

To develop an appropriate variable to describe substrate particle size, relative frequencies of particle size use were compared with availability for each size class of fish (used for analysis) in each stream. Based on the results of these comparisons, the habitat variable percentage of substrate particles ≥15 cm (including bedrock) was developed for larger smallmouth bass.

The majority of previously developed habitat suitability criteria divided microhabitat variables into equal-size intervals for analysis. When this approach was used in this study (and presumably others), problems occurred because of small sample sizes in certain intervals. The resulting suitability curves proved to be biologically uninterpretable due to imprecise or unreliable estimates of selectivity. To overcome this problem, interval ranges for depth, velocity, substrate heterogeneity, and percentage of substrate particles ≥15 cm were determined based on the following percentiles: (1) from the minimum value available in the stream to the 0^{th} percentile of fish use, (2) from $>0^{th}$ to 10^{th} percentile of fish use, (3) from $>10^{th}$ to 25^{th} percentile of fish use, (4) from $>25^{th}$ to 50^{th} percentile of fish use, (5) from $>50^{th}$ to 75^{th} percentile of fish use, (6) from $>75^{th}$ to 90^{th} percentile of fish use, (7) from $>90^{th}$ to 100^{th} percentile of fish use and (8) from $>100^{th}$ percentile of fish use to the maximum value available in the stream.

The Kolmogorov-Smirnov goodness-of-fit test was used to investigate differences in frequency distributions between use and availability proportions for continuous variables (Sokal and Rohlf, 1981). The chi-square test for differences in probabilities (2 X 6 contingency tables, Conover, 1971) was used to test for differences in frequency distributions of the categorical variable cover. The software program, Statistix (version 3.5, Analytical Software, 1991), was used to carry out Kolmogorov-Smirnov and 2 X 6 contingency table analyses. An alpha level of 0.05 was used to judge statistical significance. Strauss' linear index (L) was calculated for each interval to test for differences in use and availability proportions (Strauss, 1979). For each fish size class and variable, the alpha = 0.05 level of significance was adjusted for multiple non-independent tests.

Suitability values (i.e., use proportions divided by availability proportions) were calculated for each interval, then normalized to a scale ranging from 0 to 1, where a value of 1 represents the interval(s) most highly selected for, and a value of 0 represents an avoided or unsuitable interval(s) (Bovee, 1986).

Suitability criteria curves were constructed by developing frequency polygons of normalized suitability values (SVs). Calculated SVs for each interval were used as points on the curve, located at the midpoint of each interval, except when both adjacent SVs were larger. In such cases, the higher adjacent SVs were connected, enveloping the middle (i.e., lowest) value. Cover types are categorical, rather than continuous, variables, so habitat suitability criteria for cover are presented as bar charts.

General depth and velocity suitability criteria were developed for small (juvenile/subadults) and large (adults) size classes of smallmouth bass using criteria developed in the North Anna River; Craig Creek; Minnesota (Aadland et al., 1989); the Upper James River, Virginia (Leonard et al., 1986); and the Huron River, Michigan (Monahan, 1991). Suitability values used to construct the general curves were averages of these five studies. Criteria were limited to depths up to 220 cm and velocities up to 140 cm/s because these values exceeded the available habitats in the North Anna River and Craig Creek, where criteria transferability was tested. Also, four of the five studies either did not have suitability values calculated beyond these limits, or the reported suitability was an extrapolation beyond the upper range of habitat available in the stream where criteria were developed.

The transferability of depth, velocity, cover, and substrate habitat suitability criteria between the North Anna River and Craig Creek, as well as the transferability of depth and velocity criteria developed in other regions of the United States to the North Anna River and Craig Creek, were tested with a variation of the method used by Thomas and Bovee (1992, in review). Suitability criteria were classified as being optimal when SVs were ≥ 0.7, marginal when SVs ranged from >0 to <0.7, and unsuitable when $SV = 0$. For each smallmouth bass size class in the target stream (stream for criteria to be transferred to), habitat use and availability were cross-classified in a 2x2 contingency table (Conover, 1971) on the basis of habitat suitability criteria from the source stream. Two tables were developed for each test of transferability—one to test selection of optimal versus marginal habitat, and one to test suitable versus unsuitable habitat. One-tailed tests were done at an $\alpha = 0.05$ level of significance. Null and alternate hypotheses to be tested were:

1) H_0: Smallmouth bass will use suitable habitat in an equal or lesser proportion than it is available

   H_A: Suitable habitat will be used in a greater proportion than it is available

2) H_0: Smallmouth bass will use optimal habitat in an equal or less proportion than it is available

H_A: Optimal habitat will be used in a greater proportion than it is available

Test statistic T for the one-way variant of the chi-square test was calculated as:

$$T=N(ad-bc)^2/(a+b)(c+d)(a+c)(b+d)$$

where:

N = total number of observations

a = number of fish observed using suitable (optimal) habitat

b = number of fish observed using unsuitable (marginal) habitat

c = number of suitable (optimal) habitat availability observations

d = number of unsuitable (marginal) habitat availability observations

For suitability criteria to be transferable, both null hypotheses must be rejected. The critical T value corresponding to alpha=0.05 was 2.71.

The transferability of criteria from the North Anna River and Craig Creek to other regions of the United States could not be tested because of the lack of individual fish use and availability data from the other regions. Transferability tests of substrate criteria from the North Anna River and Craig Creek to other regions were not possible because of differences in the classifications of particle sizes and methods of data collection. Likewise, the transferability of cover criteria could not be tested because of differences in cover descriptions among studies.

Depth and velocity suitability criteria from other regions of the United States to be used in transferability tests were from Minnesota (Aadland et al., 1989); the Upper James River, Virginia (Leonard et al., 1986); and the Huron River, Michigan (Monahan). Leonard et al. (1986) developed habitat suitability criteria for smallmouth bass 102-305 mm and >305 mm. In the North Anna River, data on 126 smallmouth bass were in the smaller size category, and 18 fish were in the larger size category. In Craig Creek, 104 bass were in the smaller size category, and 14 were in the larger size category. Thomas and Bovee (1992, in review) reported that, when sample sizes of 30 were used in transferability assessments with 2x2 contingency tables, 7% of the trials resulted in a type I error (rejecting H_0 when it should not be rejected). The occurrence of type II errors was not tested. Because of small sample sizes in the larger size (adult) category for both the North Anna River and Craig Creek, the statistical tests of adult criteria transferability from the Upper James River to each study stream were of low power. Therefore, the rejection of a hypothesis is valid, but the failure to reject a hypothesis may be a result of an inadequate sample size and no valid conclusion could be made.

Smallmouth bass size classes for criteria developed by Aadland et al. (1989) were defined as 100-189 mm and >189 mm. For testing the transferability of suitability criteria from Minnesota to the North Anna River, 83 smallmouth bass in the North Anna River were within the 100-189 mm range, and 61 were more than 189 mm in length. For testing the transferability of Minnesota criteria to Craig Creek, 57 bass in Craig Creek were within the 100-189 mm length range, and 62 were more than 189 mm in length.

Monahan (1991) developed habitat suitability criteria for smallmouth bass 120-190 mm and ≥200 mm. Separate criteria were developed for seasonal and diel time periods: (1) diurnal-summer, (2) nocturnal-summer, and (3) diurnal-spring. Criteria from the diurnal-summer sampling period were tested for transferability because this time period most closely matched the time of data collection in the North Anna River and Craig Creek. Fish 120-194 mm long were placed in the smaller size category (North Anna River N=68; Craig Creek N=52), and fish ≥195 mm were placed in the larger size category (North Anna River N=49; Craig Creek N=62) for the transferability assessment. For both depth and velocity criteria, Monahan (1991) listed no unsuitable habitats (suitability value = 0), so the assessment of criteria transferability from the Huron River to the North Anna River and Craig Creek were based on the hypothesis testing optimal versus marginal habitat.

The transferability of the general criteria to the North Anna River and Craig Creek were tested using the same method as described for other criteria. When general criteria were developed, there were no ranges of either depth or velocity for either size class of fish defined as unsuitable. Therefore, transferability was tested using only the test for optimal versus marginal habitat.

Velocity habitat suitability criteria currently are developed using the mean water column velocity rather than the actual velocity a fish is perceiving (i.e, nose or focal-point velocity). To investigate the appropriateness of using mean column velocity as the only velocity variable in criteria, scatter plots of fish distance above the substrate versus total water column depth were developed. Bar charts also were constructed comparing the frequency distribution of mean column velocities used and nose velocities used by smallmouth bass. For each size class of fish in the North Anna River and Craig Creek, mean water column velocities were compared with fish nose velocities with a paired t-test (Sokal and Rohlf, 1981) with an alpha=0.05 level of significance. Additionally, regression analysis was used to determine whether nose velocities could be predicted based on mean column velocity and the proportional vertical distance of the fish above the stream bottom (i.e., fish distance above substrate/total water depth). The formula $V_n = aV_m^b (D_n/D_t)^c$ was log-transformed to obtain the following linear equation for analysis:

$$\log(V_n) = \log(a) + b \log(V_m) + c \log(D_n/D_t)$$

where:

V_n = nose velocity (cm/s)

V_m = mean column velocity (cm/s)

D_n = fish distance above stream bottom (cm)

D_t = total water column depth (cm)

a, b, and c = coefficients

Zero velocities were encountered, so a constant value of 0.1 was added to all velocities before performing the regression procedure.

One assumption in IFIM is that habitat variables are independent in their influence on habitat selection of fish (Orth and Maughan, 1982). To investigate the validity of this assumption, suitability values were calculated for four different combinations of water column depth and mean column velocities for each size class of smallmouth bass in each study stream (Appendix A). Bar charts were constructed using these suitability values, and visually assessed for interactive effects on depth selection.

4 Results

4.1 General

Data were collected on 144 smallmouth bass in the North Anna River and 119 smallmouth bass in Craig Creek. Length distributions of smallmouth bass in the North Anna River and Craig Creek were similar (figure 3). Mean fish length was slightly longer in Craig Creek than in the North Anna River, 217 mm and 197 mm, respectively. Densities in the North Anna River sites ranged from 20.4 to 72.5/ha, with an overall stream density (number of fish observed/total area sampled) of 35.4/ha (table 3). The range of densities in Craig Creek sites was comparable to the North Anna River (29.3-74.5/ha), however, the overall stream density was higher (55.4/ha) (table 3).

Water temperatures were consistently higher in the North Anna River than in Craig Creek (figure 4). The mean water temperature for the sampling period was 27.0° C in the North Anna River and 23.2° C in Craig Creek. Visibility was good in both streams, with only one instance where the minimum visual distance of 2 m was encountered on August 12 in Craig Creek. Maximum visual distances were 3.5 m in the North Anna on August 6 and 3.8 m in Craig Creek on July 15.

The distribution of depths available to SMB was different in the two study streams (KS $P=0.0002$, figure 5). This was because of a greater proportion of deep (>100 cm) areas in Craig Creek.

The distribution of velocities available to fish was different in the two study streams (KS $P=0.04$, figure 5). This was because of a greater proportion of velocities ≤5 cm/s and ≥66 cm/s and lesser proportions of velocities ranging from 12 to 29 cm/s in Craig Creek.

The distribution of cover types available was different in the two study streams ($P < 0.0001$, figure 6). Differences can be attributed to a greater proportion of habitat without cover and a lesser proportion of rock-ledge habitat in Craig Creek.

The distribution of substrate heterogeneities differed between the North Anna River and Craig Creek (KS $P<0.0001$, figure 7). The North Anna River had higher proportions of homogenous substrata (heterogeneity = 0) and heterogeneity values ranging from 1.51 to 3.5, but lower proportions of values from 0.51 to 1.5 compared to Craig Creek.

The distribution of percentages of substrate particles ≥15 cm were different in the two study streams (KS $P<0.0001$, figure 7). This was due to a higher proportion of areas with 0-30% particles ≥15 cm in Craig Creek and a higher proportion of areas with 31-100% particles ≥15 cm in the North Anna River.

4.2 Size-Related Habitat Use

Habitat use by smallmouth bass <200 mm differed from habitat use by smallmouth bass ≥200 mm. Scatter plots of velocity use by smallmouth bass in the North Anna River and Craig Creek showed variable use of velocities by fish <200 mm (figure 8). Fish ≥200 mm used a much narrower range of velocities (<0.3 m/s) than fish <200 mm in both streams. Plots of depth use showed less pronounced differences than velocities. North Anna River smallmouth bass appeared to show little difference in depth use over the range of fish lengths (figure 8). However, as with velocities, Craig Creek fish appeared to show some differences in depth use around the 200 mm length. Some smallmouth bass <200 mm used shallower water than those >200 mm, and some fish >200 mm used deeper water than SMB <200 mm (figure 8). Based on these results, smallmouth bass were divided into size categories 100-199 mm and ≥200 mm for all analyses. Henceforth, smallmouth bass 100-199 mm will be referred to as small SMB and smallmouth bass ≥200 mm will be referred to as large SMB.

Interval ranges used for depth, velocity, substrate heterogeneity, and percent of substrate particles ≥15 cm criteria development, along with fish use, habitat availability, calculated suitability values, and Strauss' L values for each interval, are shown in Appendix B.

4.3 Depth

Depth use distributions for each size class for each stream differed from what was available (all KS p values <0.001). Small SMB in the North Anna River used intervals 50-59 cm and 60-79 cm significantly more than expected based on availability (figure 9). The interval 50-59 cm was of maximum suitability (SV=1), while intervals 4-21 cm and 148-205 cm were unsuitable.

Small SMB in Craig Creek used depth interval 111-118 cm significantly more than expected based on availability, and this interval was of maximum suitability (figure 9). The unsuitable depths in Craig Creek (4-27 cm and 138-174 cm) were similar to those in the North Anna River.

Depth habitat suitability criteria for small SMB in the North Anna River are shown in figure 9. The optimal range of depths (SV ≥0.7) for small SMB in the North Anna River was 40-76 cm, with 55 cm having the maximum SV of 1. Depths of 14-39 cm and 77-176 cm were of marginal suitability (SV >0 and <0.7), while depths of 4-13 cm and deeper than 177 cm were unsuitable (SV = 0).

Optimal depths for small SMB in Craig Creek were deeper than for those in the North Anna River, ranging from 108 to 120 cm, with 114 cm having the maximum SV. Marginally suitable depths ranged from 16 to 107 cm and 121 to 155 cm, while depths of 4-12 cm and deeper than 155 cm were unsuitable (figure 9).

Large SMB in the North Anna River used the depth interval 109-120 cm significantly more than expected based on availability, and this interval was given the maximum suitability value (figure 10). Suitability values of 0 were assigned to intervals 4-19 cm and 147-205 cm.

Large SMB in Craig Creek used depth intervals 89-109 cm, 110-123 cm, and 124-132 cm significantly more than expected based on availability, with interval 124-132 cm having the maximum calculated suitability value (figure 10). Intervals 4-57 cm and 169-174 cm were not used, and, thus, were given a suitability value of 0.

The optimal range of depths for large SMB in the North Anna River was 106-129 cm, with 115 cm having the maximum SV of 1. Marginally suitable depths ranged from 12 to 105 cm and from 130 to 175 cm, and unsuitable depths were 4-11 cm and deeper than 176 cm (figure 10).

The range of optimal depths for large SMB in Craig Creek was 113-137 cm, similar to those for North Anna River large SMB, while the depth of maximum suitability was slightly deeper (128 cm). Marginally suitable depths, ranging from 31 to 113 cm and 138 to 171 cm, and unsuitable depths, ranging from 4 to 30 cm and deeper than 171 cm, were also comparable (figure 10).

4.4 Velocity

In the North Anna River, the distribution of velocities used by each size class did not differ significantly from what was available (KS small SMB P=0.08, large SMB P=0.33). In Craig Creek, however, velocity use by each size class of fish differed significantly from what was available (both KS P=<0.001).

Small SMB in the North Anna River used no velocity intervals significantly more than what was expected based on availability (figure 11). The maximum suitability value (1) was calculated for the interval 21-27 cm/s, and suitability values of 0 were calculated for intervals 0-2 cm/s and 69-105 cm/s.

Small SMB in Craig Creek used no velocity intervals significantly more than expected based on availability (figure 11). The maximum suitability value of 1 was calculated for interval 7-10 cm/s, followed closely by interval 11-17 cm/s, which had a suitability value of 0.99. Suitability values of 0 were assigned to intervals 0-1 cm/s and 53-113 cm/s.

Optimal velocities for small SMB in the North Anna River ranged from 4 to 45 cm/s, with the maximum SV at 24 cm/s (figure 11). Velocities of 0-3 cm/s and 46-86 cm/s were marginally suitable, and velocities faster than 86 cm/s were unsuitable.

Optimal, marginal, and unsuitable velocities for small SMB in Craig Creek were similar to those of North Anna River small SMB, but the velocity with a SV=1 was slower. Velocities of 7-50 cm/s were optimum, velocities of 0-6 cm/s and 51-82 cm/s were marginally suitable, and velocities 83 cm/s or faster were unsuitable (figure 11).

Large SMB in the North Anna River used no velocity intervals significantly more than expected (figure 12). Suitability values of 0 were assigned to intervals 0 cm/s and 54-105 cm/s, while interval 3-4 cm/s had the maximum suitability value.

Large SMB in Craig Creek used the velocity interval 9-12 cm/s significantly more than expected based on availability (figure 12). The maximum suitability value was assigned to the interval 13-14 cm/s, while intervals 0-3 cm/s and 51-113 cm/s were unsuitable.

The optimal velocity range for large SMB in the North Anna River was 2-19 cm/s; the velocity associated with the maximum suitability value was 3.5 cm/s. Velocities of 0-1 cm/s and 20-79 cm/s were marginally suitable, while velocities faster than 80 cm/s were unsuitable (figure 12).

Optimal velocities for large SMB in Craig Creek were from 11 to 19 cm/sec, a slightly narrower range than for large SMB in the North Anna River, and the velocity of maximum SV was faster at 13.5 cm/s. Velocities of 0-10 cm/s and 20-81 cm/s were marginally suitable. Unsuitable velocities (faster than 81 cm/s) were comparable to those of large SMB in the North Anna River (figure 12).

4.5 Vertical Distribution and Nose Velocity

Two hundred fifty-four out of 255 smallmouth bass were seen within 50 cm of the stream bottom (distance from substrate data was missing on 4 fish from each stream). Mean distances from the substrate were similar for both large and small SMB in both streams (table 4). The ranges of nose velocities used by smallmouth bass in both the North Anna River and Craig Creek were narrower and skewed more toward slower water compared to the ranges of mean column velocities used (figure 13). In Craig Creek, 96% of the smallmouth bass used nose velocities $\leq$23 cm/s, whereas only 87% used mean column velocities $\leq$23 cm/s. A similar pattern was seen in the North Anna River, where 89% of the smallmouth bass used nose velocities $\leq$23 cm/s, and only 83% used mean column velocities $\leq$23 cm/s (figure 13). Nose velocities were significantly different than mean water column velocities for each size class in each stream (all $P<0.004$) (table 4). Mean differences between the nose velocities and mean water column velocities were greater for fish in Craig Creek (small SMB = -4.61 cm/s, large SMB = -3.23 cm/s) than for fish in the North Anna River (small SMB = -2.71 cm/s, large SMB = -2.22 cm/s) (table 4).

The regression procedure for predicting nose velocities (cm/s) based on mean column velocities (cm/s) and the proportional distance of the fish above the stream bottom (fish distance above stream bottom (cm)/total water column depth (cm)) resulted in the equations:

$$V_n=1.401(V_m^{1.008})\left(\frac{D_n}{D_t}\right)^{0.501}$$

($N=115$; $P_{regression}<0.0001$; Adj. $R^2=0.729$; RMSE=0.100) for Craig Creek smallmouth bass and:

$$V_n=1.861(V_m^{0.835})\left(\frac{D_n}{D_t}\right)^{0.298}$$

($N=140$; $P_{regression}<0.0001$; Adj. $R^2=0.635$; RMSE=0.098) for North Anna smallmouth bass.

4.6 Independence of Depth and Velocity

Visual comparison of suitability values for each combination of depth and mean column velocity (figure 14) showed no evidence that variable interaction affected habitat selection by smallmouth bass in either the North Anna River or Craig Creek. Deeper water was of higher suitability than shallower water of the same mean column velocity in all cases. Faster water was of higher suitability than slower water, regardless of depth, for both size classes of smallmouth bass in Craig Creek. Deeper, faster water was of higher suitability than deeper, slower water in three of four cases, and shallower, faster water was more suitable than shallower, slower water in three of four cases (figure 14).

4.7 Cover

In the North Anna River, the distributions of cover types used by small and large SMB differed significantly from what was available ($P=0.00023$ small SMB; $P=0.0255$ large SMB). The distribution of cover types used by large SMB in Craig Creek differed significantly from what was available ($P < 0.0001$), but use by small SMB did not ($P=0.0521$).

