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MICROHABITAT CRITERIA FOR SELECTED STREAM FISHES AND METHODOLOGICAL CONSIDERATIONS FOR INSTREAM FLOW STUDIES IN MINNESOTA

TECHNICAL REPORT

1987-1989

Report to the

Legislative Commission on Minnesota Resources

Department of Natural Resources

Division of Fish and Wildlife

July, 1989

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MINNESOTA RESOURCES

Prepared by

Luther Aadland
Chantel Waltner
Mary T. Negus
Henry Drewes
Charles Anderson

Department of Natural Resources
Division of Fish and Wildlife
Section of Fisheries

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PREFACE

The quantity of water needed to maintain instream values, such as water-based recreation, fish and wildlife habitat, aesthetics, water quality, and navigation, must be determined to resolve water-use conflicts and wisely allocate water for offstream uses. Several methods for setting the protected flows are available, but not all address the habitat requirements of fish. The Instream Flow Incremental Methodology (IFIM), developed by the U.S. Fish and Wildlife Service, is a method of quantifying instream flow needs of fish by combining detailed hydraulic modeling with species-specific habitat suitability criteria to determine the "useable" habitat throughout a range of flows.

The goal of this project was to develop habitat suitability curves which can be incorporated into instream flow models of Minnesota's warm water streams. These models will be used to determine flow regimes which optimize habitat for target species of fish. Although game fish species are usually the targets of IFIM analysis, they may have considerably different requirements than their prey; thus, in this study, the entire community of fish was identified and their habitat requirements evaluated. In addition, food habits of smallmouth bass were summarized.

Habitat-use and availability data were collected from three warm water streams in Minnesota. The study streams were located within different ecoregions, and two representative reaches were selected within each stream. A variety of sampling techniques were evaluated because variable water clarity and high species diversities in the three streams did not permit accurate visual observation. A stratified-random sampling regime was used to collect over 35,000 fish from five habitat types. Microhabitat data of velocity, depth, substrate composition, and cover types were recorded at each sampling location. These data were used to cluster fish by species and life stage into six habitat-use guilds, which describe the relationships between habitat types and the presence or absence of fish species. In addition, habitat-use data were recorded for spawning smallmouth bass and Mississippi River spawning walleyes.

The complexity of warm water ecosystems necessitates management of the entire fish community, rather than just a few species. To ensure adequate protection of aquatic habitat, IFIM simulations should be done for representatives of each of the habitat-use guilds defined in this study, although species selection should be specific to the river section being studied. Through effective management of the fisheries resource using a community-oriented approach, a variety of instream values can be maintained which have economic as well as aesthetic and ecological importance.

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INTRODUCTION

Since 1977, the Minnesota Department of Natural Resources (DNR) has exercised the authority to issue permits for water appropriation and set protected instream flows. Protected flows are defined as the volume of water required to protect the instream uses of fishing, hunting, canoeing, waste assimilation, navigation, conveyance to downstream users, and various other water-based recreational pursuits. The DNR Division of Waters is responsible for issuing permits for surface water appropriations, and to date, over 1,500 permits have been granted for direct withdrawals from surface waters. More than half of the permitted withdrawals (by volume and by number) are from streams and rivers (J.Japs, Division of Waters, personal communication). The majority of these stream and river permits are issued for agricultural purposes, although the largest users, in terms of volume, include hydropower and thermal cooling facilities, and industrial processing. To date, protected flows have been established on 43 Minnesota streams.

The DNR Section of Fisheries is responsible for protecting the interests of anglers and others concerned about fish and for maintaining healthy populations of game fish (species sought by angling), species which affect game fish (such as forage fish), and species with intrinsic value (rare, endangered, or threatened). While the Section actively manages nearly 2,000 miles of cold water trout streams, very little is known about the species and community interactions in the 10,000 miles of warm and cool water streams. Warm water streams are very complex, typically containing more than 50 fish species. Consequently, the potential for biotic interactions in warm water streams is much greater than in cold water trout streams, which have relatively simple species assemblages. Basic information on species habitat needs, stream flow requirements, distribution, and population dynamics is needed to protect the integrity of the entire warm water stream community.

STANDARD SETTING AND INCREMENTAL METHODS

Two general classes of methods are used to set protected instream flows. Standard setting methods utilize hydrologic records and hydraulic channel characteristics. Some fundamental problems arise in using standard setting methods to set protected flows. First, accurate stream flow gages are in place in only 19 of Minnesota's 39 watersheds, and these hydrologic data have typically been collected only during the last 30 or fewer years. When used in standard setting methods, these data may yield inadequate protected flows for heavily impacted streams. Second, these methods do not require information on species habitat needs or recreational uses, and therefore do not address the protection of specific habitats.