Small SMB in the North Anna River used rock ledges significantly more than expected based on availability (figure 15). Rock ledges were of optimal suitability, and all other cover categories were of marginal suitability with suitability values between 0.19 and 0.4 (figure 15).

Small SMB in Craig Creek used no cover type significantly more than expected (figure 15). Velocity shelters and rock ledges were optimal cover types; all others were of marginal suitability (figure 15).

Large SMB in the North Anna River used rock ledges significantly more than expected based on availability, while fish avoided aquatic vegetation and overhead cover (figure 16). Rock ledges and velocity shelters were of optimal suitability, while aquatic vegetation and overhead cover were unsuitable. All other cover types were marginally suitable (figure 16).

Large SMB in Craig Creek used rock ledges and velocity shelters significantly more than expected based on availability (figure 16). Velocity shelters were of optimal suitability, overhead cover was unsuitable, and the remaining cover types were marginally suitable (figure 16).

4.8 Substrate Heterogeneity

The distribution of substrate heterogeneity use by small SMB differed significantly from what was available in the North Anna River (KS $P=0.001$), but not in Craig Creek (KS $P=1.0$). Frequency distributions of substrate heterogeneity use by large SMB did not differ significantly from what was available in the North Anna River (KS P=0.8315), but did in Craig Creek (KS P=0.018).

Small SMB in the North Anna River used the substrate heterogeneity interval 0.92-1.63 significantly more than expected based on availability (figure 17). Interval 2.42-2.78 was calculated with a maximum suitability value of 1, and interval 3.68-3.92 was unsuitable. In Craig Creek, no heterogeneity intervals were used more than expected based on availability (figure 17). A suitability value of 1 was assigned to the interval 2.56-3.34, and a suitability value of 0 was given to the interval 3.35-3.77; all other interval suitability values ranged from 0.32 to 0.56.

Optimal substrate heterogeneity values for small SMB in the North Anna River ranged from 1.06 to 2.93, with 2.6 having the maximum suitability value. Marginally suitable ranges were 0-1.05 and 2.04-3.79, while values greater than 3.79 were unsuitable (figure 17).

Heterogeneity values of 2.44-3.13 were of optimal suitability to small SMB in Craig Creek, with the maximum suitability value calculated at 2.95. Values of 0-2.43 and 3.14-3.55 were marginally suitable, while heterogeneity values greater than 3.56 were unsuitable, similar to those of small SMB in the North Anna River (figure 17).

Large SMB in the North Anna River used no substrate heterogeneity interval significantly more than expected (figure 18). Heterogeneity interval 1.48-2.04 was assigned a suitability value of 1, while the interval 3.35-3.92 was given the minimum suitability value of 0. All other intervals had suitability values ranging from 0.42 to 0.47.

Large SMB in Craig Creek used no heterogeneity interval significantly more than was expected based on availability (figure 18). Suitability values of 1 were assigned to intervals 2.26-2.98 and 2.99-3.82, with all other interval suitability values ranging from 0.18 to 0.68.

Optimal substrate heterogeneity values for large SMB in the North Anna River ranged from 0.23 to 2.07, and values ranging from 0 to 1.22 and 2.08 to 3.63 were marginally suitable (figure 18).

As with large SMB in the North Anna River, all levels of substrate heterogeneity were suitable for large SMB in Craig Creek, however, optimal and marginal complexities were very different. Values greater than 2.07 were of optimal suitability, and values from 0 to 2.07 were marginally suitable (figure 18).

4.9 Percentage of Substrate Particles ≥15 cm

Bar charts comparing the relative frequencies of smallmouth bass use and availability for each substrate particle size category are shown in figures 19 and 20. Bar charts for small SMB in the North Anna River and Craig Creek show no apparent differences between particle sizes used and what was available (figure 19), indicating that small SMB in both streams were not selecting for substrate particle sizes. However, for large SMB in Craig Creek, a distinct difference can be seen between the use and availability relative frequencies of particle sizes smaller than large cobble (15 cm) as compared to relative frequencies of particles larger than or equal to large cobble. Fish used the smaller particles in a lower proportion than what was available, whereas fish used particles greater than or equal to large cobble (≥15 cm) in a higher proportion than was available (figure 20). Differences in use and availability for large SMB in the North Anna River were evident only in the categories of sand/silt and bedrock. Fish used sand/silt in a lower proportion than was available, and used bedrock in higher proportion to what was available (figure 20). Consequently, the percentage of substrate particles ≥15 cm may be a useful habitat descriptor for larger SMB.

The distributions of substrate particles ≥15 cm used by, and available to, large SMB in the North Anna River and Craig Creek were significantly different (KS $P=0.04$ and $P<0.0001$, respectively). Large SMB in the North Anna River used substrate areas with 49-70% particles ≥15 cm significantly more than expected based on what was available, and this interval was assigned a suitability of 1 (figure 21). Areas having 0% particles ≥15 cm had the lowest suitability value of 0.14. No interval was calculated as having a suitability value of 0 because fish used the entire range of percentages.

Large SMB in Craig Creek used substrate areas containing more than 52% of substrate particles ≥15 cm significantly more than expected (figure 21). The maximum suitability value (1) was calculated for the interval 52-90%, and the lowest suitability value (0.05) was calculated for the interval of 0%.

For large SMB in the North Anna River, the optimal percentage of substrate particles ≥15 cm ranged from 19 to 74%, and marginally suitable percentages ranged from 0 to 18% and >74% (figure 21). Percentages greater than 52% were optimal to large SMB in Craig Creek, with marginally suitable percentages ranging from 0 to 52% (figure 21).

4.10 General Criteria

Optimal depths, as described by general criteria for the smaller size class of smallmouth bass (juveniles/subadults), ranged from 46 to 137 cm. Marginal depths ranged from 1 to 45 cm and deeper than 137 cm (figure 22). Optimal velocities for small SMB ranged from 6 to 51 cm/s, with marginal velocities ranging from 0 to 5 cm/s and greater than 51 cm/s.

Optimal depths for the large size class of smallmouth bass (adults) ranged from 90 to 153 cm, with marginal depths ranging from 1 to 90 cm (figure 22). Optimal velocities ranged from 6 to 29 cm/s, and marginal velocities ranged from 0 to 5 cm/s and greater than 29 cm/s (Appendix C).

4.11 Transferability Between the North Anna River and Craig Creek

4.11.1 Depth

Depth suitability criteria developed from Craig Creek for small SMB were not transferable to the North Anna River. The null hypothesis for suitable versus unsuitable habitat was rejected because no fish in the North Anna River used depths described as unsuitable based on criteria from Craig Creek. However, the null hypothesis for optimal versus marginal was not rejected because optimal depths were available in a higher proportion than they were used (table 5). Likewise, depth suitability criteria for small SMB from the North Anna River were not transferable to Craig Creek. The null hypothesis was rejected for suitable versus unsuitable habitat ($T=4.25$; $P=0.02$), but was not rejected for optimal versus marginal habitat ($T=0.006$; $P=0.47$) (table 5).

Depth suitability criteria for large SMB were transferable between the two streams. Testing Craig Creek criteria in the North Anna River, both null hypotheses for suitable versus unsuitable and optimal versus marginal were rejected ($T= 21.7$; $P<0.0001$ and $T=16.47$; $P<0.0001$, respectively) (table 5). Testing North Anna River criteria in Craig Creek, the null hypothesis for suitable versus unsuitable habitats was rejected because no fish from Craig Creek used habitats described as unsuitable by North Anna River criteria, and the null hypothesis for optimal versus marginal was rejected ($T=51.03$; $P<0.0001$) (table 5).

4.11.2 Velocity

Velocity suitability criteria for small SMB were not transferable from Craig Creek to the North Anna River. No fish in the North Anna River used unsuitable habitat as described by Craig Creek criteria, so the null hypothesis for suitable versus unsuitable habitats was rejected. However, the null hypothesis for optimal versus marginal habitats was not rejected ($T=1.72$; $P=0.095$) (table 5). Conversely, velocity criteria for small SMB were transferable from the North Anna River to Craig Creek. No fish in Craig Creek used unsuitable habitat as described by North Anna River criteria, and the null hypothesis for the optimal versus marginal test was rejected ($T=14.68$; $P<0.0001$) (table 5).

Craig Creek velocity suitability criteria for large SMB were not transferable to the North Anna River, but North Anna River criteria were transferable to Craig Creek. No fish in the North Anna River used unsuitable habitat as described by Craig Creek criteria, so the null hypothesis for suitable versus unsuitable habitats was rejected ($T=0.415$, $P=0.19$). However, the null hypothesis for the optimal versus marginal test was not rejected ($T=0.00006$; $P=0.497$) (table 5). Using North Anna River criteria in Craig Creek, both null hypotheses (suitable versus unsuitable and optimal versus marginal), were rejected ($T=11.17$; $P=0.0004$ and $T=21.09$; $P=0.0001$, respectively) (table 5).

4.11.3 Cover

There was no cover type defined as unsuitable for small SMB in either Craig Creek or the North Anna River because small SMB in both streams used all cover categories. Therefore, transferability of cover habitat suitability criteria for small SMB is dependent only on the test of the null hypothesis for optimal versus marginal habitat. Criteria were not transferable from Craig Creek to the North Anna River ($T=0.043$; $P=0.2114$) (table 5). Conversely, criteria were transferable from the North Anna River to Craig Creek ($T=3.53$; $P=0.0302$) (table 5)..

Cover suitability criteria for large SMB were not transferable from Craig Creek to the North Anna River, but were transferable from the North Anna River to Craig Creek.

4.11.4 Substrate Heterogeneity

Substrate heterogeneity suitability criteria developed for small SMB were not transferable from Craig Creek to the North Anna River. The null hypothesis for suitable versus unsuitable habitat was not rejected because suitable habitats were available in a higher proportion than they were used. The test of optimal versus marginal also was not rejected ($T=2.60$; $P=0.053$) (table 5). Likewise, criteria for small SMB in the North Anna River were not transferable to Craig Creek. There were no unsuitable substrate combinations, as defined by North Anna River criteria, available in Craig Creek, so the null hypothesis for suitable versus unsuitable habitat could not be tested. The null hypothesis for optimal versus marginal habitat was not rejected (T=0.223, P=0.318) (table 5). The North Anna River had no unsuitable substrate heterogeneity values, as defined by Craig Creek criteria, available to large SMB, so the null hypothesis for suitable versus unsuitable habitat could not be tested. Craig Creek suitability criteria for large SMB were not transferable to the North Anna River (T=0.541; P=0.262) (table 5). Likewise, substrate heterogeneity criteria for large SMB in the North Anna River were not transferable to Craig Creek. Suitable habitats were available in a higher proportion than they were used, so the null hypothesis for suitable versus unsuitable habitats was not rejected (table 5).

4.11.5 Percentage of Substrate Particles ≥15 cm.

There were no percentages of the substrate containing particles ≥15 cm in either stream having calculated suitability values of 0; consequently, the transferability of habitat suitability criteria for this variable was based on the results of the hypothesis testing optimal versus marginal habitats.

Habitat suitability criteria for the percentage of substrate particles ≥15 cm were not transferable from the North Anna River to Craig Creek (T=0.37; P=0.2725) (table 5). Criteria were transferable from Craig Creek to the North Anna River (T =6.03; P=0.0057 table 5).

4.12 Transferability of Criteria Developed in Other Regions of the United States

4.12.1 Upper James River, Virginia (Leonard et al. 1986)

Depth habitat suitability criteria developed in the Upper James River for smallmouth bass 102-305 mm (figure 23) were transferable to both the North Anna River and Craig Creek. The null hypotheses for suitable versus unsuitable and optimal versus marginal habitats were rejected for each set of transferability tests; all P values were less than 0.0003 (tables 6 and 7).

Velocity suitability criteria for bass 102-305 mm (figure 23) were not transferable from the Upper James River to the North Anna River. The null hypotheses for both suitable versus unsuitable and optimal versus marginal habitats were not rejected (table 6). Conversely, criteria were transferable from the Upper James River to Craig Creek. Both null hypotheses were rejected, having P values less than 0.022 (table 7).

Depth habitat suitability criteria for smallmouth bass >305 mm (figure 24) were transferable to both the North Anna River and Craig Creek. The null hypotheses for suitable versus unsuitable and optimal versus marginal habitats were rejected for each set of transferability tests; all P values were less than 0.011 (tables 6 and 7).

The hypotheses testing the transferability of velocity habitat suitability criteria for smallmouth bass >305 mm (figure 24) to both the North Anna River and Craig Creek were inconclusive because of small sample sizes. Neither null hypothesis was rejected for either test from the Upper James River to the North Anna River (both P>0.16) (table 6) and to Craig Creek, the null hypothesis for optimal versus marginal was not rejected (P>0.05) (table 7).

4.12.2 Snake, Zumbro, and Yellow Medicine Rivers, Minnesota
(Aadland et al. 1989)

Depth habitat suitability criteria developed for smallmouth bass 100-189 mm in Minnesota (figure 23) were transferable to the North Anna River. The null hypothesis for optimal versus marginal habitat was rejected (T=15.66 p<0.0001), and no fish in the North Anna River used unsuitable depths as described by Minnesota criteria (table 6). Minnesota criteria for fish 100-189 mm were not transferable to Craig Creek; no fish used unsuitable depths as described by Minnesota criteria, but the null hypotheses testing optimal versus marginal depths was not rejected (T=1.94; P=0.0821) (table 7).

There were no unsuitable velocities (suitability value=0), as defined by Aadland et al. (1989) criteria (figure 23), available to fish 100-189 mm in either the North Anna River or Craig Creek. Therefore, the transferability of Minnesota criteria to each stream was based on the results of the hypotheses testing optimal versus marginal habitats. Velocity criteria were not transferable to the North Anna River (T=2.20; P=0.0689) (table 6), but were transferable to Craig Creek (T=22.2 P<0.0001) (table 7).

Depth suitability criteria for smallmouth bass >189 mm (figure 24) were transferable to the North Anna River. The null hypothesis testing optimal versus marginal habitats was rejected (T=20.06; P<0.0001), and no fish used unsuitable depths as described by Minnesota criteria (table 6). Likewise, depth criteria for large fish were transferable to Craig Creek because no fish used unsuitable habitat, and the null hypothesis testing optimal versus marginal depths was rejected (T=82.32; P<0.0001) (table 7).

As with the smaller size category of fish, there were no unsuitable velocities, as defined by criteria of Aadland et al. (1989) (figure 24), available to smallmouth >189 mm in either the North Anna River or Craig Creek, so the transferability of Minnesota criteria to each stream was based on the results of the hypotheses testing optimal versus marginal habitats. Velocity criteria were not transferable to either the North Anna River (T=0.22 P=0.3681) (table 6) or to Craig Creek (T=2.40 P=0.0609) (table 7).

4.12.3 Huron River, Michigan (Monahan 1991)

Depth habitat suitability criteria developed for smallmouth bass 120-190 mm (figure 23) were not transferable from the Huron River to the North Anna River (T=0.58; P=0.2209) (table 6) but were transferable to Craig Creek (T=13.19; P=0.0002) (table 7). Depth suitability criteria for fish >200 mm (figure 24) were transferable to both the North Anna River (T=4.76; P=0.0196) (table 6) and to Craig Creek (T=22.11; P<0.0001) (table 7).

Velocity habitat suitability criteria for the smaller size category of fish (figure 23) were not transferable to either the North Anna River (T=1.10; P=0.1473) (table 6) or to Craig Creek (T=2.29; P=0.065) (table 7). Likewise, velocity criteria for the larger size category (figure 24) were not transferable to either the North Anna River (T=1.24; P=0.133) (table 6) or to Craig Creek (T=1.50; P=0.1102) (table 7).

4.13 Transferability of General Criteria

General sets of depth criteria developed for both size classes of smallmouth bass were transferable to both the North Anna River and Craig Creek (P for all <0.0001). Velocity criteria for small SMB also were transferable to both the North Anna River (P=0.0285) and Craig Creek (P<0.0001). Velocity criteria developed for large SMB were transferable to Craig Creek (P<0.0001), but not to the North Anna River (P=0.16).

5 Discussion

The results of this study indicate that suitable and unsuitable smallmouth bass habitats are consistent among sets of criteria, but problems with transferring criteria arise because of inconsistent definitions of optimal and marginal habitats. Additional factors, such as sample sizes used in criteria development, the effects of interacting variables, and biological interactions, can add problems when determining whether a set of suitability criteria can be used in a system other than where they were developed.

5.1 Sample Sizes

Bovee (1986) recommended using sample sizes of at least 150 to construct "a reasonably smooth frequency histogram." However, Herricks and Gantzer (1982, as cited by Monahan, 1991) rated criteria curves by Larimore and Garrels (1982) based on the number of initial observations, and considered curves developed from sample sizes of 30 or less to be "poor," 31-50 to be "fair," 51-75 "good," 75-100 "very good," and over 100 "excellent." Based on the sample sizes used to construct each set of suitability criteria used in this study, all criteria appear to be representative of habitat selection by smallmouth bass in their respective study stream, with the exception of criteria for adult smallmouth bass developed by Leonard et al. (1986), which was based on a sample size of 6. Probably the most accurate set of criteria (based on sample size) were those developed by Aadland et al. (1989) for smallmouth bass 100-189 mm (N=335). However, criteria for fish >189 mm by Aadland et al. and those developed by Monahan (1991) all had sample sizes over 100. Although sample sizes for each smallmouth bass size class in Craig Creek (small SMB N=59; large SMB N=60) and the North Anna River (small SMB N=93; large SMB=50) were relatively small, criteria curves ranged from fair to very good, as defined by Herricks and Gantzer.

Criteria used in the transferability tests had to be accurate to the point of completing the objective of this study to assess the transferability of criteria among streams. Results were based on whether habitats were suitable, unsuitable, optimal, or marginal. Bovee (1986) recommends sample sizes of 25-50 for the verification of suitability criteria to be applied to a stream of interest using the abbreviated convergence method. Sample sizes for all criteria (except those developed for adult smallmouth bass by Leonard et al., 1986) were above those recommended by Bovee for verification studies. The number of fish observations in the tails of frequency distributions were low, suggesting that suitability calculations in the upper and lower ends of criteria curves were somewhat inaccurate. However, because of the way unsuitable habitat was defined (i.e., unused habitat), suitability of these areas was accurate enough to differentiate between suitable and unsuitable habitats. For these reasons, it is believed that the sample sizes for criteria used in this study were adequate to complete the objectives.

5.2 Depth

With the exception of criteria developed in Virginia by Leonard et al. (1986), depth criteria for smaller size classes of smallmouth bass (juveniles and subadults >100 mm) did not transfer well between regions—four of the eight transferability tests (50%) failed. In each case, failure to transfer was due to the inability of criteria to describe optimal versus marginal habitats. Criteria did not transfer between the North Anna River and Craig Creek. Optimal depths in the North Anna River were shallower than those in Craig Creek, with no overlap occurring between the optimal ranges. Minnesota criteria transferred to the North Anna River, but not to Craig Creek. Although 58% of the smallmouth bass 100-189 mm in Craig Creek used what was described as optimal depths by Minnesota criteria, this was not proportionately greater than was available. Huron River criteria transferred to Craig Creek, but not to the North Anna River. Monahan (1991) used only use data to construct criteria curves. Bovee (1986) states that use criteria are greatly influenced by environmental availability, and the more similar the source and study streams, the higher the probability of transferable criteria. It may be that the Huron and North Anna rivers differed enough in stream morphologies that failure to include habitat availability in the development of criteria prevented it from being transferable.

Depth criteria for adult smallmouth bass were transferable to the North Anna River and Craig Creek in all cases. Optimal depths from all studies fell within a range of 70-173 cm. The selection of this range of intermediate depths is consistent with other studies on adult smallmouth bass (Probst et al., 1984; Rankin, 1986; Todd and Rabeni, 1989), suggesting that depth selection by adult smallmouth bass is similar among streams when adequate amounts of these depths are available. Reasons for this are unknown; however, we hypothesize that this depth range offers smallmouth bass the widest variety of foraging opportunities from surface to benthic and from riffle to pool.

5.3 Velocity

Velocity criteria developed for smaller size classes of smallmouth bass did not transfer well among regions. In only three of eight transferability tests—North Anna River to Craig Creek, Upper James River to Craig Creek, and Minnesota to Craig Creek—were the criteria transferable. Craig Creek criteria did not transfer to the North Anna River, even though the curves (figure 14) appear similar. Optimal velocities in Craig Creek shifted slightly toward faster water than those in the North Anna River (7-50 cm/s and 4-45 cm/s, respectively). The difference in the lower ends of the optimal ranges may be the reason Craig Creek criteria was not transferable to the North Anna River. The 3 cm/s shift to faster water in the Craig Creek criteria excluded 19% of the fish in the North Anna River (i.e., 19% of North Anna fish used velocities 4-7 cm/s, the difference in the lower ends of the criteria curves). Criteria developed by Leonard et al. (1986) were not transferable to the North Anna River; however, only one fish in the North Anna River used what was described as unsuitable habitat, so the failure of criteria to transfer was probably due to the inability of criteria to describe optimal versus marginal habitat rather than a failure to describe suitable versus unsuitable. Huron River criteria were not transferable to either the North Anna River or Craig Creek. Only 24% of the fish in the North Anna River and 22% of the fish in Craig Creek used what was described as optimal velocities by Monahan's criteria (1991), which was not significantly greater than what was available.