The second class of instream flow assessment techniques includes the incremental methods. These approaches require extensive data collection and allow for the protection of specific habitats by identifying fish habitat requirements. The Instream Flow Incremental Methodology (IFIM) is the most widely used incremental method. It allows for the simulation of the physical habitat throughout a range of flows and can be used to protect or enhance fish and wildlife habitat and a variety of recreational uses. The IFIM was developed by the Cooperative Instream Flow Service Group (U.S. Fish and Wildlife Service) to evaluate changes in usable habitat in response to incremental changes in stream flow or channel structure. The optimum range of microhabitat requirements, such as depth, velocity, substrate, and cover, are depicted for individual fish species in the form of Suitability Index (SI) curves. The SI curves can be constructed at three levels of reliability. Category I curves are based on professional judgement regarding a species; little or no empirical data are involved. Category II curves are based on frequency data collected where target species were observed (habitat-use curves); these data are site and flow specific. Category III curves, or "preference curves", are the most desirable, because they are based on direct observations of habitat use and are corrected for habitat availability. Habitat availability data are used to describe and quantify the habitat types and relative proportions available to the fish.

After species habitat requirements (depicted by category I, II, or II curves) have been determined and channel hydraulic characteristics have been measured, the variables are input into the Physical Habitat Simulation System (PHABSIM). The PHABSIM is the computer-run component of IFIM which calculates and simulates changes in the amount of "usable" fish habitat or Weighted Useable Area (WUA) for a range of flows by converting the hydraulic information (depth, velocity, substrate) into a measure of useable habitat (Milhous et al. 1989). These techniques allow for the determination of a stream-flow rate which maximizes WUA for a single species or a group of species.

GOALS

Minnesota streams provide benefits to a variety of instream users, but many streams, which once supported angling and other recreational uses, have been degraded by poor water and land management practices. In order to balance the competing water uses with the protection of instream values, the DNR has been given the authority to establish protected flow levels (a specific flow volume below which all appropriations are suspended). These protected flows will be more effective if they are developed with methods which recognize specific habitats and fish preferences in warm and cool water streams. Therefore, detailed habitat suitability and preference data must be obtained to determine the effects of flow on fishes. In this study, the use of the IFIM in Minnesota was assessed. Several objectives were specified to accomplish this goal. First, detailed information on habitat use by stream fishes must be obtained, so a greater understanding of the stream community can be developed. Second, because few SI curves have been constructed for cool and warm water species, habitat suitability criteria for all fish species collected must be developed. Lastly, these habitat suitability criteria must be compared to those already existing in the literature, because in some instances, SI curves from other sources may be needed for use in Minnesota. Therefore, curve transferability must be assessed by comparing suitability curves developed in three Minnesota study streams with SI curves from other sources.

Game fish species are usually the targets of IFIM analyses, since these species are the focus of public concerns. Smallmouth bass Micropterus dolomieui, channel catfish Ictalurus punctatus, and walleye Stizostedion vitreum vitreum, were the species initially chosen for this study since they are important game fish in Minnesota. However, these species, which tend to be top predators, may not be the best choices for IFIM analyses (Orth and Maughan 1982; Lyons et al. 1988; Leonard and Orth 1989). A community-oriented approach may be more appropriate. Biotic interactions, particularly competition and predation, are known to affect the distribution of organisms in aquatic systems (Werner and Mittelbach 1981; McComas and Drenner 1982; Werner and Gilliam 1984), although their importance has been assumed to be negligible in most IFIM studies. One reason for this assumption could be that most of the IFIM studies have been conducted on cold water trout streams, in which the fish biomass is dominated by a few species. Since Minnesota streams and representative fish species are unique in many respects, habitat suitability criteria for the IFIM analysis will be developed within the state for all fish species collected.

STUDY SITES

Habitat preference data were collected at six sites; two each on the Zumbro, Snake, and Yellow Medicine rivers (Figure 1). These rivers were chosen because each represented a different geomorphic region within the state and contained populations of walleye, channel catfish, and smallmouth bass (the target species for the IFIM study). Study sites were each 400 m long (along the thalweg) and were chosen for their diversity in habitat types. The Zumbro River is located in a transitional area of the Western Corn Belt Plains and Driftless Area ecoregions of southeastern Minnesota. The study sites were located approximately 2 and 6.5 km (1.2 and 4 miles) downstream from Zumbro Dam. Mean width of the Zumbro River sites was 42 m (138 ft), velocities ranged from 0-131 cm/s (0-4.3 ft/s), and depths ranged from 3-354 cm (0.1-11.6 ft; Table 1). In addition to these two sites, observations of smallmouth bass nests were made from the dam to the bottom of the downstream site.

The Snake River is located in northeastern Minnesota. One study site was located approximately 1 km (0.6 miles) downstream from Cross Lake in the North Central Hardwood Forests ecoregion and the second was located about 2 km (1.2 miles) upstream from the confluence with the St. Croix River in the Northern Lakes and Forests ecoregion. Mean width of the Snake River sites was 45 m (148 ft), velocities ranged from 0-88 cm/s (0-2.9 ft/s), and depths ranged from 3-214 cm (0.1-7 ft; Table 1).

The Yellow Medicine River is located in the Northern Glaciated Plains ecoregion of western Minnesota. The study sites were located approximately 4 and 5 km (2.5 and 3 miles) upstream from the confluence with the Minnesota River. The Yellow Medicine River sites were narrower than the Zumbro and Snake river sites, with a mean width of 22 m (72 ft). Similarly, the ranges of velocities and depths were narrower, 0-86 cm/s (0-2.8 ft/s), and 6-139 cm (0.2-4.6 ft), respectively (Table 1).

In addition to our three primary study streams, spawning walleye observations were made at two sites on the Mississippi River, located approximately 10 and 13 river kilometers (6 and 8 miles) downstream from Lake Bemidji. This section of river is an important spawning area for walleyes in the downstream lakes.

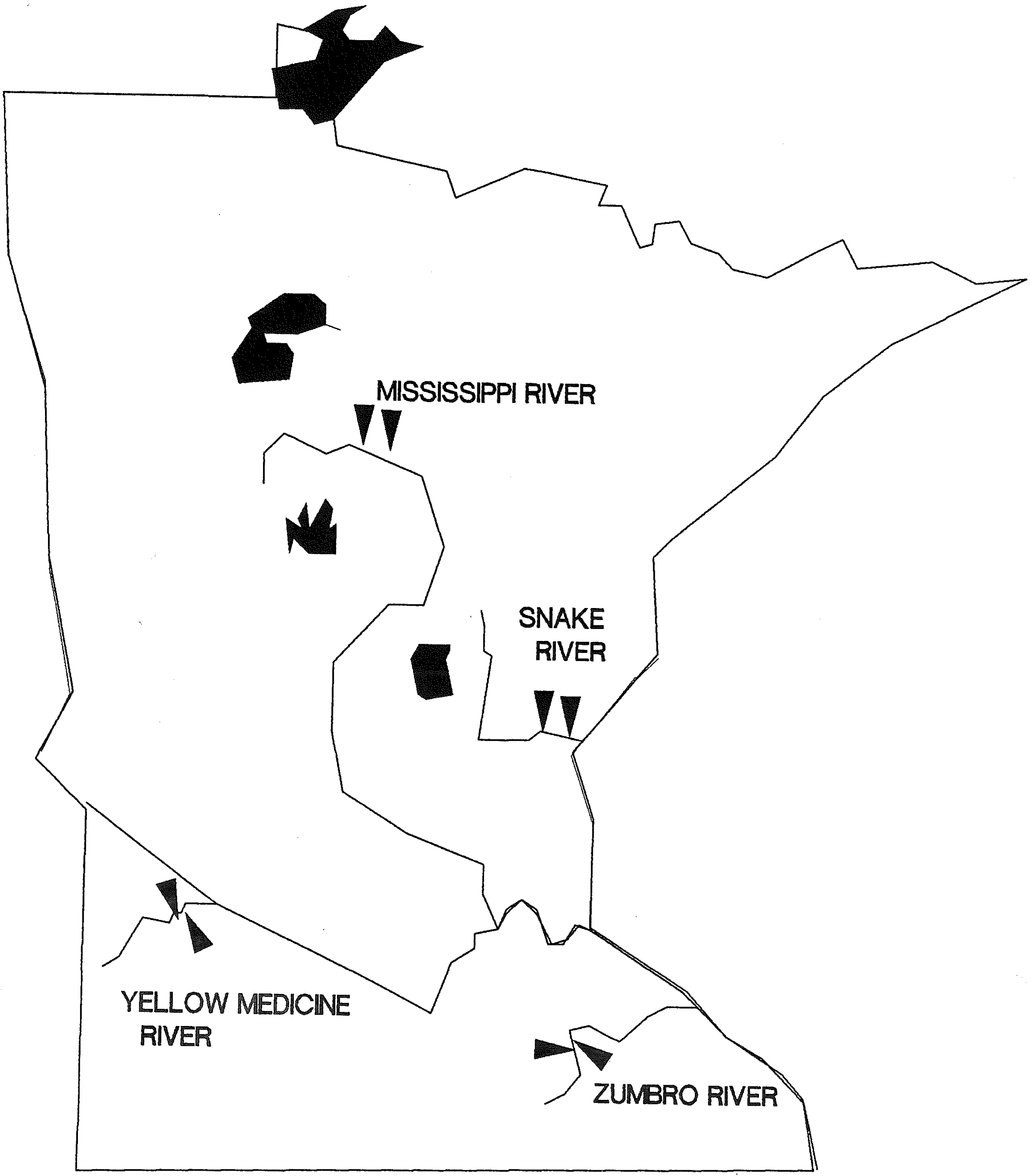


Figure 1. Map of Minnesota showing location of study streams and sites where habitat suitability data was collected. The study sites are indicated by arrows.

TABLE 1. Physical, hydrologic, and chemical characteristics of the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

Characteristic	Zumbro	Yellow Medicine	Snake
Median annual flow m^3/s (cfs)	13.5 (476)	2.2 (78)	15.0 (529)
Maximum recorded flow m^3/s (cfs)	1017 (35887)	487 (17185)	405 (14291)
Minimum flow m^3/s (cfs)	0.8 (28)	0	0.2 (7)
Median March flow m^3/s (cfs)	32.8 (1157)	2.7 (95)	6.3 (222)
Median April flow m^3/s (cfs)	20.5 (723)	4.4 (155)	55.3 (1951)
Median July flow m^3/s (cfs)	11.1 (392)	1.3 (46)	10.2 (360)
Median September flow m^3/s (cfs)	7.2 (254)	0.2 (7)	6.8 (240)
Median January flow m^3/s	5.3 (187)	0.1 (4)	2.9 (102)
Gradient m/km (ft/mi)	0.5 (2.6)	2.3 (12.2)	1.9 (10.1)
Mean width m (ft)	42 (138)	22 (72)	45 (148)
Total Phosphorus (ppb)	112-157	82-143	52-135
Nitrates (ppb)	712-5590	5-32	32-206
Total Suspended Solids (ppm)	3.7-5.3	10.2-19.8	22.6-49.1
Conductivity (mmhos/cm)	530-620	990-1340	181-260