Likewise, velocity criteria for larger fish did not transfer well among regions. In only one of eight tests on larger fish (North Anna River to Craig Creek) were the criteria transferable. In all seven of the tests resulting in nontransferability, failure to describe optimal versus marginal velocities was the basis for criteria not being transferable. The test of transferability from the Upper James River to the North Anna River also resulted in failure to describe suitable versus unsuitable habitat, but only one fish was found using what was described as unsuitable habitat. The failure of criteria to transfer was undoubtedly due to the failure of criteria to describe optimal versus marginal habitat, rather than a failure to describe suitable versus unsuitable.

Failure to describe suitable versus unsuitable habitat in a transferability assessment indicates that criteria are flawed. However, failure of criteria to transfer as a result of the test for optimal versus marginal habitat alone indicates that the optimal range is positioned incorrectly—too narrow or too broad (Thomas and Bovee, in review). When transferability tests on depth and velocity failed, it was because of the inability to describe optimal versus marginal habitat. The ability to transfer depth and velocity criteria for small size classes from other regions to the North Anna River and Craig Creek was poor, suggesting real differences in habitat selection between regions. For larger size classes, transferability of depth criteria was good, but transferability of velocity criteria was poor. That optimal velocity ranges from criteria curves used in this study differ substantially (figures 23 and 24) is inconsistent with other field studies that indicate smallmouth bass select for similar ranges of relatively slow velocities. Probst et al. (1984) reported that smallmouth bass >100 mm selected velocities less than 15 cm/s, and fish size was negatively correlated with velocity. Similarly, Rankin (1986) found that smallmouth bass >40 mm selected velocities from 0-15 cm/s in 17 of 18 sample stations. Todd and Rabeni (1989) found adult smallmouth bass to select velocities less than 20 cm/s, while Orth et al. (1981) found adults to select even slower velocities (<10 cm/s). In a laboratory study, Sechnick et al. (1986) reported both juvenile (140-160 mm) and adult (240-260 mm) smallmouth bass preferred velocities less than 10 cm/s. Although the maximum velocities selected in these studies differed slightly, all agree in that smallmouth bass select velocities slower than 20 cm/s. The ability to transfer adult smallmouth bass depth criteria and agreement between some studies on optimal velocity ranges suggests that both depth and velocity are considered when smallmouth bass select habitat. The combination of these two variables may be important in defining what is optimal habitat.

5.4 Interactive Effects of Depth and Velocity

The validity of assuming that habitat variables act independently on habitat selection by fish has been questioned (Orth and Maughan, 1982). Interactive effects of depth and velocity were not apparent in this study. However, Orth and Maughan found that the interactive effects among depth, velocity, and substrate helped to explain differences in central stoneroller, *Campostoma anomalum*, microdistributions. Therefore, there is reason to believe that interactive effects of variables influence habitat selection by fish. These interactive effects may explain the lack of transferability between streams in two ways. First, the optimal depth range may depend on velocity, and vice versa. Depths (or velocities) that otherwise would be optimal to smallmouth bass may not be because the velocities (or depths) in the area are unsatisfactory. Second, the amount of optimal habitat available in streams for which criteria transferability are being tested may be limited due to this interaction. To demonstrate this, scatter plots of depths and associated velocities available in the North Anna River and Craig Creek were compared with optimal ranges, as described by criteria from other studies. Recalling that neither depth nor velocity criteria developed for fish 100-199 mm in Craig Creek were transferable to the North Anna River, consider the optimal region for Craig Creek fish overlaid on the North Anna River availability plot (figure 25). Looking at depth and velocity independently, there appear to be adequate amounts of optimal habitats for each variable in the North Anna River. However, looking at them simultaneously, only 7 of 869 availability observations fell within the optimal region. If depth and velocity are interactively determining optimal habitat selection, practically no optimal habitat, as described by Craig Creek criteria, is available to fish in the North Anna River. Similarly, recall that depth criteria developed for fish >189 mm in Michigan were transferable to Craig Creek, but velocity criteria were not. Looking at the depth versus velocity availability plot (figure 25), a large portion of the optimal region (as described by Monahan, 1991) is not available in Craig Creek.

Additional information on habitat use by smallmouth bass may be needed to develop velocity suitability criteria. Combining data from the North Anna River and Craig Creek, 254 out of 255 smallmouth bass were seen within 0.5 m of the stream bottom. Other studies also have reported smallmouth bass being positioned close to the substrate (Probst et al., 1984; Rankin, 1986). Mean column velocities were taken at 0.6 of the total depth, which, as seen in figure 26, was near the maximum height at which fish were found in the water column. Because velocities at fish positions in the water column (i.e., nose velocities) were significantly lower than the mean water column velocities used to construct velocity suitability criteria, criteria developed from mean column velocities may not reflect the true velocities selected by fish. Rankin (1986) used bottom velocities to calculate preference because smallmouth bass were positioned within 15 cm of the stream bottom, where maximum velocities were slower than those "higher in the water column." Rankin (1986) reported that smallmouth bass of all sizes typically selected velocities below 15 cm/s, similar to the nose velocities used by smallmouth bass in the North Anna River and Craig Creek (table 4). The differences between frequency distributions of mean column velocities used and nose velocities used (figure 15) further demonstrate that mean water column velocity does not represent the velocity used by an individual smallmouth bass. Velocity criteria cannot be expected to be accurate if the data used to construct the criteria do not represent the habitat used. Differences between habitat suitability criteria developed from mean column velocities and criteria developed from nose velocities could not be examined because availability data that would allow the development of nose velocity criteria was not collected. Shirvell (1989) calculated usable spawning habitat area for chinook salmon using habitat suitability criteria based on both mean column velocity and bottom velocities (15 cm from stream bottom), and found that using bottom velocities predicted twice as many actual fish locations than were predicted when mean column velocity was used. The amount of usable area was similar between the two calculations, but areas that were actually used by chinook salmon were determined to be unusable when mean column velocity criteria were used. To more accurately describe velocity selection by smallmouth bass, velocity measurements should be taken lower in the water column, where velocities are more representative of those that fish are actually using. If nose velocities (or bottom velocities) are ignored in IFIM assessments, calculations of weighted usable area may be inaccurate because of incomplete velocity information.

5.5 General Depth and Velocity Criteria

The general criteria developed for depth and velocity from the five sets of criteria used in this study transferred well to both the North Anna River and Craig Creek. Criteria transferred in all cases, except velocity criteria for adult fish to the North Anna River. The improved success of transferring general criteria, as opposed to site-specific criteria, suggests that combining suitability criteria from multiple sources may help in the search for a set of generally applicable criteria. Combining criteria may help to avoid problems associated with the use of small sample sizes to construct criteria (criteria will be based on a larger sample of fish). It also may help to more accurately describe the suitability of the upper and lower ranges of habitat variables that are often scarce or unavailable in the streams where site-specific criteria are developed. Having one set of generally applicable habitat suitability criteria is desirable, and future studies on transferability should include general criteria.

5.6 Cover

Cover criteria for smallmouth bass (100-199 mm) were transferable from the North Anna River to Craig Creek, but not from Craig Creek to the North Anna River. Rock ledges were optimal in both streams; however, fish in Craig Creek also found velocity shelters and overhead cover (out of the water) to be optimal. That overhead cover was found optimal may be erroneous because only three fish (5%) were found using it, but because it was only 2% of the available cover types, it was calculated as being in the optimal range.

Cover criteria for bass ≥200 mm were transferable from the North Anna River to Craig Creek, but not from Craig Creek to the North Anna River.

Velocity shelters were found to be optimal cover in both streams, while rock ledges were optimal in the North Anna River, but not Craig Creek.

Few fish of either size class in either stream used aquatic vegetation, woody debris, or overhead cover. Little use of woody debris differs from Probst et al. (1984), who reported that the distribution of smallmouth bass in two Missouri streams was strongly related to rootwads, log complexes, and suspended logs. Todd and Rabeni (1989) also reported that fish >240 mm selected for logjams in summer months. However, woody debris consisted of only 5% of the available cover types in Craig Creek and 8% of the available cover types in the North Anna River, so differences with other studies in the importance of woody debris may be explained by availability.

Studies on smallmouth bass consistently report the presence of cover as an important aspect of smallmouth bass streams. However, the type of cover that fish select for and comparisons of optimal cover types between studies become unclear because cover definitions vary widely. Cover definitions range from the general (e.g., instream object), to the specific (e.g., boulder, velocity shelter), to the nebulous (edge). The classification of cover types in the development of habitat suitability criteria is an area that needs attention. During this study, fish often were seen near objects (within 1 m), but rarely were seen actually using them. Yet there was an association with objects that could serve as velocity shelters. Objects such as logs and rock ledges also may function as velocity shelters, but, by definition, are placed in other categories. It is difficult to know exactly why fish are using a cover object, so the development of cover categories based on this assumed knowledge may be biasing results. The development of standardized definitions of cover types is needed to facilitate transferability assessments of cover suitability criteria.

5.7 Substrate

Substrate heterogeneity criteria were not transferable between the North Anna River and Craig Creek for either size class of smallmouth bass. Heterogeneity values were not used in a higher proportion than was available by fish of either size class in Craig Creek, or by large fish in the North Anna River (figures 17 and 18), which indicates that complexity was not a factor in habitat selection. This agrees with Bain et al. (1988), who found substrate heterogeneity was not an important variable in determining the presence or absence of smallmouth bass. Therefore, it is recommended that substrate heterogeneity not be used as a variable when constructing suitability criteria for smallmouth bass.

Previous studies indicate substrates dominated by sand are least selected for (or avoided), and substrates dominated by larger particle sizes (cobble to boulder) are most highly selected for by both juvenile and adult smallmouth bass (Aadland et al., 1989; Leonard et al., 1986; Paragamian, 1981; Todd and Rabeni, 1989; Rankin, 1986; Munther, 1970). The lower limit of selected particle sizes seems to vary between studies from sand (Aadland et al., 1989) to large cobble (Leonard et al., 1986) for juvenile bass, and from sand (Aadland et al., 1989) to boulder (Orth et al., 1981) for adult bass. Small SMB in this study showed no selectivity for substrate particle size; however, large SMB in both streams selected for areas with relatively high percentages of larger particles (≥15 cm), and against areas with no large particles (figure 21). The ability to transfer criteria from Craig Creek to the North Anna River, and consistent reporting of smallmouth bass selecting for large substrate particles warrants investigation of a variable similar to the percentage of substrate particles ≥15 cm. Additionally, the amount of effort needed for data collection would be reduced compared to other quantitative methods because only two particle size categories are used (< and ≥15 cm).

Invertebrate numbers in streams increase as particle sizes increase (deMarch, 1976). The selection of substrates by smallmouth bass may be influenced by the distribution of benthic prey species (Munther, 1970; Rankin, 1986). In a laboratory study by Sechnick et al. (1986), smallmouth bass exhibited no preference for substrate types, but a lack of prey in the experiment may have been responsible. It is well known that crayfish are a preferred prey of smallmouth bass, and smallmouth bass distributions have been related to crayfish densities (Munther, 1970). Crayfish were seen in Craig Creek, but were not seen in the North Anna River, which may help to explain higher selectivity for complex substrates and larger particle sizes by fish in Craig Creek. This leads to an important question: Are smallmouth bass selecting substrates based on particle sizes, areas that hold benthic prey species, or a combination of both? To determine which aspects of the stream substrate are important in habitat selection, this basic question must be answered with studies that manipulate substrate particle sizes and prey densities. Results from these studies have implications on the worth of suitability criteria based on substrate particle sizes and the need for additional criteria based on prey availability.

5.8 Biological Factors

Practitioners often assume that physical factors alone can be used to predict habitat quality. Biological processes, such as predation (Werner et al., 1983; Mittlebach, 1981), food availability (Wilzbach, 1985; Munther, 1970), and intra- and interspecific competition (Mittlebach, 1981; Fausch and White, 1981) have been shown to affect habitat selection in fish. Fish species compositions, as well as prey species, vary from region to region, stream to stream, and year to year. Thus, the processes that affect habitat selection can be expected to vary also. Because of this, habitat suitability criteria may vary from region to region. Currently, it is not known whether inconsistencies observed were because of biological factors or methodological constraints (e.g., sample size, river morphology).

6 Summary and Conclusions

The ability to transfer site-specific depth and velocity criteria developed for smaller size classes of smallmouth bass to the North Anna River and Craig Creek was inconsistent. Depth criteria transferred in only four of eight attempts; velocity transferred in only three of eight attempts.

Site-specific depth criteria developed for larger size classes of smallmouth bass transferred well to (and between) the North Anna River and Craig Creek; all tests of transferability were positive. Optimum depths from all studies fell between 70 and 173 cm. Site-specific velocity criteria for larger fish, however, did not transfer well. Only one test of transferability, from the North Anna River to Craig Creek, was positive; all others failed.

Cover criteria for each size class of smallmouth bass were not transferable from Craig Creek to the North Anna River, but were transferable from the North Anna River to Craig Creek. Cover definitions varied between this and other studies; standardized definitions of cover types are recommended. Suitability criteria developed for substrate heterogeneity were not transferable between the North Anna River and Craig Creek for either size class of fish, and are not recommended as a variable for smallmouth bass habitat suitability criteria. Criteria developed for the percentage of substrate particles ≥15 cm were not transferable from the North Anna River to Craig Creek, but were transferable from Craig Creek to the North Anna River. Smallmouth bass ≥200 mm selected areas dominated by substrate particles ≥15 cm. The percentage of substrate particles ≥15 cm should be investigated for future use as a habitat suitability variable.

Two hundred fifty-four out of 255 fish were observed within 50 cm of the stream bottom, and nose velocities were significantly less than mean column velocities. Taking velocity measurements lower in the water column (approximately 16 cm above the stream bottom for smaller fish, and 20 cm for larger fish) (table 4), where velocities may be more representative of the habitat smallmouth bass are using, may help to more accurately describe smallmouth bass velocity preferences. A variety of factors, both biotic and abiotic, can cause habitat selection within a species to be unique to each stream system; therefore, suitability criteria also may be unique to each system. Assumed transferability can cause inaccurate calculations of weighted usable area, leading to inappropriate flow recommendations that potentially can harm an existing population of smallmouth bass. The lack of consistent transferability of habitat suitability criteria in this study shows that site-specific criteria do not have general applicability across different regions.

General depth and velocity criteria transferred well to the North Anna River and Craig Creek for both the larger and smaller size classes of smallmouth bass. The improved success of transferability warrants investigation of developing general criteria for smallmouth bass. However, until this is done, the development of site-specific criteria when applying instream flow techniques to a stream of interest is warranted.

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Tables

Table 1.
Characteristics used to define ecoregions associated with study streams. (Omernik, 1987)

Characteristic	Stream: North Anna River	Stream: Craig Creek
Ecoregion	South Eastern Plains	Central Appalachian Ridge & Valley
Land Form Surface	smooth to irregular plains	open hills to open low mountains, low mountains
Potential Natural Vegetation	oak/hickory/pine, southern mixed forest (beech, sweetgum, magnolia, pine, oak)	Appalachian oak
Land Use	mosaic of cropland, pasture, woodland and forest, urban	mosaic of cropland pasture, woodland and forest, forested mountains with agricultural valley bottoms
Soils	ultisols	mesic inceptisols

Table 2.
Fish species present in Craig Creek (Raleigh et al., 1974) and the North Anna River (Robert Graham, Virginia Power, pers comm.). Species lists include fish comprising more than 80% of total fish collected. Species are listed in descending order of abundance.

Scientific Name	Common Name
Craig Creek	
1. *Luxilus cornutus*	Common shiner
2. *Cottus bairdi*	Mottled sculpin
3. *Nocomis leptocephalus*	Bluehead chub
4. *Lepomis auritus*	Redbreast sunfish
5. *Campostoma anomalum*	Stoneroller
6. *Nocomis raneyi*	Bull chub
7. *Percina crassa*	Piedmont darter
8. *Pimephales notatus*	Bluntnose minnow
9. *Moxostoma rhothoecum*	Torrent sucker
10. *Ambloplites rupestris*	Rock bass
11. *Notropis hudsonius*	Spottail shiner
12. *Moxostoma cervinum*	Black jumprock
North Anna River	
1. *Notropis procne*	Swallowtail shiner
2. *Cyprinella analostana*	Satinfin shiner
3. *Lepomis auritus*	Redbreast sunfish
4. *Notropis rubellus*	Rosyface shiner
5. *Notorus insignis*	Margined madtom
6. *Percina peltata*	Shield darter
7. *Anguilla rostrata*	American eel
8. *Lythrurus ardens*	Rosefin shiner

Table 3.
Numbers and densities (#/ha) of smallmouth bass (SMB) ≥100 mm by sample site on the North Anna River and Craig Creek.

	Site Number	Area (ha.)	Number of SMB	Density (SMB/ha.)
North Anna River	1	0.475	7	14.7
	2	0.386	28	72.5
	3	0.441	9	20.4
	4	0.60	27	45
	5	0.283	10	35.3
	6	0.565	31	54.9
	7	0.78	19	24.4
	8	0.541	13	24
Total:			144	
Stream Density			35.4	
Craig Creek	1	0.483	36	74.5
	2	0.543	29	53.4
	3	0.444	13	29.3
	4	0.326	20	61.3
	5	0.353	21	59.5
Total:			119	
Stream Density			55.4	

Table 4.
Mean distances above the substrate, mean nose velocities, and results of paired T tests between mean column velocity and nose velocity for small (100-199 mm) and large (≥200 mm) size classes of smallmouth bass in the North Anna River and Craig Creek.

	North Anna River		Craig Creek	
	small	large	small	large
N	93	51	59	60
$\bar{x}$ fish distance above substrate (cm)	15	17	16	22
$\bar{x}$ nose velocity (cm/s)	10.6	9.3	9.3	5.8
(Standard error)	(0.96)	(1.439)	(1.178)	(0.583)
range	0-44	0-46	0-38	0-22
$\bar{x}$ difference (cm/s) (nose - $\bar{x}$ column vel.)	-2.7	-2.2	-4.6	-3.2
(Standard Error)	(0.9096)	(0.712)	(0.8301)	(0.5696)
Paired T test (P value)	0.0037	0.0031	<0.0001	<0.0001

Table 5.
Results of 2x2 contingency tables testing transferability of habitat suitability criteria between the North Anna River (NA) and Craig Creek (CC).

Criteria Tested	Fish Length (mm)	Hypothesis Tested: Suitable vs Unsuit.	Optimal vs Marginal
		Depth	
NA to CC	100-199	T=4.25 p=0.02	T=0.006 p=0.47
	≥200	***	T=51.03 p=0.0001
CC to NA	100-199	***	****
	≥200	T=21.7 p<0.0001	T=16.47 p<0.0001
		Velocity	
NA to CC	100-199	***	T=14.68 p<0.0001
	≥200	T=11.17 p=0.0004	T=21.09 p<0.0001
CC to NA	100-199	***	T=1.72 p=0.095
	≥200	***	T<0.0001 p=0.497
		Cover	
NA to CC	100-199	**	T=3.53 p=0.0302
	≥200	***	T=0.926 p=0.1679
CC to NA	100-199	**	T=0.043 p=0.2114
	≥200	T=47.45 p<0.0001	T=3.88 p=0.0244
		Substrate Heterogeneity	
NA to CC	100-199	**	T=0.223 p=0.318
	≥200	****	T=2.60 p=0.053
CC to NA	100-199	****	T=2.043 p=0.7645
	≥200	**	T=0.541 p=0.262
		Percentage of Substrate Particles ≥15cm	
NA to CC	≥200	*	T=0.37 p=0.2725
CC to NA	≥200	*	T=6.03 p=0.0057

* = no unsuitable habitat given in source criteria
** = no unsuitable habitat, as defined by source criteria, available
*** = no fish used unsuitable habitat as defined by source criteria
****= available in a higher proportion than used

Table 6.
Results of 2x2 contingency tables testing transferability of habitat suitability criteria from other studies to the North Anna River.

Criteria Source	Fish Length (mm)	Hypothesis Tested: Suitable vs Unsuit.	Hypothesis Tested: Optimal vs Marginal
		Depth	
Leonard et al. (1986)	102-305	T=15.86 p<0.0001	T=20.93 p<0.0001
	>305	T=7.17 p=0.0037	T=11.82 p=0.0003
Aadland et al. (1989)	100-189	***	T=15.66 p<0.0001
	>189	***	T=20.06 p<0.0001
Monahan (1991)	120-194	*	T=0.58 p=0.2209
	>194	*	T=4.76 p=0.0196
		Velocity	
Leonard et al. (1986)	102-305	T=0.72 p=0.1975	T=2.50 p=0.0571
	>305	T=0.02 p=0.4497	T=0.93 p=0.1675
Aadland et al. (1989)	100-189	**	T=2.20 p=0.0689
	>189	**	T=0.22 p=0.3681
Monahan (1991)	120-194	*	T=1.10 p=0.1473
	>194	*	T=1.24 p=0.133

* = no unsuitable habitat given in source criteria

** = no unsuitable habitat, as defined by source criteria, available or used in the North Anna River

*** = no fish used unsuitable habitat as defined by source criteria

Table 7.
Results of 2x2 contingency tables testing transferability of habitat suitability criteria from other studies to Craig Creek.

Criteria Source	Fish Length (mm)	Hypothesis Tested: Suitable vs Unsuit.	Hypothesis Tested: Optimal vs Marginal
		Depth	
Leonard et al. (1986)	102-305	T=11.88 p=0.0003	T=51.99 p<0.0001
	>305	T=5.31 p=0.0106	T=12.83 p=0.0002
Aadland et al. (1989)	100-189	***	T=1.94 p=0.0821
	>189	***	T=82.32 p<0.0001
Monahan (1991)	120-194	*	T=13.19 p=0.0002
	>194	*	T=22.11 P<0.0001
		Velocity	
Leonard et al. (1986)	102-305	T=4.10 p=0.0215	T=22.83 p<0.0001
	>305	***	T=2.70 p=0.0501
Aadland et al. (1989)	100-189	**	T=22.20 p<0.0001
	>189	**	T=2.40 p=0.0609
Monahan (1991)	120-194	*	T=2.29 p=0.0650
	>194	*	T=1.50 p=0.1102

* = no unsuitable habitat given in source criteria
** = no unsuitable habitat, as defined by source criteria, available or used in the North Anna River
*** = no fish used unsuitable habitat as defined by source criteria

Figures

Figure 1.
Location of sample sites on the North Anna River.

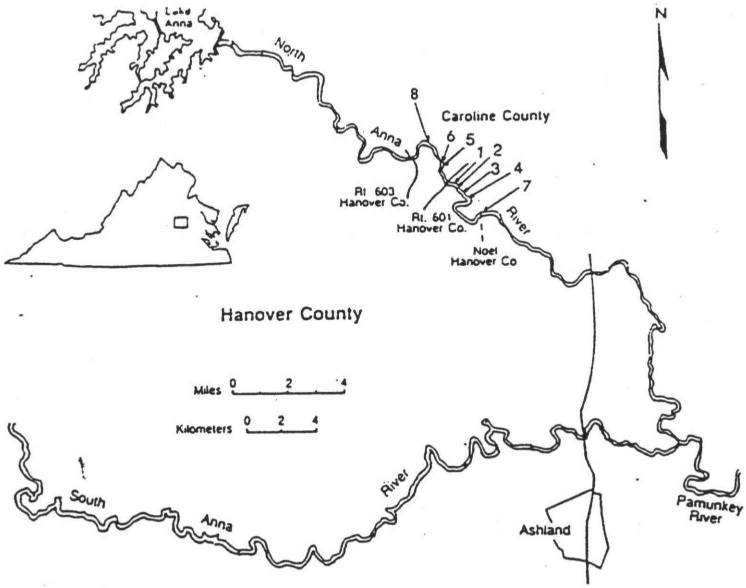


Figure 2.
Location of sample sites on Craig Creek.

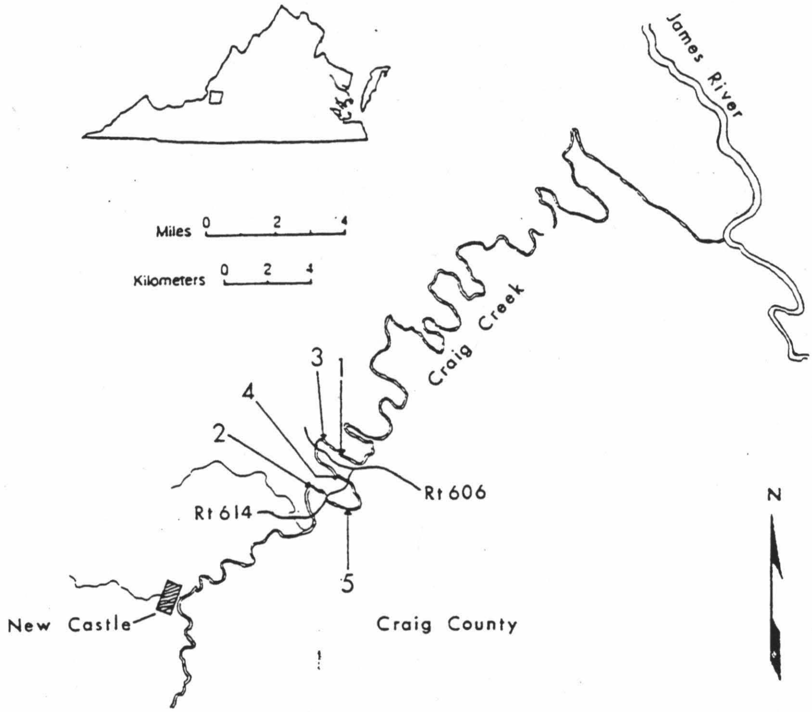


Figure 3.
Length frequency distributions of smallmouth bass in the North Anna River (NA: N = 144, $\bar{x}$ = 197 mm) and Craig Creek (CC: N = 119, $\bar{x}$ = 217 mm). Numbers on the X axis indicate midpoints of length interval.

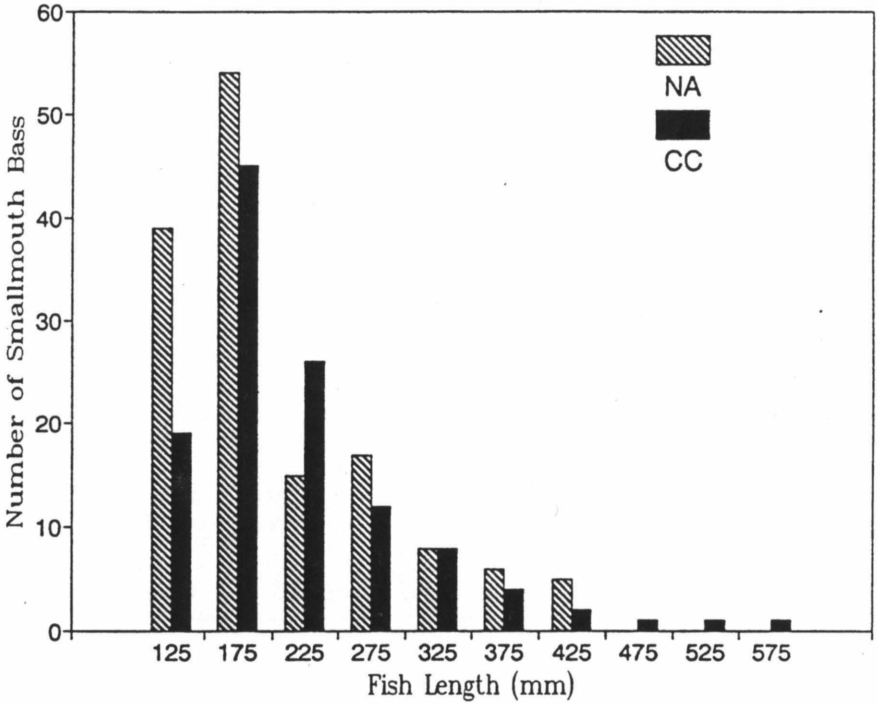


Figure 4.
Temperature profiles of the North Anna River and Craig Creek during sampling period (May 14-August 12, 1991).

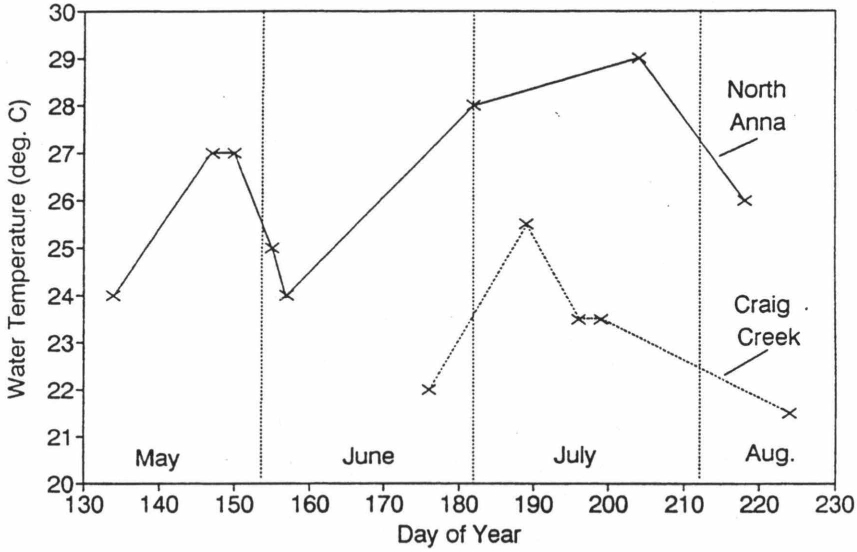
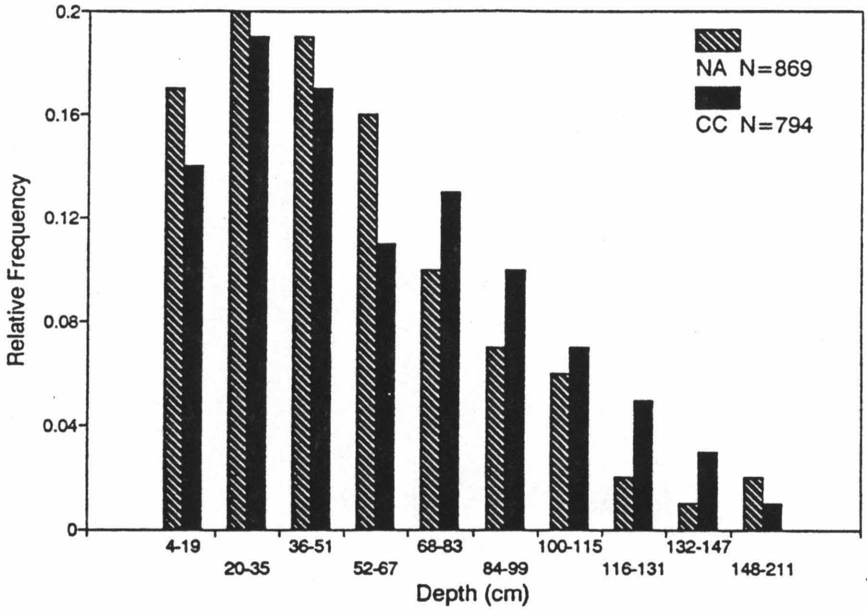


Figure 5.
Relative frequency distributions of depths (top) and velocities (bottom) available in the North Anna River (NA) and Craig Creek (CC).



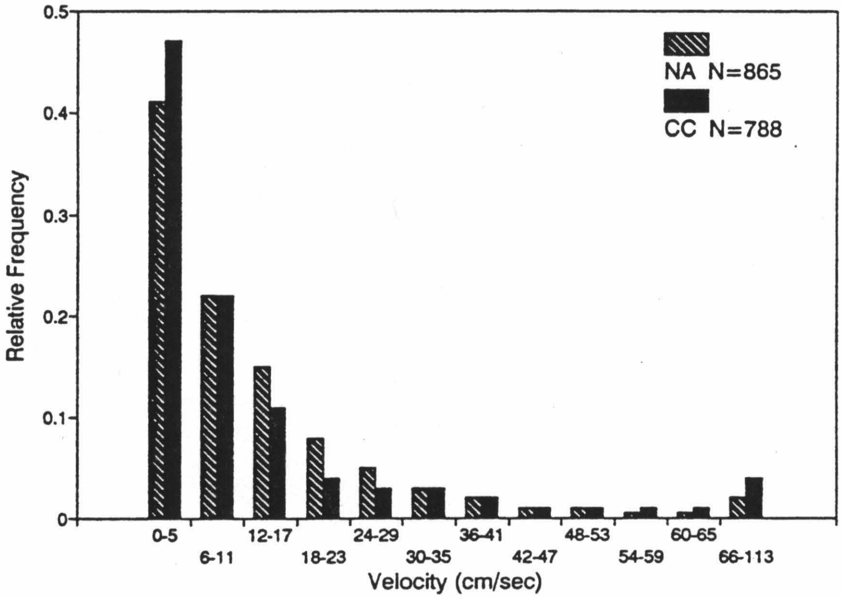


Figure 6.
Relative frequency distributions of cover types available in the North Anna River (NA N=860) and Craig Creek (CC N=787).

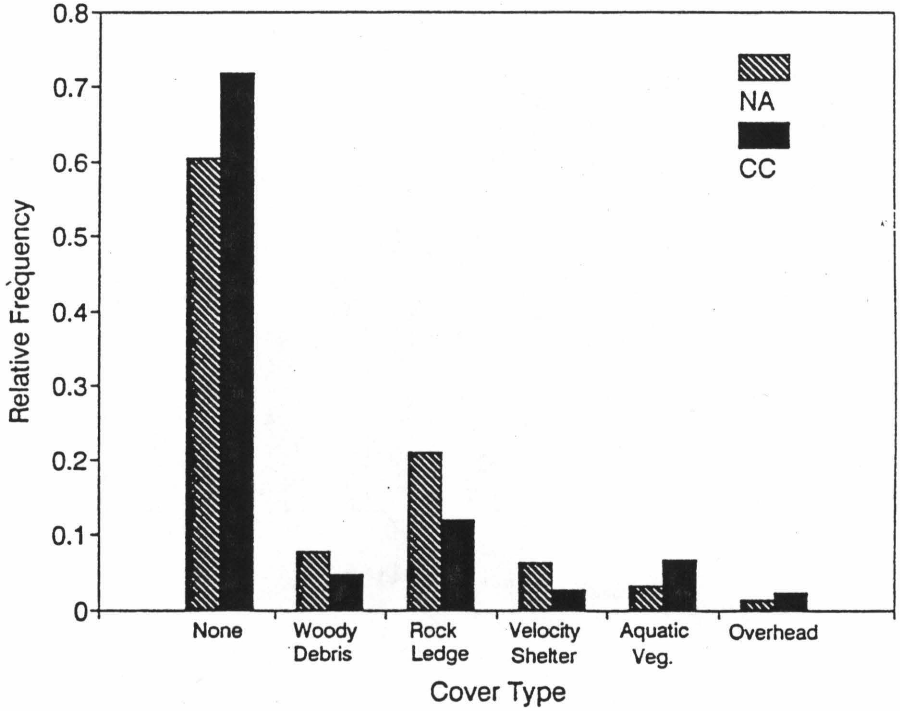
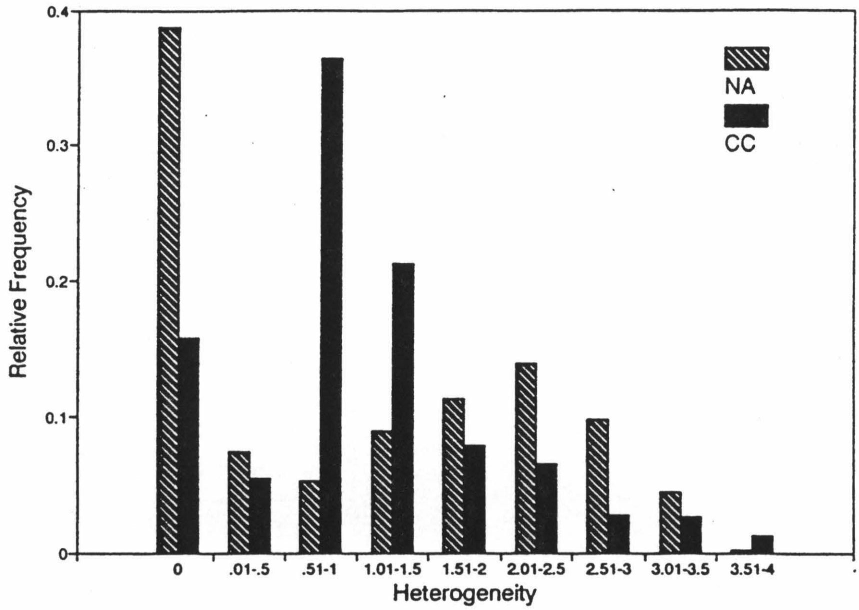


Figure 7.
Relative frequency distributions of substrate heterogeneities (top) and percentages of substrate particles ≥15 cm (bottom) available in the North Anna River (NA N=872) and Craig Creek (CC N=799).



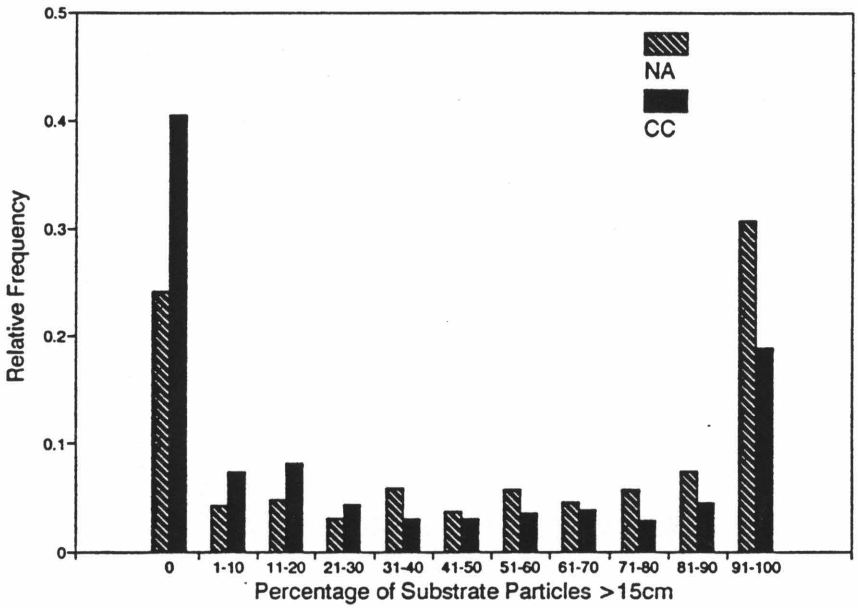


Figure 8.
Scatter plots of smallmouth bass length versus mean water column velocity used (top) and depth used (bottom) in the North Anna River (NA N=144) and Craig Creek (CC N=119).

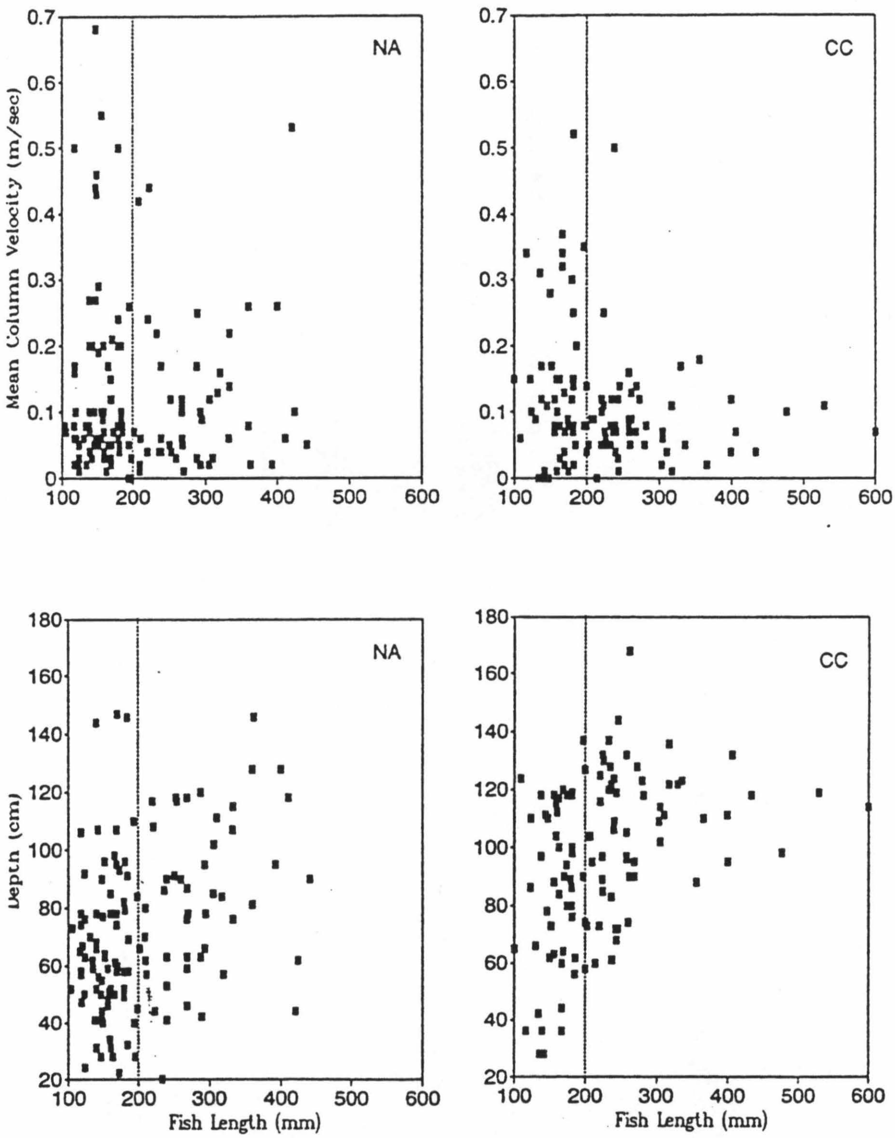


Figure 9.
Top: Relative frequency distributions of depths available versus depths used by smallmouth bass 100-199 mm in the North Anna River (left, use N=93 available N=869) and Craig Creek (right, use N=59 available N=794). Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass 100-199 mm in the North Anna River (left) and Craig Creek (right).