METHODS

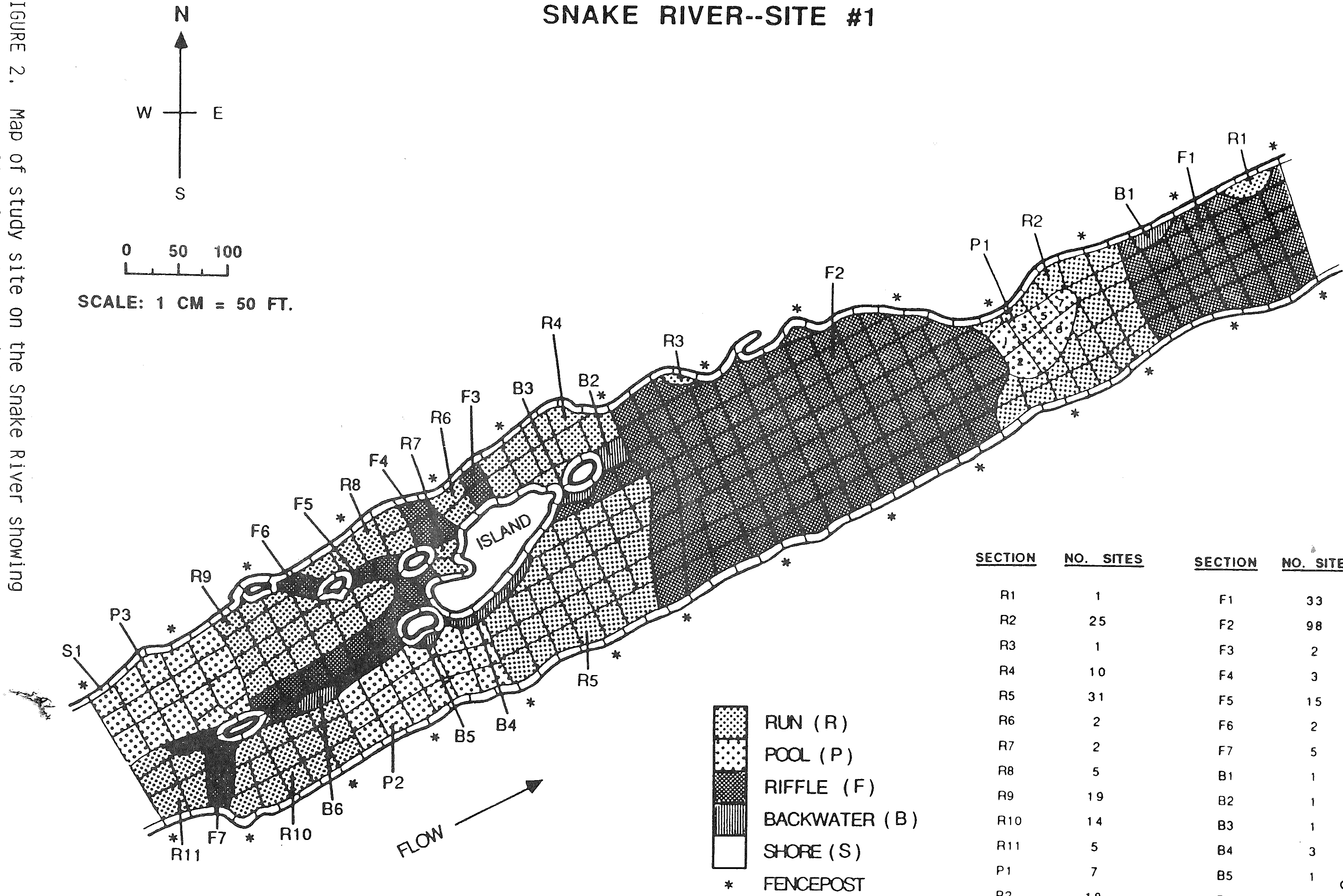
SAMPLING DESIGN

Three sets of data were collected in this study. First, habitat availability data were collected by the transect method used by Bovee (1986). These microhabitat data were used to map and describe the sites and included measurements of depth and velocity, determination of substrate composition, and the identification of cover types, if present. Fourteen transects were spaced 30 m (100 ft, or approximately one stream width) apart, perpendicular to the thalweg in each study site on each river. Habitat data were collected at 3 m (10 ft) intervals in the Zumbro and Snake rivers, every 1.5 m (5 ft) in the Yellow Medicine River, and at each shoreline edge along these transects. Discharge measurements were also made each time habitat availability was collected.

Habitat was subjectively classified as pool, riffle, run, backwater, or channel margin (the area within 1.8 m (6 ft) of the shoreline) so sampling locations within these strata could be chosen using a stratified random design. At the beginning of each sampling period, maps were drawn which divided these strata into individual sampling cells measuring approximately 7.6 m (25 ft) square on the Zumbro River, and 3 x 7.6 m (9.8 x 25 ft) on the Snake and Yellow Medicine Rivers (Figure 2). A random numbers table was used to determine the order by which the 5 strata types were sampled on a given sampling date. Sampling cells within a strata were also chosen using a random numbers table. To avoid bias due to repeated sampling of a specific cell, each location was only sampled once during a sampling period. Sampling periods were 3 - 4 weeks long (Table 2).

Second, fish species and lengths were recorded for every sample. Fish collected in each sample were placed immediately into a container of water, identified to species, and measured for total length in millimeters. When many fish of a particular species life stage were caught in one sample, only the first ten measurements were recorded. The number of fish remaining was recorded along with a corresponding length range. After the fish regained equilibrium, they were returned to the location of capture.

Third, microhabitat data were recorded at each sampling location, regardless of whether or not fish were captured. These habitat data comprised the habitat availability data base from which habitat preference relationships were developed (see Data Analysis; Habitat-Use and Preference Relationships). Variables recorded with each sample included date, water temperature (°C), air temperature (°C),



SECTION	NO. SITES	SECTION	NO. SITES
R1	1	F1	33
R2	25	F2	98
R3	1	F3	2
R4	10	F4	3
R5	31	F5	15
R6	2	F6	2
R7	2	F7	5
R8	5	B1	1
R9	19	B2	1
R10	14	B3	1
R11	5	B4	3
P1	7	B5	1
P2	18	B6	1
P3	17	S1	141

FIGURE 2. Map of study site on the Snake River showing sampling locations and strata.

TABLE 2. Instream Flow Incremental Methodology (IFIM) sampling periods for the Zumbro, Yellow Medicine, and Snake rivers in Minnesota.

Date	River	Site #
August 14-Sept. 3, 1987	Zumbro	1
September 14-Oct. 2, 1987	Zumbro	2
April 20-May 4, 1988	Yellow Medicine	2
April 26-28, 1988	Mississippi River - Spawning Walleye Observations	
May 5-13, 1988	Yellow Medicine	1
May 19-June 1, 1988	Zumbro - Spawning Smallmouth Bass Observations	
May 19-26, 1988	Zumbro	2
June 2-7, 1988	Zumbro	1
June 15-21, 1988	Snake	1
June 22-30, 1988	Snake	2
July 7-13, 1988	Zumbro	1
July 15-20, 1988	Zumbro	2
August 4-12, 1988	Snake	2
August 11-17, 1988	Snake	1
August 22-29, 1988	Yellow Medicine	2
August 31-Sept. 13, 1988	Zumbro	1
September 12-15, 1988	Zumbro	2

staff gage reading, weather, sample location, gear type, three water depth measurements, three mean column velocity measurements, percentage of each substrate type, embeddedness, cover types, shade, species of fish captured, fish length, and number of fish at a length. Water velocity was measured with a Price AA Current Meter, a Gurley Current Meter, or a Pygmy Meter (for depths less than 30.5 cm (1 ft)). Velocity was measured at 0.6 of the depth in water less than 0.76 m (2.5 ft). In water deeper than 0.76 m, velocity was measured at 0.2 and 0.8 of the depth and averaged. Depth and velocity were measured at three points within each sample location- at the upstream and downstream boundaries of the sample cell and in the middle. These measurements were averaged to obtain one depth and one velocity value per sample.

Substrate was characterized according to the size categories in Table 3. At each sampling location, substrate complexity, or the percent of the area covered by each substrate type, was recorded to the nearest 10%. The substrate size categories are similar to those used by Bovee (1986), but fewer categories were used. With practice, substrate composition could be determined visually in clear water, by feeling with hands or feet in turbid water, or with a 3 m (10 ft) copper pipe in deep, turbid areas. The dominant substrate was defined as the substrate found in the largest quantity in a cell.

Embeddedness was determined according to Bovee (1986), and given a ranking of 1 (0-25%), 2 (25-50%), 3 (50-75%), or 4 (75-100%). Cover types were recorded as no cover, undercut bank, vegetation, woody cover, boulder, flotsam, canopy, or edge (cover provided by current breaks). Shade was recorded as present or absent.

TABLE 3. Size categories used for characterizing substrate.

Substrate Type	Diameter (in.)	Diameter (mm)
Silt	<0.0024	0 - 0.062
Sand	0.0024 - 0.125	0.062 - 3.2
Gravel	0.125 - 2.5	3.2 - 64
Cobble	2.5 - 5.0	64 - 128
Rubble	5.0 - 10.0	128 - 256
Small boulder	10.0 - 20.0	256 - 508
Large boulder	20.0 - 40.0	508 - 1016
Bedrock	<40	<1016

SAMPLING GEAR

Seven types of sampling gear were assessed in August - October, 1987. The prepositioned area shocker was determined to be the most versatile and quantitative gear. Pools, and other areas too deep to effectively sample with the prepositioned shocker, required other methods. The same area (14 m^2 (150 ft^2)) was sampled with all techniques to allow pooling of data collected by the various gear. Only the purse seine and prepositioned area shocker were used in the 1988 field season.