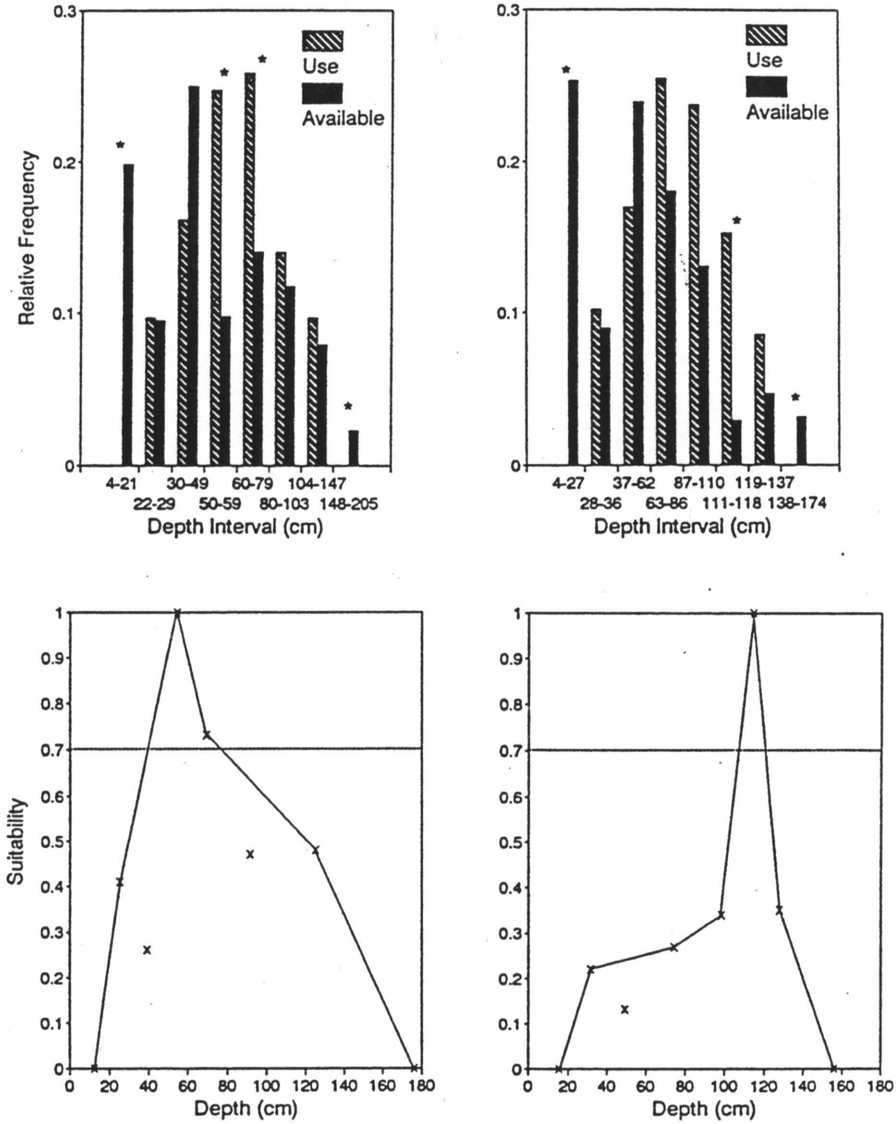


Figure 10.
Top: Relative frequency distributions of depths available versus depths used by smallmouth bass ≥200 mm in the North Anna River (left, use N=51 available N=869) and Craig Creek (right, use N=60 available N=794). Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass ≥200 mm in the North Anna River (left) and Craig Creek (right).

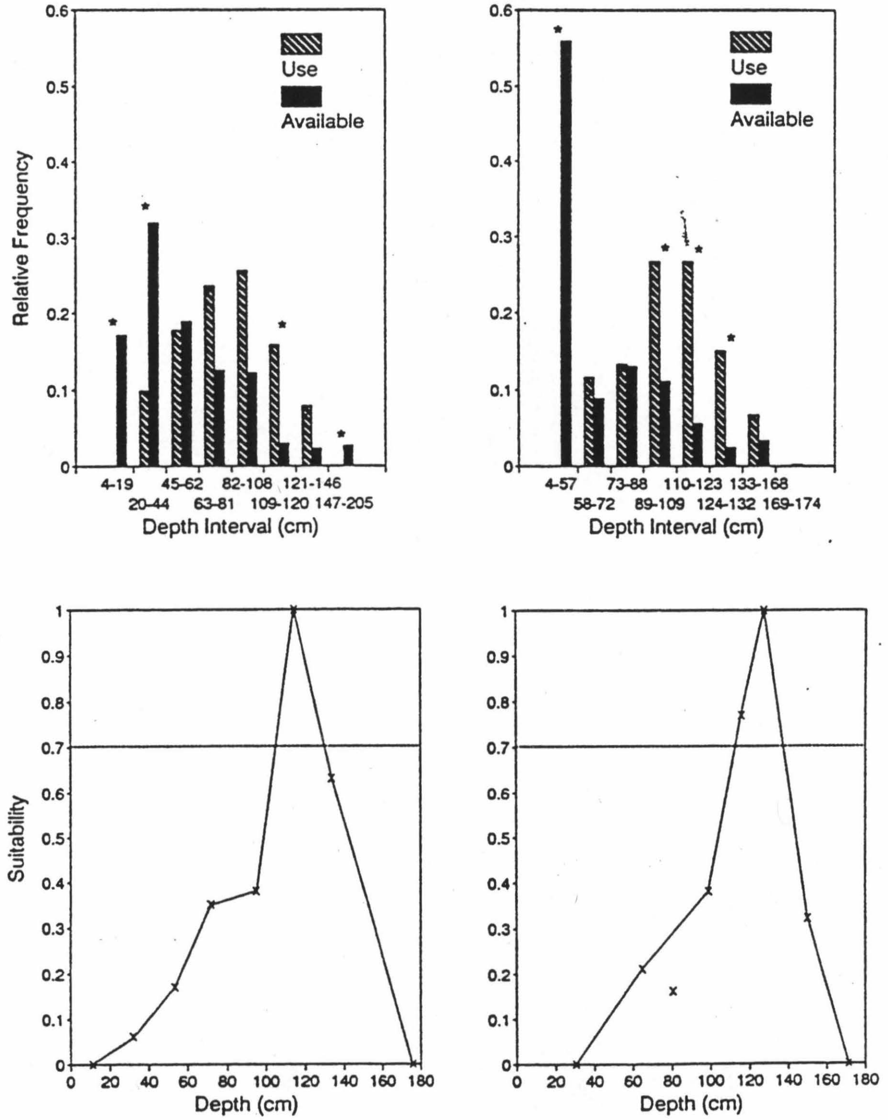


Figure 11.
Top: Relative frequency distributions of velocities available versus velocities used by smallmouth bass 100-199 mm in the North Anna River (left, use N=91 available N=865) and Craig Creek (right, use N=59 available N=788). Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass 100-199 mm in the North Anna River (left) and Craig Creek (right).

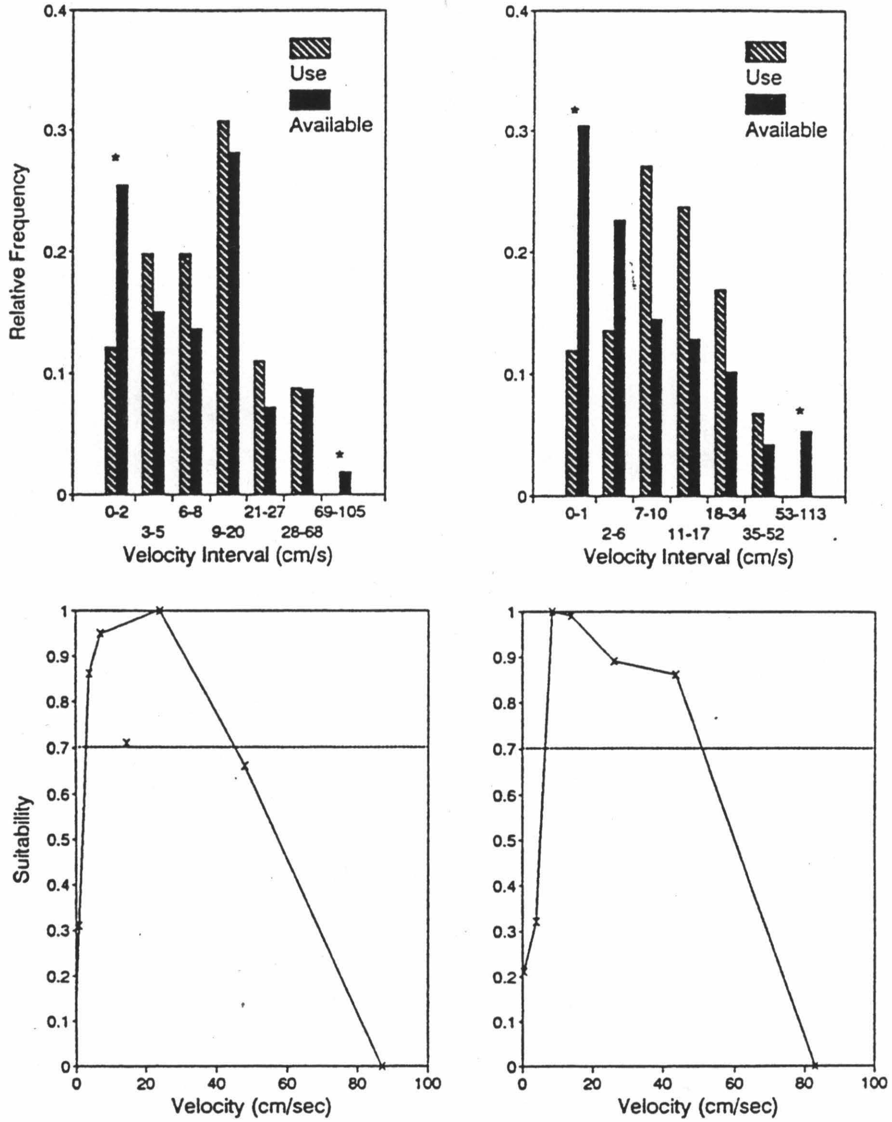


Figure 12.
Top: Relative frequency distributions of velocities available versus velocities used by smallmouth bass ≥200 mm in the North Anna River (left, use N=51 available N=865) and Craig Creek (right, use N=60 available N=788). Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass ≥200 mm in the North Anna River (left) and Craig Creek (right).

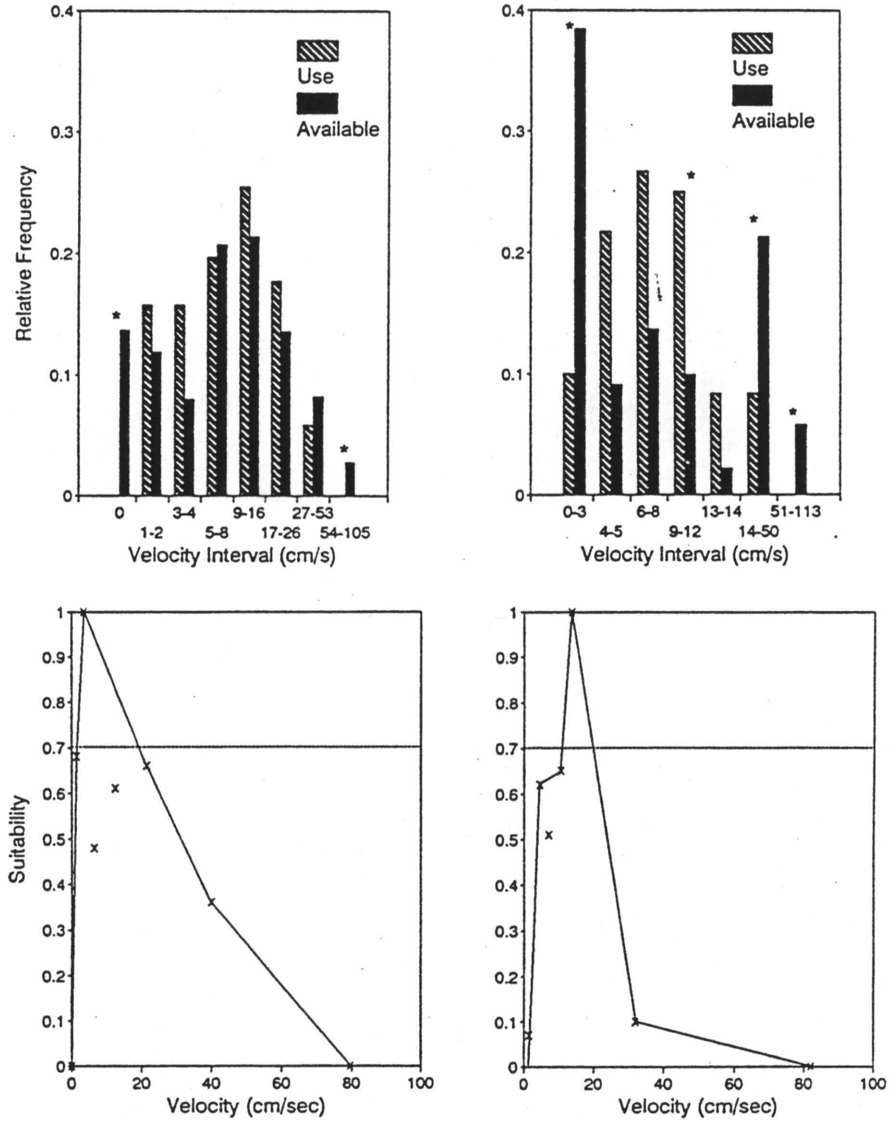
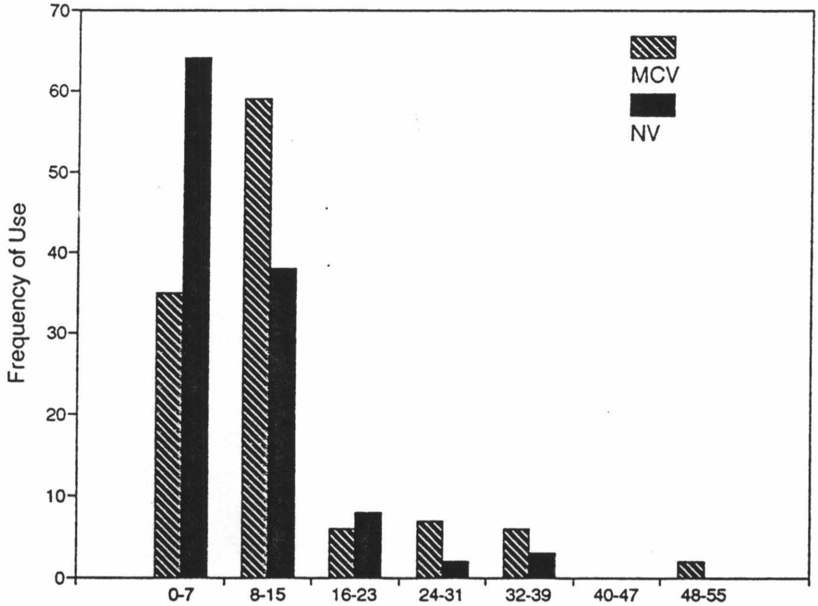


Figure 13.
Frequency distributions of nose velocities (NV) and mean column velocities (MCV) used by smallmouth bass in Craig Creek (top) and the North Anna River (bottom).



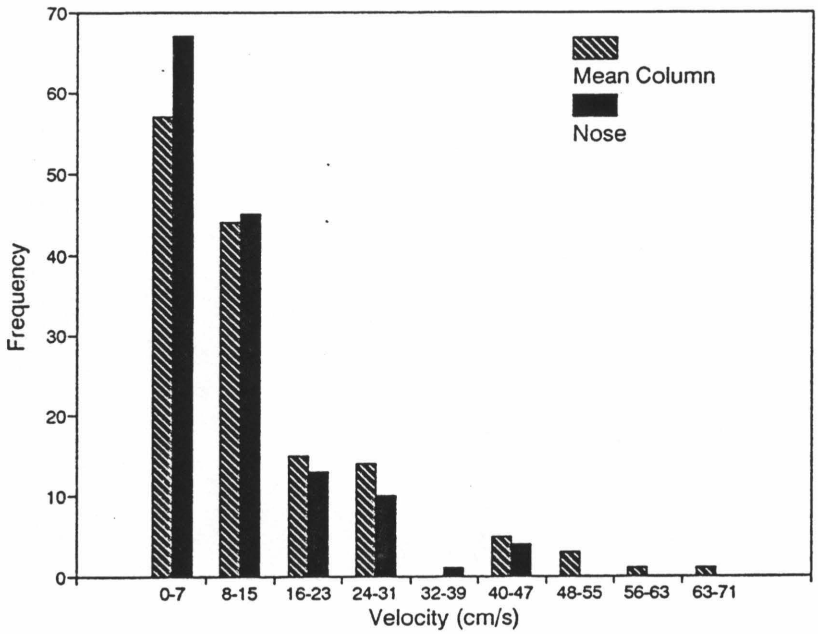


Figure 14.
Top: Suitability values calculated for four different combinations of depth and mean column velocity for smallmouth bass 100-199 mm in the North Anna River (right, N=93) and Craig Creek (left, N=59). Bottom: Suitability values calculated for four different combinations of depth and mean column velocity for smallmouth bass ≥200 mm in the North Anna River (right, N=51) and Craig Creek (left, N=60).

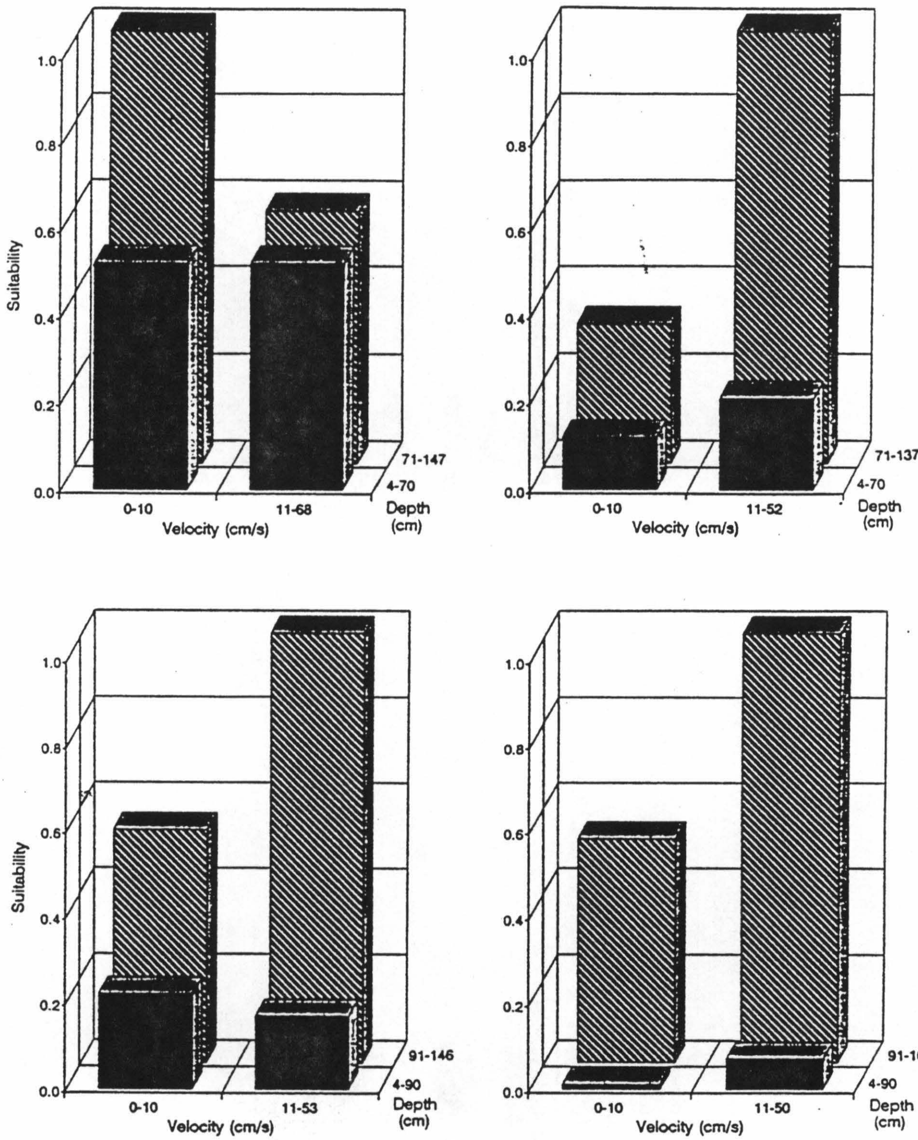


Figure 15.
Top: Relative frequency distributions of cover types available versus cover types used by smallmouth bass 100-199 mm in the North Anna River (left, use N=93 available N=860) and Craig Creek (right, use N=59 available N=787). Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass 100-199 mm in the North Anna River (left) and Craig Creek (right).