Prepositioned Area Shocker

The prepositioned area shocker used in this study was modeled after that described by Bain et al. (1985). The first one used was modeled directly after Bain's prototype with insulation on sections of the electrodes. When schools of shiners were observed passing through the unit unaffected, the electrodes were modified and made of bare 6 gauge copper wire. The modifications noticeably increased the effectiveness and durability of the device under the conditions encountered in this study (Figure 3). Our modified units apparently had a more uniform electrical field; thus, fish were never observed to pass through the grid unaffected. By using the heavier uninsulated wire, the unit was also less cumbersome to set. The prepositioned area shocker sampled an area 1.8 x 7.6 m (6 x 25 ft). After the unit was set, it was left undisturbed for a minimum of 11 minutes, as recommended by Bain et al. (1985). A catch net with 3.2 mm (1/8") mesh was held directly downstream from the grid (Figure 3). Two people with dip nets with 3.2 mm (1/8") mesh were positioned on either side of the catch net. The unit was powered by a 3000 watt, 250 volt AC generator, which, in contrast to direct current (DC), allowed fish to be stunned and collected where they were located without the movement associated with electrotaxis. The prepositioned area shocker was activated for 20 seconds, after which one of the investigators entered the grid to net and dislodge any fish caught in the substrate. For safety, both netters remained outside of the grid and one person remained at the switch at all times during operation. The prepositioned area shocker was very effective for all sampling locations less than 1.2 m (4 ft) deep and was used to collect over 95% of the samples taken in this study.

Purse Seine

Deep pool areas 1.2 - 3.4 m (5 - 11 ft) were sampled with a 15.2 x 3.7 m (50 x 12 ft) 6 mm (1/4") mesh purse seine in the 1988 field season. End poles were added to the seine to allow a more complete closure (Figure 3). One end of the seine was held stationary as the other end was pulled out into an arc, then walked or swum downstream. Upon closure, the seine was pursed, pulled ashore, and emptied.

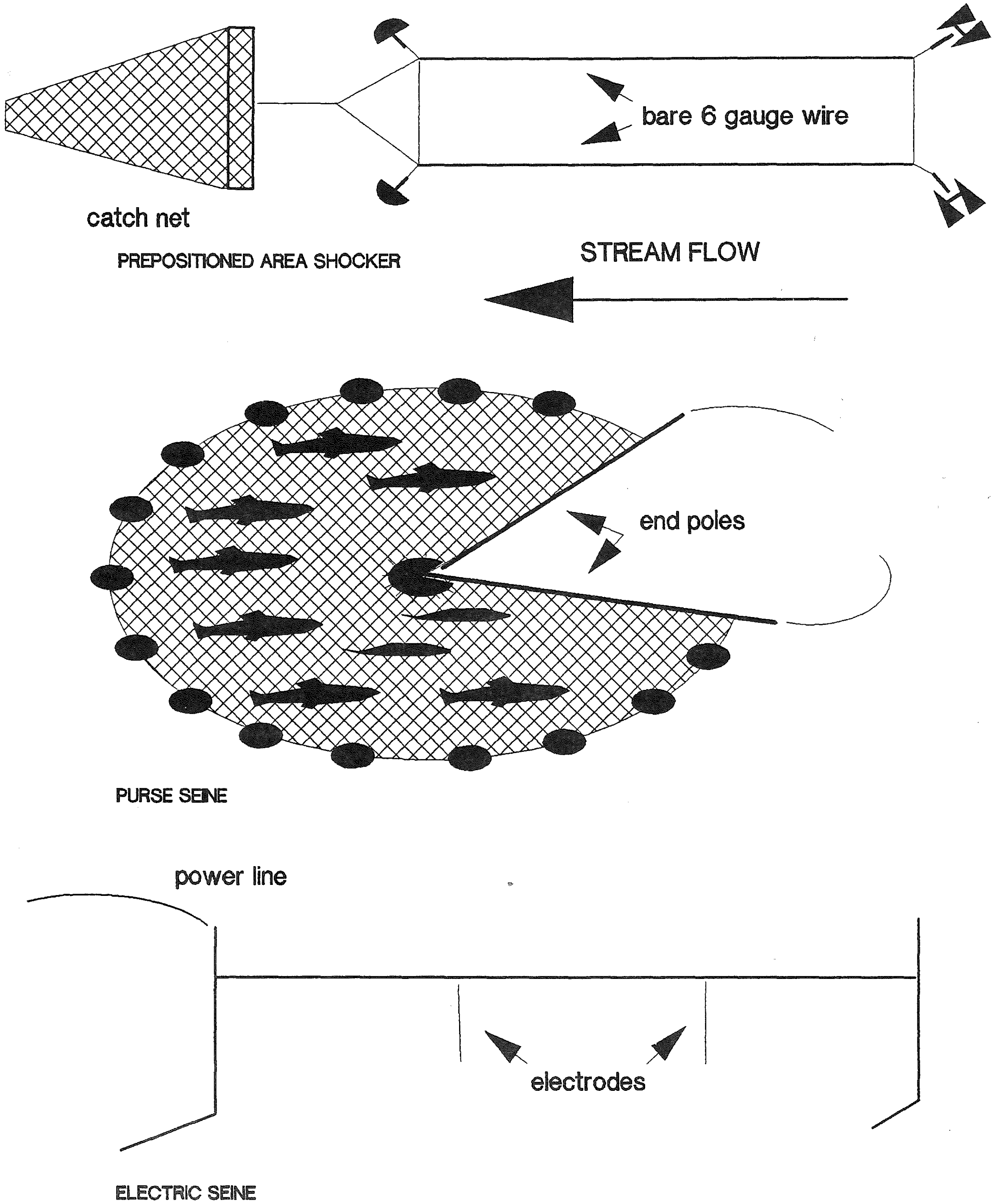


FIGURE 3. Devices used for sampling fish in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota for development of habitat suitability criteria.

Electric Seine

A 3.6 m (12 ft) electric seine was also constructed and used for sampling in some situations in 1987 (Figure 3). The electric seine was effective for sampling fish in water less than 1 m (3.3 ft), but did not have any advantages over the prepositioned shocker which was a more subtle technique. The same power source was used for the prepositioned shocker and the electric seine.

Mobile Probes

Mobile probes were used in 1987 for some sampling locations which had large amounts of cover. They were not used in 1988 since the prepositioned area shocker proved more effective for these areas. The mobile probes were 2.1 m (7 ft) long and were also operated with the 3000 W AC generator.

Conventional Seine

A 7.6 x 1.8 m (25 x 6 ft) seine with 3 mm (1/8") mesh was tested in the 1987 field season. Conventional seines were not used during the 1988 field season due to the greater effectiveness of the purse seine.

Snorkeling

Areas deeper than 1.5 m (5 ft) were sampled by snorkeling in 1987. Two adjacent 7.6 m (25 ft) passes were made over an area, and all fish within the area were counted and identified. This method was discontinued in 1988 due to its incompatibility with other gear, its ineffectiveness in turbid water, and the difficulty of making species identifications.

Cast Nets

Two 3 m (10 ft) diameter cast nets, one with 6 mm (1/4") mesh and one with 10 mm (3/8") mesh, were field tested in 1987 for sampling moderately deep pool and backwater areas. Although cast nets were moderately effective for sampling water up to 1 m (3.3 ft) deep, they were not used in 1988 due to the variability of the area which they effectively sampled and the greater effectiveness of the prepositioned area shocker.

Visual Observation

Spawning walleyes and smallmouth bass were visually observed and habitat data were recorded in those areas. Habitat use by spawning walleyes was recorded April 26-28, 1988 at two sites on the Mississippi River, located approximately 10 and 13 river kilometers (6 and 8 miles) downstream from Lake Bemidji. Both nighttime and daytime observations were made as three equally-spaced observers walked upstream through known spawning areas. Bridge spikes with net floats were used to mark locations of spawning walleyes. Depth, velocity, substrate, and cover were recorded later at these locations.

During May, 1988 smallmouth bass nests in the Zumbro River were observed while drifting downstream in a boat. These observations were made from Zumbro Dam to the end of our downstream study site. When a nest or smallmouth bass was seen, observers waded through the area, located additional nests and recorded microhabitat data at each nest. Section of Fisheries personnel from Lake City, Minnesota located many of the spawning areas previously during boat electrofishing and tagging operations and marked the areas with floats. Since these boat electrofishing operations effectively sampled the majority of the river we drifted through, it is likely that the important spawning areas were identified.

DATA ANALYSIS

All habitat preference histograms and suitability curves were constructed from presence/absence (unweighted) data of a species unless otherwise indicated. Weighted data (habitat-use weighted by the numbers of individuals of a species life stage in the sample) were used occasionally to construct suitability curves, especially if the fish were spawning or in the fry stage, because these fish were concentrated in very localized areas. Assumptions associated with this decision are covered in the discussion section. No data from different gear types were pooled for a species life stage if a gear type was ineffective for that life stage. Length breaks separating life stages were determined from length frequency data collected during the first field season when possible and from life history literature from similar latitudes (Appendix II).

HABITAT AVAILABILITY

Frequency distributions of the microhabitat data were calculated to represent the available habitat for sampled areas within the sites. Data from each river and each flow were evaluated separately, but the two study sites from each river were combined. The proportions of available habitat were used in combination with fish habitat-use data to create habitat preference histograms and curves.

HABITAT-USE AND PREFERENCE RELATIONSHIPS

Habitat-use and preference values were calculated for each species life stage for velocity, depth, substrate complexity, relative substrate, dominant substrate and the largest substrate coded. To calculate these:

1) Each habitat variable was divided into intervals; for example, depth intervals would be set up as 0-5 cm, 5.1-15 cm, 15.1-25 cm, and so on.

2) For each interval (indicated by a subscript i), the total number of samples taken T_i, the number of samples which contained the species life stage of interest S_i, and the number of individuals of the species life stage N_i were calculated.

3) The proportion of samples that were taken in each available habitat interval was calculated as $H_i = T_i / \Sigma T_i$.

4a) When calculating an unweighted preference with presence/absence data, habitat use U_i was calculated as $U_i = S_i / \Sigma S_i$.

4b) When calculating a weighted preference with data on each individual fish, habitat use U_i was calculated as $U_i = N_i / \Sigma N_i$.

5) A preference index P_i was calculated as $P_i = U_i / H_i$.