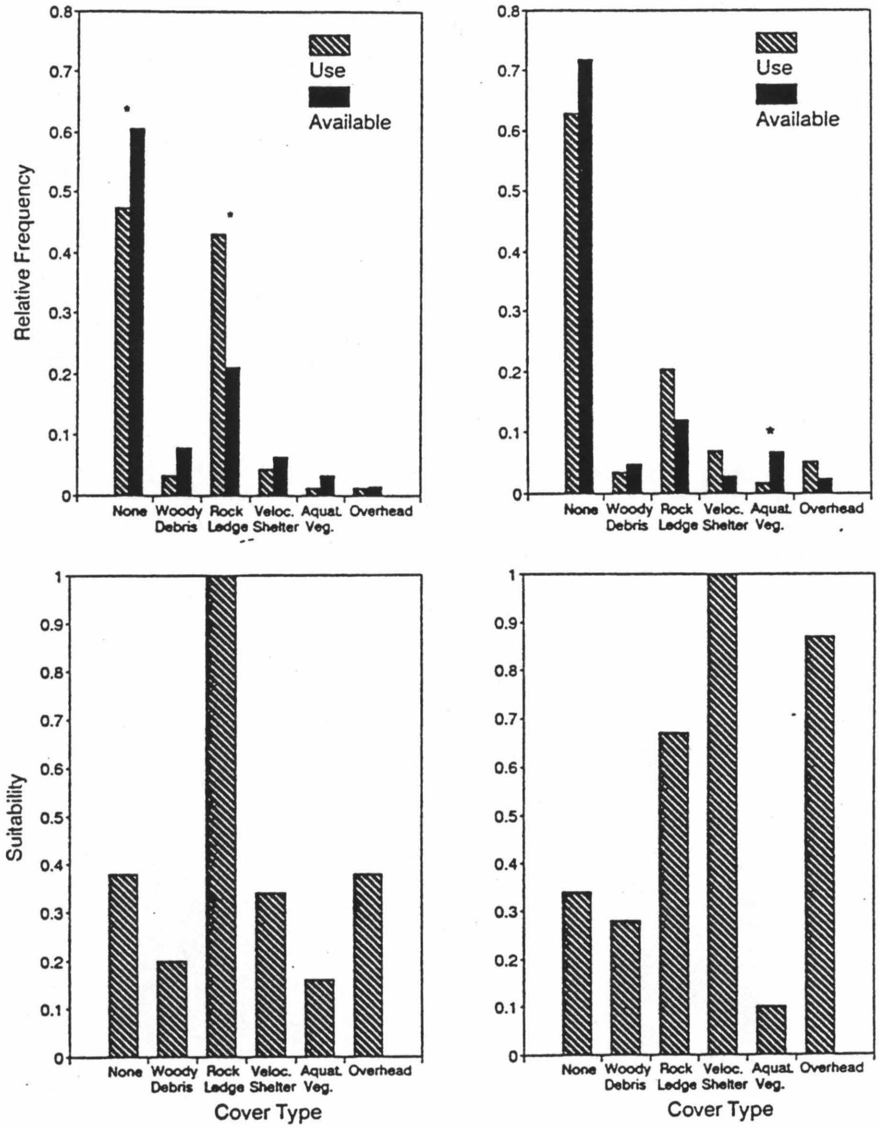


Figure 16.
Top: Relative frequency distributions of cover types available versus cover types used by smallmouth bass ≥200 mm in the North Anna River (left, use N=51 available N=860) and Craig Creek (right, use N=60 available N=787). Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass ≥200 mm in the North Anna River (left) and Craig Creek (right).

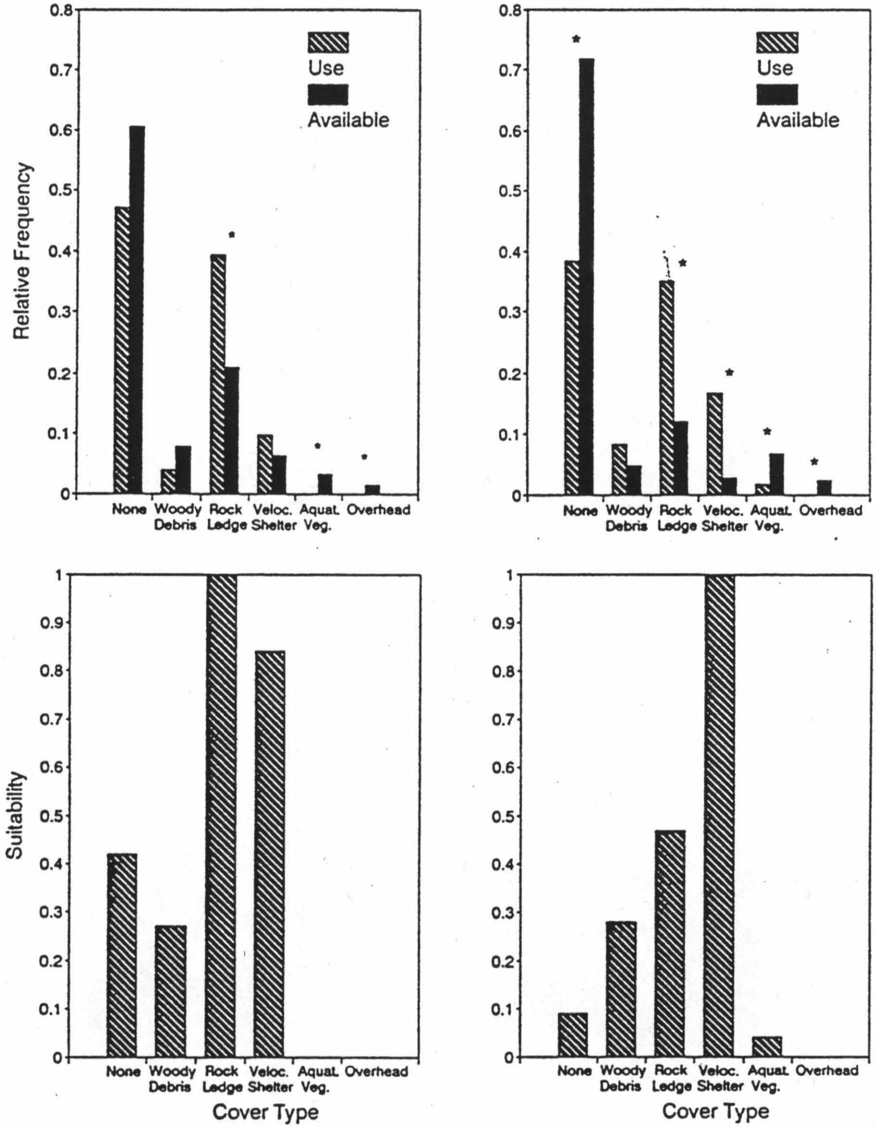


Figure 17.
Top: Relative frequency distributions of substrate heterogeneity levels available to and used by smallmouth bass 100-199 mm in the North Anna River (left, use N=93 available N=872) and Craig Creek (right, use N=59 available N=799). Note: * = significant Strauss' L. Bottom: Suitability criteria for smallmouth bass 100-199 mm in the North Anna River (left) and Craig Creek (right).

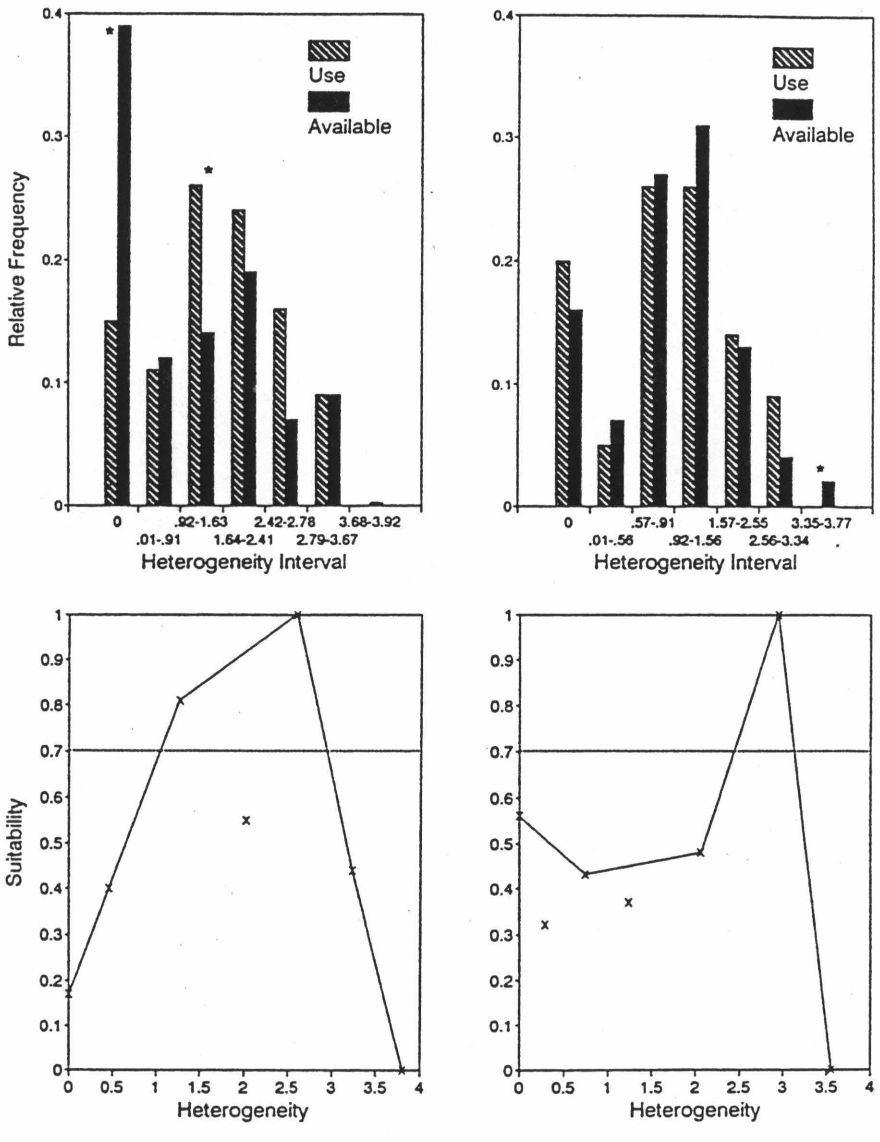


Figure 18.
Top: Relative frequency distributions of substrate heterogeneity levels available to and used by smallmouth bass ≥200 mm in the North Anna River (left, use N=51 available N=872) and Craig Creek (right, use N=60 available N=799). Note: * = significant Strauss' L. Bottom: Suitability criteria for smallmouth bass ≥200 mm in the North Anna River (left) and Craig Creek (right).

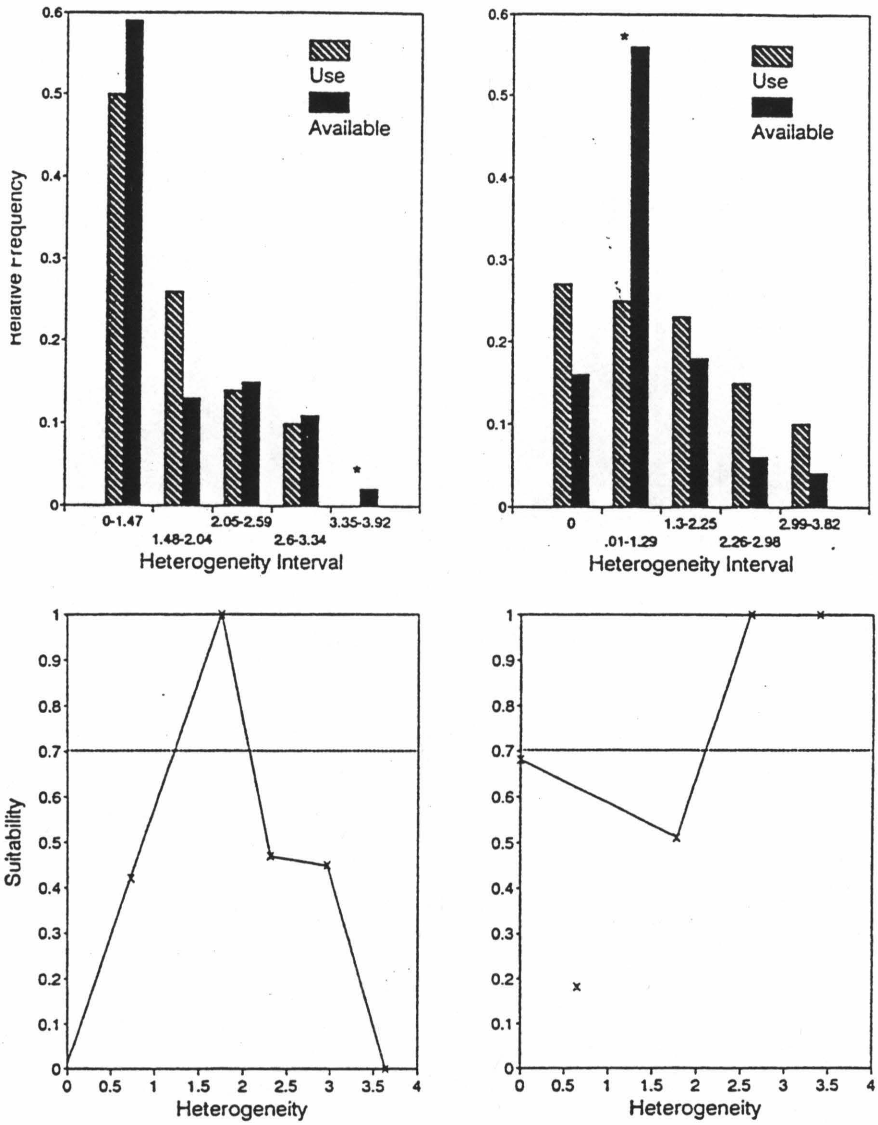
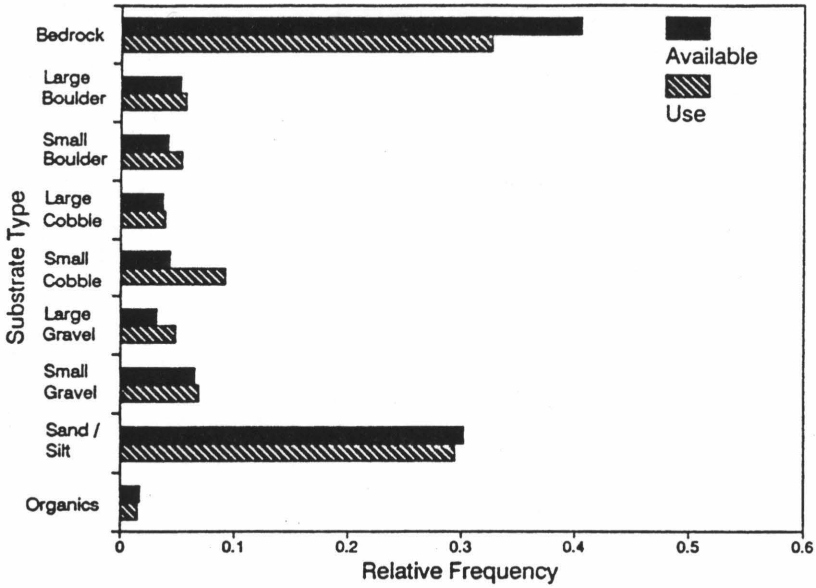


Figure 19.
Relative frequency distributions of substrate types available to and used by smallmouth bass 100-199 mm in the North Anna River (top, use N=1827, available N=17340) and Craig Creek (bottom, use N=1180, available N=15907).



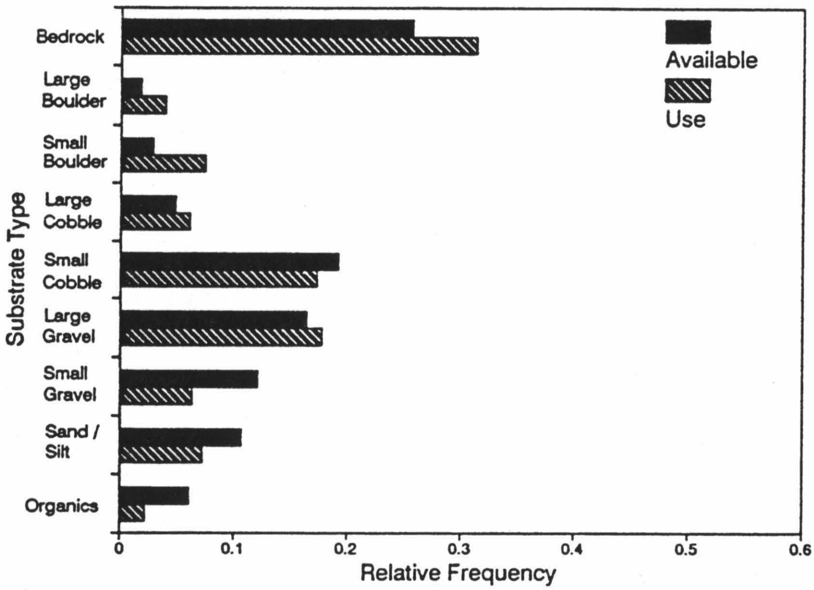
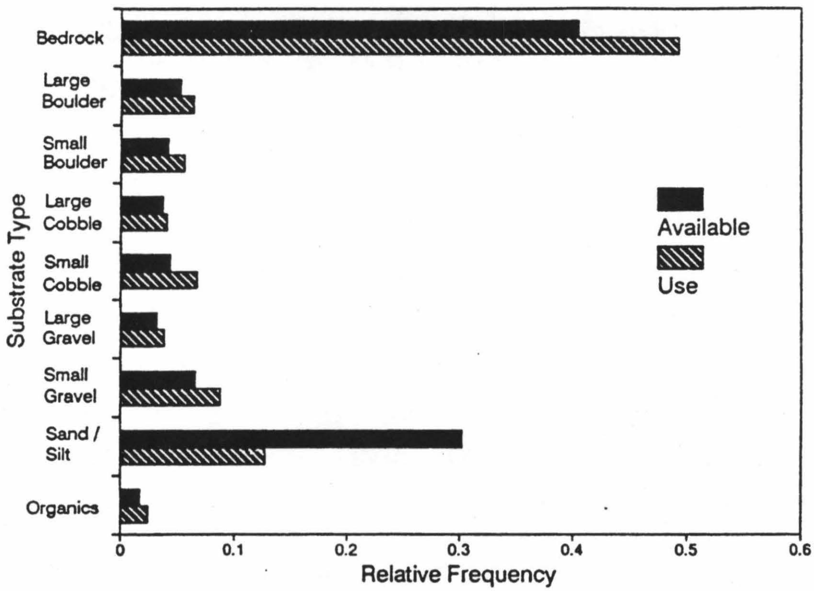


Figure 20.
Relative frequency distributions of substrate types available to and used by smallmouth bass ≥200 mm in the North Anna River (top, use N=997, available N=17340) and Craig Creek (bottom, use N=1192, available N=15907).



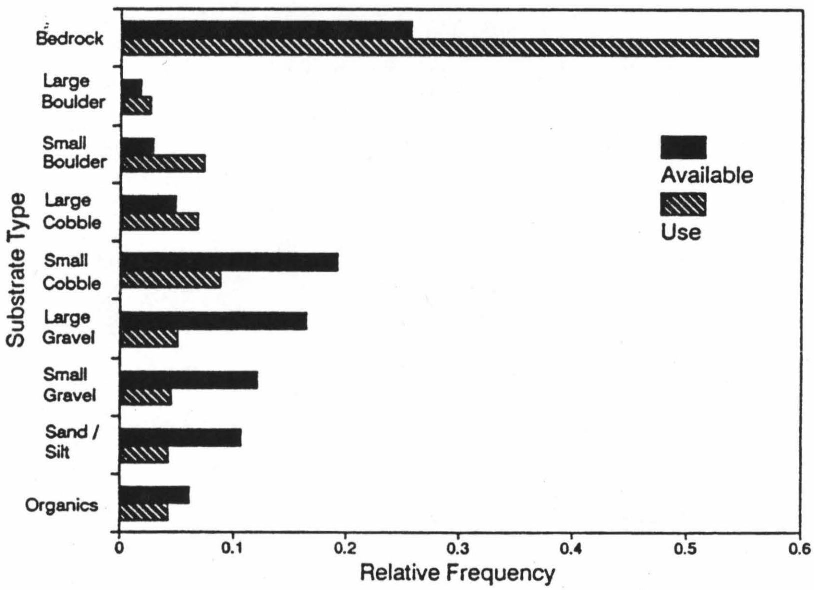


Figure 21.
Top: Relative frequency distributions of percentages of substrate particles ≥15 cm available to and used by smallmouth bass ≥200 mm in the North Anna River (left, use N=51 available N=872) and Craig Creek (right, use N=60 available N=799).
Note: * = significant Strauss' L.
Bottom: Suitability criteria for smallmouth bass ≥200 mm in the North Anna River (left) and Craig Creek (right).

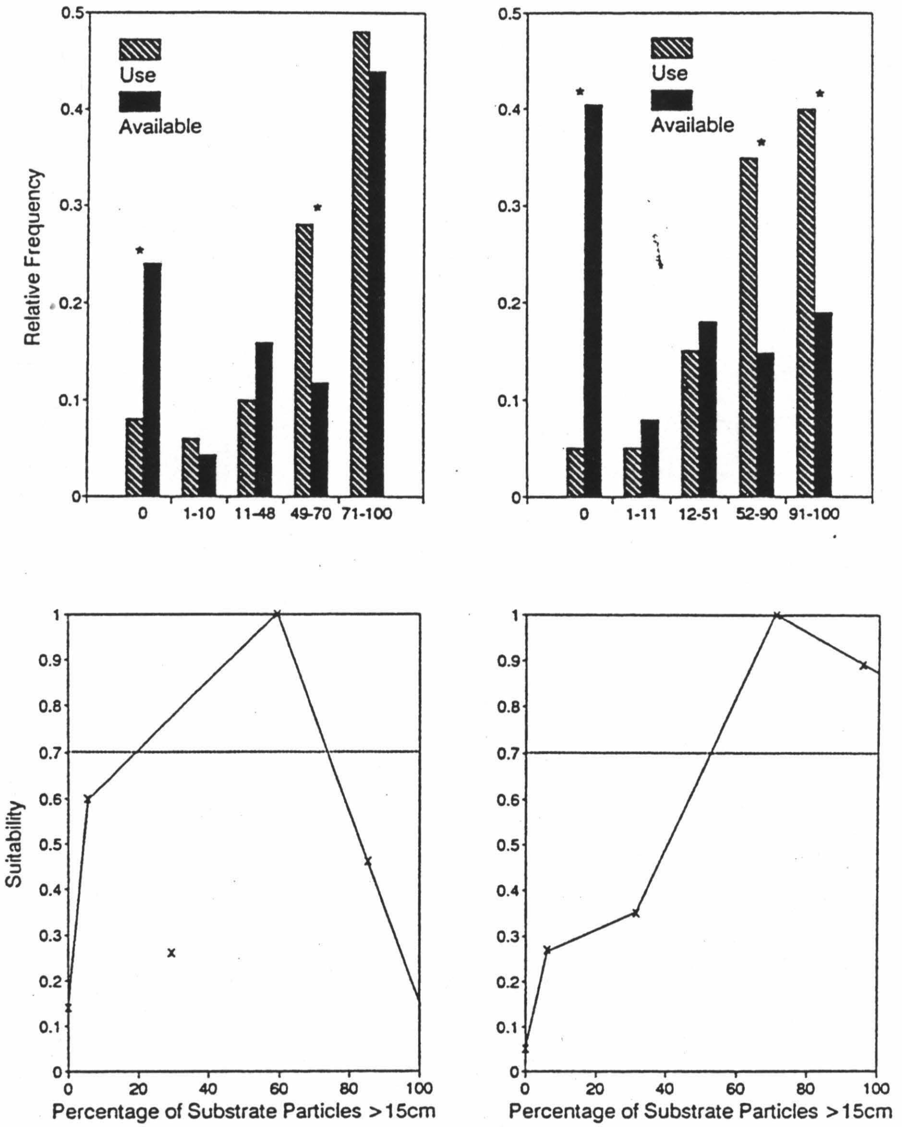


Figure 22.
Top: General depth (left) and velocity (right) habitat suitability criteria curves developed for juvenile/subadult smallmouth bass.
Bottom: General depth (left) and velocity (right) habitat suitability criteria developed for adult smallmouth bass.

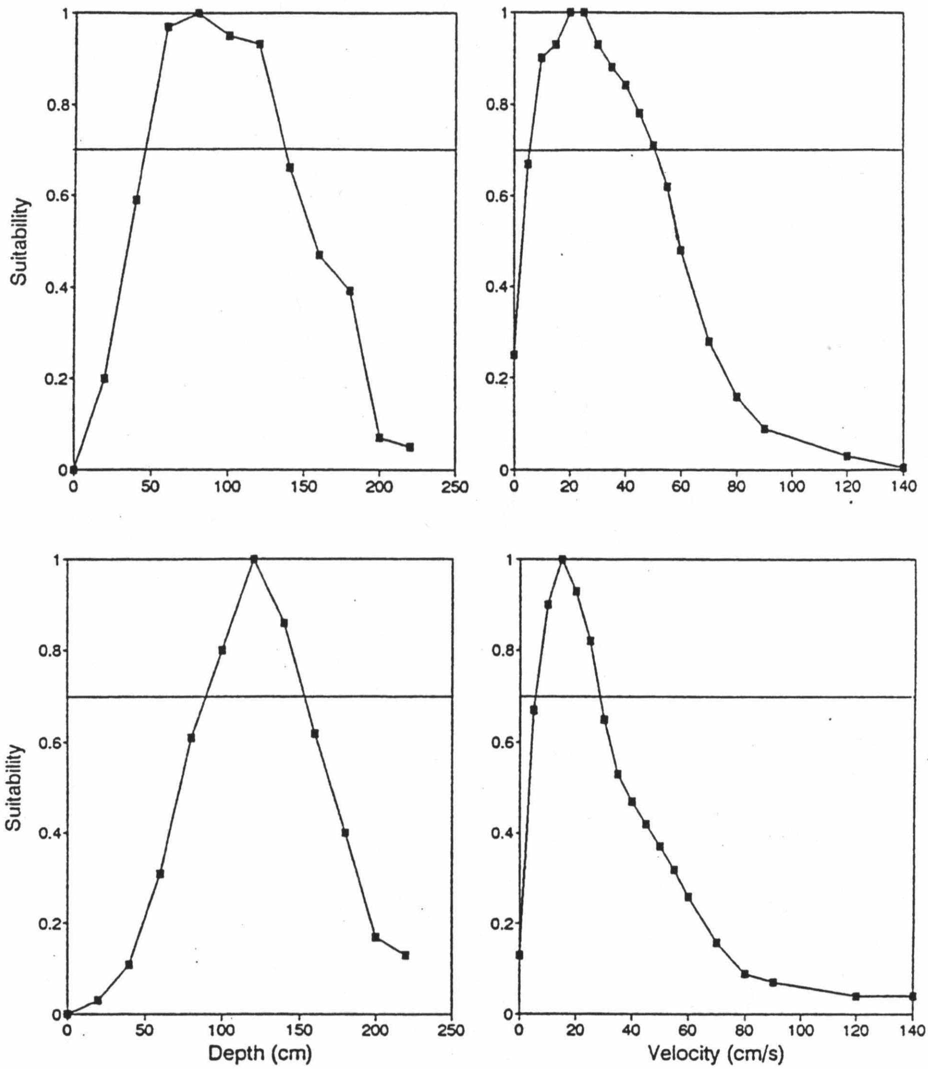


Figure 23.
Depth (top) and velocity (bottom) suitability criteria for smallmouth bass 100-189 mm in Minnesota (Aadland et al. 1989), 102-305 mm in the Upper James River, (Leonard et al., 1986), 120-190 mm in the Huron River (Monahan, 1991), and 100-199 mm in the North Anna River (NA) and Craig Creek (CC).

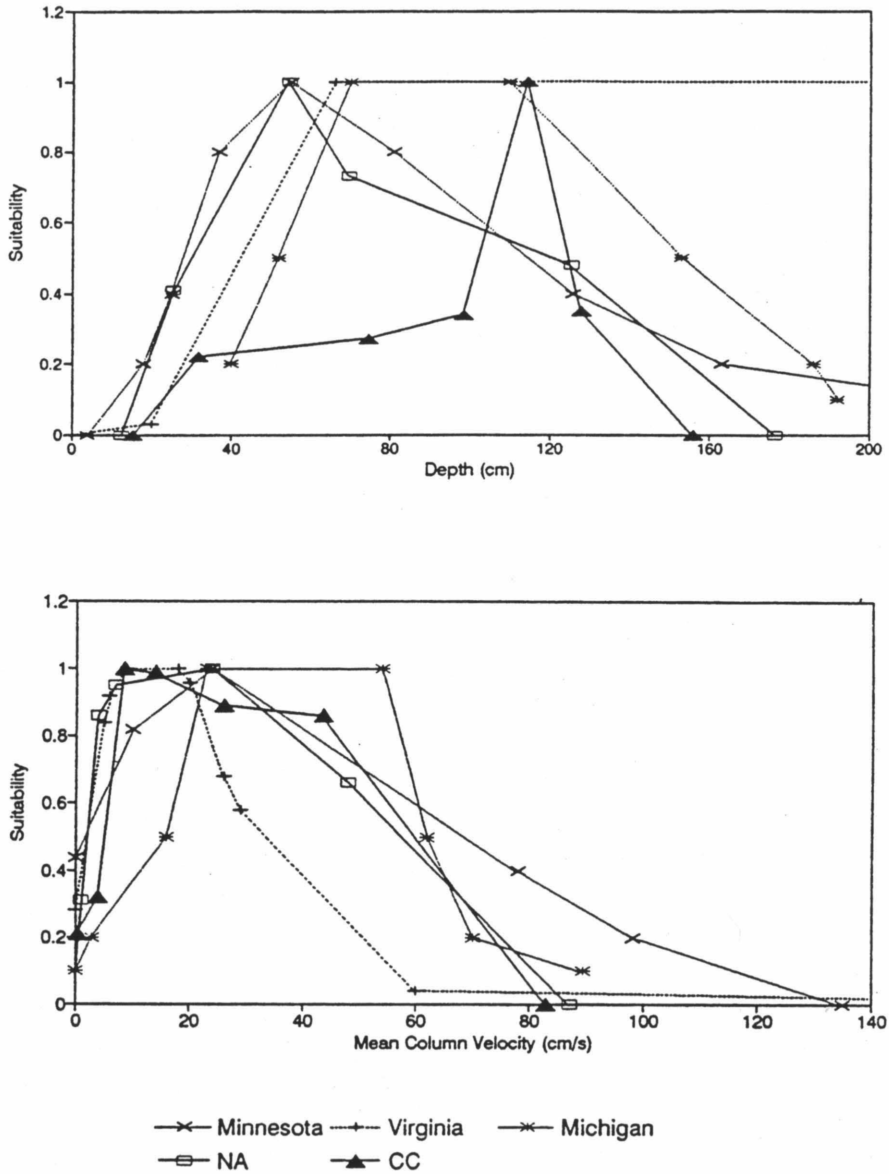
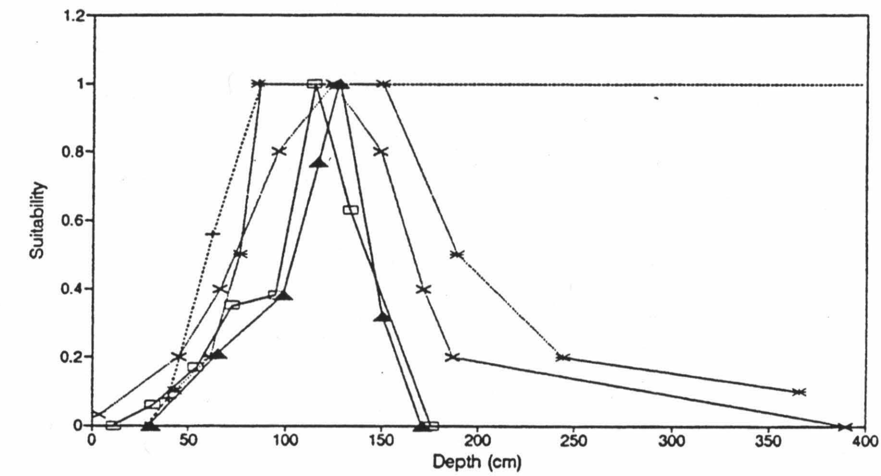


Figure 24.
Depth (top) and velocity (bottom) suitability criteria for smallmouth bass >189 mm in Minnesota (Aadland et al., 1989), >305 mm in the Upper James River (Leonard et al., 1986), ≥200 mm in the Huron River (Monahan, 1991), and ≥200 mm in the North Anna River (NA) and Craig Creek (CC).



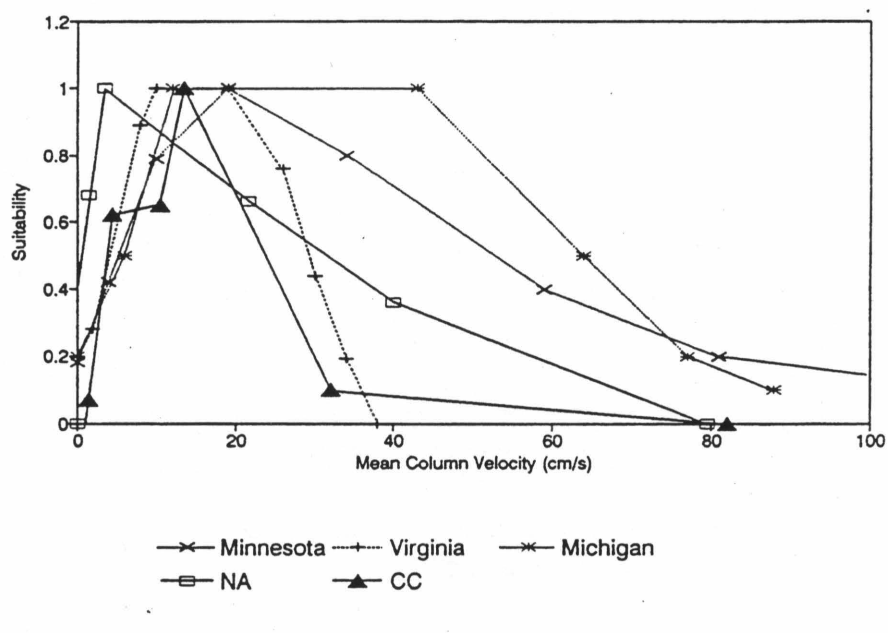
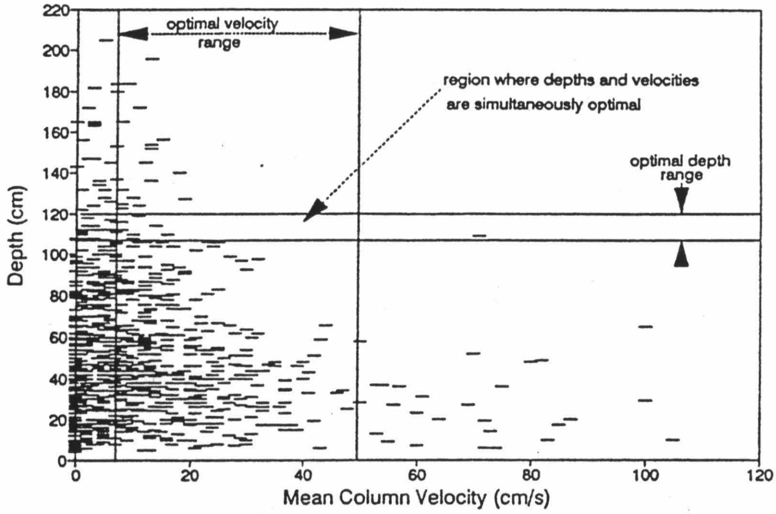


Figure 25.
Top: Optimal depth and velocity ranges, as described by criteria developed for smallmouth bass 100-199 mm in Craig Creek, overlaid on a scatter plot of depths and associated velocities available in the North Anna River.
Bottom: Optimal depth and velocity ranges, as described by criteria developed for smallmouth bass >189 mm in the Huron River (Monahan 1991) overlaid on a scatter plot of depths and associated velocities available in Craig Creek.



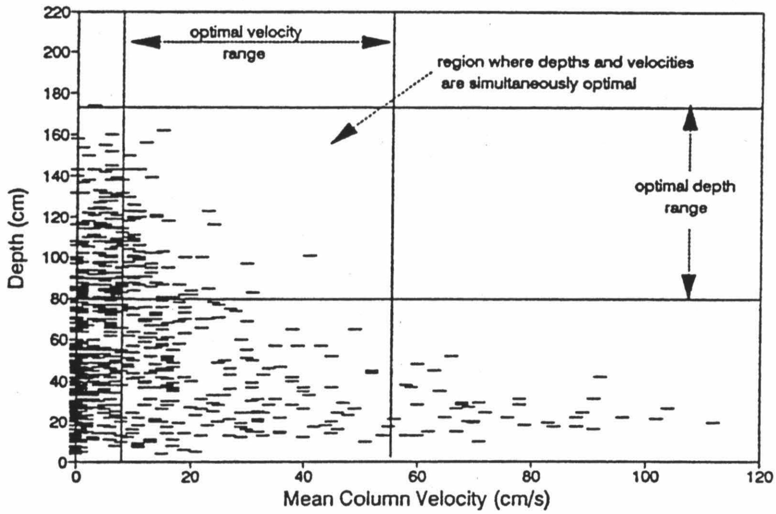
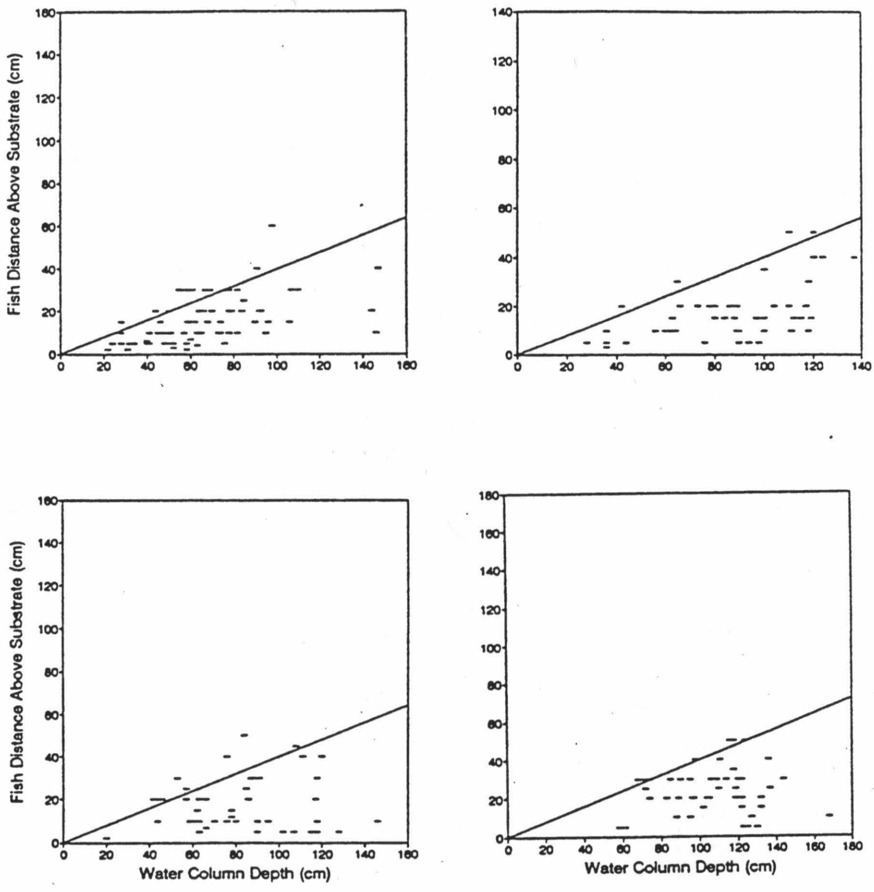


Figure 26.
Scatter plots of water column depth versus the vertical distance above the substrate smallmouth bass were seen for fish 100-199 mm in the North Anna River (top-left) and Craig Creek (top-right) and for fish ≥200 mm in the North Anna River (bottom-left) and Craig Creek (bottom-right). Diagonal line represents the distance above the substrate where mean column velocity is typically measured (0.6 of the water column depth).



Appendix A:
Suitability Calculations

Table A1.
Suitability calculations used to investigate interactive effects of depth and mean column velocity on habitat selection by smallmouth bass 100-199 mm and ≥200 mm in the North Anna River and Craig Creek. Numbers represent numbers of fish, numbers of availability observation (in parentheses) and suitability values (in bold).

North Anna Smallmouth Bass 100-199 mm

		Depth (cm)	
		4-70	71-147
Velocity (cm/s)	0-10	34 (360) **0.52**	27 (149) **1**
	11-68	26 (279) **0.52**	6 (57) **0.58**

Craig Creek Smallmouth Bass 100-199 mm

		Depth (cm)	
		4-70	71-137
Velocity (cm/s)	0-10	11 (302) **0.12**	20 (209) **0.32**
	11-52	12 (198) **0.21**	16 (54) **1**

North Anna Smallmouth Bass ≥200 mm

		Depth (cm)	
		4-90	91-146
Velocity (cm/s)	0-10	21 (429) **0.22**	11 (78) **0.54**
	11-53	12 (305) **0.17**	7 (31) **1**

Table A1 (cont.).

Craig Creek Smallmouth Bass ≥200 mm

		Depth (cm)	
		4-90	91-168
Velocity (cm/s)	0-10	11 (392) **0.01**	30 (139) **0.52**
	11-50	7 (227) **0.07**	12 (29) **1**

Appendix B:

Table B1

Depth interval calculations for each size class of smallmouth bass in the North Anna River and Craig Creek including: interval ranges used, normalized preference values and Strauss' L values with associated P values.

* = significant P value adjusted for multiple non-independent tests.

North Anna River Smallmouth Bass 100-199mm

Depth Interval (cm)	Number of Smb Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
4-21	0	0	172	0.1979	0	0	-0.198	<0.0001	*
22-29	9	0.0968	82	0.0944	1.026	0.41	0.002	0.9522	
30-49	15	0.1613	217	0.2497	0.646	0.26	-0.088	0.0316	
50-59	23	0.2473	85	0.0978	2.528	1	0.149	<0.0001	*
60-79	24	0.2581	122	0.1404	1.838	0.73	0.118	0.0118	*
80-103	13	0.1398	102	0.1174	1.191	0.47	0.022	0.562	
104-147	9	0.0968	69	0.0794	1.219	0.48	0.017	0.5962	
148-205	0	0	20	0.023	0	0	-0.023	<0.0001	*
N=	93		869						

North Anna River Smallmouth Bass >200mm

Depth Interval (cm)	Number of Smb Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
4-19	0	0	148	0.1703	0	0	-0.17	<0.0001	*
20-44	5	0.098	277	0.3188	0.308	0.06	-0.221	<0.0001	*
45-62	9	0.1765	163	0.1876	0.941	0.17	-0.011	0.8414	
63-81	12	0.2353	108	0.1243	1.893	0.35	0.111	0.0658	
82-108	13	0.2549	106	0.122	2.09	0.38	0.133	0.0324	
109-120	8	0.1569	25	0.0288	5.453	1	0.128	0.0124	*
121-146	4	0.0784	20	0.023	3.408	0.63	0.055	0.147	
147-205	0	0	22	0.0253	0	0	-0.025	<0.0001	*
N=	51		869						

Craig Creek Smallmouth Bass 100-199mm

Depth Interval (cm)	Number of Smb Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
4-27	0	0	201	0.2531	0	0	-0.253	<0.0001	*
28-36	6	0.1017	71	0.0894	1.137	0.22	0.012	0.7642	
37-62	10	0.1695	190	0.2393	0.708	0.13	-0.069	0.177	
63-86	15	0.2542	143	0.1801	1.412	0.27	0.074	0.204	
87-110	14	0.2373	104	0.131	1.812	0.34	0.106	0.0614	
111-118	9	0.1525	23	0.029	5.266	1	0.124	0.0086	*
119-137	5	0.0847	37	0.0466	1.819	0.35	0.038	0.303	
138-174	0	0	25	0.0315	0	0	-0.031	<0.0001	*
N=	59		794						

Table B1 (cont.).

Craig Creek Smallmouth Bass >200mm

Depth Interval (cm)	Number of Smb Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
4-57	0	0	443	0.5579	0	0	-0.558	<0.0001	*
58-72	7	0.1167	70	0.0882	1.323	0.21	0.029	0.4966	
73-88	8	0.1333	103	0.1297	1.028	0.16	0.004	0.9282	
89-109	16	0.2667	88	0.1108	2.406	0.38	0.156	0.0074	*
110-123	16	0.2667	44	0.0554	4.812	0.77	0.211	0.0002	*
124-132	9	0.15	19	0.0239	6.268	1	0.126	0.0068	*
133-168	4	0.0667	26	0.0327	2.036	0.32	0.034	0.2984	
169-174	0	0	1	0.0013	0	0	-0.001	0.4296	
N=	60		794						

Table B2.

Velocity interval calculations for each size class of smallmouth bass in the North Anna River and Craig Creek including: interval ranges used, normalized preference values and Strauss' L values with associated P values.
*** = significant P value adjusted for multiple non-independent tests.**

North Anna River Smallmouth Bass 100-199mm

Velocity Interval (cm/sec)	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0-2	11	0.1209	220	0.2543	0.475	0.31	-0.133	0.0002	*
3-5	18	0.1978	130	0.1503	1.316	0.86	0.048	0.2714	
6-8	18	0.1978	118	0.1364	1.45	0.95	0.061	0.1586	
9-20	28	0.3077	244	0.2821	1.091	0.71	0.026	0.61	
21-27	10	0.1099	62	0.0717	1.533	1	0.038	0.2628	
28-68	8	0.0879	75	0.0867	1.014	0.66	0.001	0.976	
69-105	0	0	16	0.0185	0	0	-0.018	0.0001	*
N=	91		865						

North Anna River Smallmouth Bass >200mm

Velocity Interval (cm/sec)	Number of Smb Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0	0	0	118	0.1364	0	0	-0.136	<0.0001	*
1-2	8	0.1569	102	0.1179	1.33	0.68	0.039	0.4532	
3-4	8	0.1569	69	0.0798	1.966	1	0.077	0.1362	
5-8	10	0.1961	179	0.2069	0.948	0.48	-0.011	0.8494	
9-16	13	0.2549	185	0.2139	1.192	0.61	0.041	0.5156	
17-26	9	0.1765	117	0.1352	1.305	0.66	0.041	0.4532	
27-53	3	0.0588	71	0.0821	0.717	0.36	-0.023	0.5028	
54-105	0	0	24	0.0277	0	0	-0.028	<0.0001	*
N=	51		865						

Craig Creek Smallmouth Bass 100-199mm

Velocity Interval (cm/sec)	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0-1	7	0.1186	240	0.3046	0.39	0.21	-0.186	<0.0001	*
2-6	8	0.1356	178	0.2259	0.6	0.32	-0.09	0.0548	
7-10	16	0.2712	114	0.1447	1.875	1	0.127	0.0324	
11-17	14	0.2373	101	0.1282	1.851	0.99	0.109	0.0548	
18-34	10	0.1695	80	0.1015	1.669	0.89	0.068	0.1738	
35-52	4	0.0678	33	0.0419	1.619	0.86	0.026	0.4354	
53-113	0	0	42	0.0533	0	0	-0.053	<0.0001	*
N=	59		788						

Table B2 (cont.).

Craig Creek Smallmouth Bass >200mm

Velocity Interval (cm/sec)	Number of Smb Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0-3	6	0.1	303	0.3845	0.26	0.07	-0.285	<0.0001	*
4-5	13	0.2167	71	0.0901	2.405	0.62	0.127	0.0188	
6-8	16	0.2667	107	0.1358	1.964	0.51	0.131	0.025	
9-12	15	0.25	78	0.099	2.526	0.65	0.151	0.008	*
13-14	5	0.0833	17	0.0216	3.863	1	0.062	0.0854	
14-50	5	0.0833	167	0.2119	0.393	0.1	-0.129	<0.0001	*
51-113	0	0	45	0.0571	0	0	-0.057	<0.0001	*
N=	60		788						

Table B3.

Cover interval calculations for each size class of smallmouth bass in the North Anna River and Craig Creek including: interval ranges used, normalized preference values and Strauss' L values with associated P values.

* = significant P value adjusted for multiple non-independent tests.

North Anna River Smallmouth Bass 100-199mm

Cover Description	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
None	44	0.4731	520	0.6047	0.7824	0.38	-0.1316	0.0156	*
Woody Debris	3	0.0323	67	0.0779	0.4146	0.2	-0.0456	0.258	
Rock Ledge	40	0.4301	181	0.2105	2.0432	1	0.2196	<0.0001	*
Veloc. Shelter	4	0.043	54	0.0628	0.6847	0.34	-0.0198	0.3788	
Aquat. Veg.	1	0.0108	26	0.0323	0.3344	0.16	-0.0215	0.0802	
Overhead	1	0.0108	12	0.014	0.7714	0.38	-0.0032	0.7794	
N=	93		860						

North Anna River Smallmouth Bass>200mm

Cover Description	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
None	24	0.4706	520	0.6047	0.7782	0.42	-0.1341	0.0614	
Woody Debris	2	0.0392	67	0.0779	0.5032	0.27	-0.0387	0.177	
Rock Ledge	20	0.3922	181	0.2105	1.8632	1	0.1817	0.0094	*
Veloc. Shelter	5	0.098	54	0.0628	1.5605	0.84	0.0352	0.4066	
Aquat. Veg.	0	0	26	0.0323	0	0	-0.0323	<0.0001	*
Overhead	0	0	12	0.014	0	0	-0.014	0.0004	*
N=	51		860						

Craig Creek Smallmouth Bass 100-199mm

Cover Description	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
None	37	0.6271	564	0.7166	0.8751	0.34	-0.0895	0.1676	
Woody Debris	2	0.0339	37	0.047	0.7213	0.28	-0.0131	0.5962	
Rock Ledge	12	0.2034	94	0.1194	1.7035	0.67	0.084	0.1164	
Veloc. Shelter	4	0.0678	21	0.0267	2.5393	1	0.0411	0.215	
Aquat. Veg.	1	0.0169	53	0.0673	0.2511	0.1	-0.0504	0.008	*
Overhead	3	0.0508	18	0.0229	2.2183	0.87	0.0279	0.337	
N=	59		787						

Table B3 (cont.).

Craig Creek Smallmouth Bass>200mm

Cover Description	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
None	23	0.3833	564	0.7166	0.5349	0.09	-0.3333	<0.0001	*
Woody Debris	5	0.0833	37	0.047	1.7723	0.28	0.0363	0.3174	
Rock Ledge	21	0.35	94	0.1194	2.9313	0.47	0.2306	0.0003	*
Veloc. Shelter	10	0.1667	21	0.0267	6.2434	1	0.14	0.0038	*
Aquat. Veg.	1	0.0167	53	0.0673	0.2481	0.04	-0.0506	0.0072	*
Overhead	0	0	18	0.0229	0	0	-0.0229	<0.0001	*
N=	60		787						

Table B4.

Substrate heterogeneity interval calculations for each size class of smallmouth bass in the North Anna River and Craig Creek including: interval ranges used, normalized preference values and Strauss' L values with associated P values.

*** = significant P value adjusted for multiple non-independent tests.**

North Anna River Smallmouth Bass 100-199mm

Heterogeneity Interval	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0	14	0.15	338	0.39	0.384615	0.17	-0.24	<0.0001	*
.01-.91	10	0.11	102	0.12	0.916667	0.4	-0.01	0.7718	
.92-1.63	24	0.26	118	0.14	1.857143	0.81	0.12	0.0108	*
1.64-2.41	22	0.24	165	0.19	1.263158	0.55	0.05	0.2802	
2.42-2.78	15	0.16	65	0.07	2.285714	1	0.09	0.0208	
2.79-3.67	8	0.09	82	0.09	1	0.44	0	1	
3.68-3.92	0	0	2	0.002	0	0	-0.002	0.1868	
N=	93		872						

North Anna River Smallmouth Bass>200mm

Heterogeneity Interval	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0-1.47	25	0.5	520	0.59	0.847458	0.42	-0.09	0.215	
1.48-2.04	13	0.26	111	0.13	2	1	0.13	0.0394	
2.05-2.59	7	0.14	131	0.15	0.933333	0.47	-0.01	0.8414	
2.6-3.34	5	0.1	94	0.11	0.909091	0.45	-0.01	0.818	
3.35-3.92	0	0	16	0.02	0	0	-0.02	<0.0001	*
N=	50		872						

Craig Creek Smallmouth Bass 100-199mm

Heterogeneity Interval	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0	12	0.2	126	0.16	1.25	0.56	0.04	0.4532	
.01-.56	3	0.05	58	0.07	0.714286	0.32	-0.02	0.5028	
.57-.91	15	0.26	218	0.27	0.962963	0.43	-0.01	0.865	
.92-1.56	15	0.26	243	0.31	0.83871	0.37	-0.05	0.401	
1.57-2.55	9	0.14	104	0.13	1.076923	0.48	0.01	0.8336	
2.56-3.34	5	0.09	33	0.04	2.25	1	0.05	0.1868	
3.35-3.77	0	0	17	0.02	0	0	-0.02	<0.0001	*
N=	59		799						

Table B4 (cont.).

Craig Creek Smallmouth Bass>200mm

Heterogeneity Interval	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0	16	0.27	126	0.16	1.6875	0.68	0.11	0.0614	
.01-1.29	15	0.25	451	0.56	0.446429	0.18	-0.31	<0.0001	*
1.3-2.25	14	0.23	145	0.18	1.277778	0.51	0.05	0.3734	
2.26-2.98	9	0.15	45	0.06	2.5	1	0.09	0.0548	
2.99-3.82	6	0.1	32	0.04	2.5	1	0.06	0.126	
N=	60		799						

Table B5.

Percentage of substrate particles ≥15 cm interval calculations for smallmouth bass ≥200 mm in the North Anna River and Craig Creek including: interval ranges used, normalized preference values and Strauss' L values with associated P values.
*** = significant P value adjusted for multiple non-independent tests.**

North Anna River Smallmouth Bass>200mm

% Particles >15cm Interval	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0	4	0.08	210	0.2408	0.332	0.14	-0.161	<0.0002	*
1-10	3	0.06	37	0.0424	1.414	0.6	0.018	0.61	
11-48	5	0.1	139	0.1594	0.627	0.26	-0.059	0.1802	
49-70	14	0.28	103	0.1181	2.37	1	0.162	0.012	*
71-100	24	0.48	383	0.4392	1.093	0.46	0.041	0.5754	
N=	50		872						

Craig Creek Smallmouth Bass>200mm

% Particles >15cm Interval	Number of SMB Using	Use Relative Frequency	Number of Availability Observations	Availability Relative Frequency	Non-norm. Pref.	Normal. Pref.	Strauss' L value	P value alpha=.05	
0	3	0.05	323	0.4042	0.124	0.05	-0.354	<0.0001	*
1-11	3	0.05	63	0.0788	0.634	0.27	-0.029	0.332	
12-51	9	0.15	144	0.1802	0.832	0.35	-0.03	0.5286	
52-90	21	0.35	118	0.1477	2.37	1	0.202	<0.001	*
91-100	24	0.4	151	0.1889	2.117	0.89	0.211	<0.001	*
N=	60		799						

Appendix C:

Table C1.
Information used to construct general suitability criteria. Average suitability values are the means of suitability values reported for Minnesota (Aadland et al., 1989), Upper James River (Leonard et al., 1986), Huron River (Monahan, 1991), the North Anna River and Craig Creek. General criteria were constructed using the normalized suitability values.
Note: * = no suitability values given by source; ** = suitability value given was an extrapolation beyond available habitat and not used in general criteria development.

Smaller Size Class of Smallmouth Bass

Depth (cm)	Suitability Value						
	MN	Upper James R.	Huron River	North Anna R.	Craig Creek	Average Suitability	Normalized Suitability
0	0	0	*	0	0	0	0
20	0.26	0.03	*	0.24	0.06	0.15	0.2
40	0.83	0.45	0.02	0.71	0.23	0.45	0.59
60	0.96	0.87	0.72	0.9	0.25	0.74	0.97
80	0.81	1	1	0.68	0.29	0.76	1
100	0.63	1	1	0.59	0.4	0.72	0.95
120	0.45	1	0.88	0.5	0.74	0.71	0.93
140	0.32	1	0.65	0.34	0.2	0.5	0.66
160	0.22	1	0.44	0.16	0	0.36	0.47
180	0.18	1	*	0	0	0.3	0.39
200	0.15	**	*	0	0	0.05	0.07
220	0.12	**	*	0	0	0.04	0.05

Velocity (cm/s)	Suitability Value						
	MN	Upper James R.	Huron River	North Anna R.	Craig Creek	Average Suitability	Normalized Suitability
0	0.44	0.28	0.10	0.13	0.19	0.23	0.25
5	0.63	0.84	0.25	0.89	0.47	0.62	0.67
10	0.82	1.00	0.36	0.96	1.00	0.83	0.90
15	0.88	1.00	0.48	0.97	0.98	0.86	0.93
20	0.95	0.96	0.79	0.99	0.94	0.92	1.00
25	0.99	0.73	1.00	0.99	0.90	0.92	1.00
30	0.93	0.56	1.00	0.92	0.88	0.86	0.93
35	0.88	0.48	1.00	0.84	0.87	0.81	0.88
40	0.82	0.39	1.00	0.77	0.87	0.77	0.84
45	0.77	0.30	1.00	0.70	0.83	0.72	0.78
50	0.71	0.21	1.00	0.63	0.72	0.65	0.71
55	0.66	0.13	0.94	0.54	0.61	0.57	0.62
60	0.60	0.04	0.63	0.46	0.50	0.44	0.48
70	0.49	0.04	0.20	0.29	0.28	0.26	0.28
80	0.38	0.03	0.15	0.12	0.07	0.15	0.16
90	0.28	0.03	0.10	0.00	0.00	0.08	0.09
120	0.08	0.02	*	0.00	0.00	0.03	0.03
140	0.00	0.02	*	0.00	0.00	0.01	0.01

Table C1 (cont.).

Larger Size Class of Smallmouth Bass

Depth (cm)	Suitability Value MN	Upper James R.	Huron River	North Anna R.	Craig Creek	Average Suitability	Normalized Suitability
0	0.00	0.00	*	0.00	0.00	0.00	0.00
20	0.10	0.00	*	0.02	0.00	0.03	0.03
40	0.18	0.08	*	0.10	0.06	0.10	0.11
60	0.34	0.52	0.19	0.23	0.18	0.29	0.31
80	0.59	0.89	0.72	0.36	0.29	0.57	0.61
100	0.83	1.00	1.00	0.54	0.40	0.75	0.80
120	0.97	1.00	1.00	0.89	0.84	0.94	1.00
140	0.87	1.00	1.00	0.53	0.64	0.81	0.86
160	0.61	1.00	0.87	0.24	0.18	0.58	0.62
180	0.29	1.00	0.62	0.00	0.00	0.38	0.40
200	0.19	**	0.44	0.00	0.00	0.16	0.17
220	0.17	**	0.33	0.00	0.00	0.12	0.13

Velocity (cm/s)	Suitability Value MN	Upper James R.	Huron River	North Anna R.	Craig Creek	Average Suitability	Normalized Suitability
0	0.18	0.20	0.20	0.00	0.00	0.12	0.13
5	0.48	0.59	0.45	0.97	0.62	0.62	0.67
10	0.79	1.00	0.83	0.88	0.65	0.83	0.90
15	0.91	1.00	1.00	0.78	0.93	0.92	1.00
20	0.99	0.97	1.00	0.69	0.68	0.86	0.93
25	0.92	0.79	1.00	0.60	0.44	0.75	0.82
30	0.85	0.44	1.00	0.52	0.20	0.60	0.65
35	0.78	0.14	1.00	0.44	0.09	0.49	0.53
40	0.70	0.00	1.00	0.36	0.08	0.43	0.47
45	0.62	0.00	0.95	0.31	0.07	0.39	0.42
50	0.54	0.00	0.83	0.27	0.06	0.34	0.37
55	0.46	0.00	0.71	0.22	0.05	0.29	0.32
60	0.39	0.00	0.60	0.18	0.04	0.24	0.26
70	0.30	0.00	0.36	0.09	0.02	0.15	0.16
80	0.21	0.00	0.17	0.00	0.00	0.08	0.09
90	0.19	0.00	0.10	0.00	0.00	0.06	0.07
120	0.17	0.00	*	0.00	0.00	0.04	0.04
140	0.16	0.00	*	0.00	0.00	0.04	0.04

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