6) Preference values were obtained on a normalized scale of 0.0 to 1.0 by dividing each preference index by the maximum preference index. A preference value of 0 indicates least preferred or not used; a value of 1 denotes maximum preference or most frequently used.

When more than one flow was sampled, preference values were calculated for each flow. A composite preference curve was then computed by weighting the preference data for each flow by the number of observations at that flow and fitting a curve to the composite preference values.

DEVELOPMENT OF HABITAT PREFERENCE CURVES

Preference curves were constructed for each species life stage and represent the optimum range of microhabitat variables of depth, velocity, substrate, and cover. Several techniques were assessed to construct the habitat preference curves from preference values, including histogram analysis, nonparametric tolerance limits, and nonlinear regression. All three techniques are described below. Preference curves were developed for depth and velocity, and histograms were used to depict preferences among cover and substrate types. Curves can also be fit to ordered substrate ranges, but the value of doing this is questionable. Curves are not normally fit to cover data, since cover is an attribute of an area rather than a quantitative variable.

Histogram Analysis

A histogram is created by plotting the preference values against the habitat variable being examined (depth, velocity, substrate, or cover). This technique is the simplest but may misrepresent the preference relationship. Sampling error tends to produce irregular histograms, especially when the sample size is small for certain portions of the variable range. For example, greater depths have smaller and smaller sample sizes, and consequently, greater error. These irregularities can be reduced somewhat by widening the interval from which the preference values are derived.

Nonparametric Tolerance Limits (NPTL)

In order to fit a curve using NPTL, upper and lower limits must be identified, which contain 50, 75, 90, and 95% of the observations. Nonparametric tolerance limits for different sample sizes and confidence levels were calculated by Somerville (1958). A preference curve is derived from tolerance limit curves for habitat use and availability. The resulting "preference curve" forms a polygonal bell. This technique was described in detail by Bovee (1986). NPTL can be used to fit various types of data, but gives a relatively simplistic representation of the preference function.

Nonlinear Regression

Nonlinear regression was used to fit curves to the preference values represented by the bars of a histogram. Nonlinear regression techniques probably gave the best estimate of the preference function and were best suited to the requirements of this study. Several nonlinear regression software packages are available; the NONLIN module of SYSTAT (Wilkinson 1988) was used in this study. Nonlinear regression uses an appropriate equation to describe the preference function. Preference values for depth or velocity and the equation used to describe the relationship are input into the program. Coefficients in the equation are manipulated by the computer until the sum of squared deviations of the preference values from the curve is minimized (least squares). The generalized Poisson density function yields a low least squares value, and because of its robustness, accurately fits skewed distributions. Consequently, all velocity preference curves were fit using the generalized Poisson equation:

$$\text{Preference} = (((B-X)/(B-A))\hat{\ }C)*e\hat{\ }((C/D)*(1-((B-X)/(B-A))\hat{\ }D))$$

where:
- A = value of "X" where f(X) = 1.0
- B = value of "X" where f(X) = 0.0 (X<B)
- C = shape parameter for part of the curve to the right of X=A
- D = shape parameter for part of the curve to the left of X=A
- e = base of the natural logarithm
- X = habitat variable (Bovee 1986)

The Poisson equation describes a bell-shaped curve (it may be severely skewed) and is most appropriate where preference approaches zero at the upper end of the variable range. Depth preferences for some pool species, however, may continue to increase as depth increases throughout the sampled range. Either the Poisson equation or the logistic function can be used to fit these asymptotic preference functions. If the maximum observed preference values are equal to one, the Poisson will peak at that point. If it is reasonable to assume that values beyond the observed range also have a preference of one, all values to the right of the Poisson curve's peak are given a preference of one. This yields a curve which has a lower least squares and is a better fit than the logistic equation, due to the more robust abilities of the Poisson equation.

The logistic function has been used in situations where the preference relationship approaches an asymptote at the upper end of the variable range. Its form is:

Preference = A/(1+B(e^(-C*X)))

where: A = the maximum value of f(X)
B = control parameter for value of f(X) when X = 0.0
C = control parameter for the value of "X" at the inflection point of the curve (Bovee 1986).

The logistic equation does not necessarily normalize the maximum preference value to one, so all values must be divided by the maximal preference estimate to yield a preference curve. This can cause the curve to inflate preference values at the low end of the variable range.

Once an appropriate nonlinear equation was selected, two NONLIN minimization methods, the Quasi-Newton and the Simplex, were used to fit the equation to the preference data by adjusting the coefficients. The Quasi-Newton is more methodical and quicker than Simplex. By using first and second derivatives of the least squares function, it calculates the degree to which it should change the coefficients from one iteration to the next. The Simplex is a more random technique but is capable of solving nonlinear regression equations in some situations where the Quasi-Newton is not. Frequently, both methods were tried. Choosing the starting values for the coefficients required some understanding of how the coefficients affected the equation and the nature of the fish's habitat preferences. The default setting was 0.1 for all coefficients, but these settings were set to more reasonable values.

Tolerance limits, which decide how particular the program will be in reaching a solution, were also reset from the default when convergence could not be reached. The output gave the estimates of the coefficients and the standard error of each. Once satisfactory coefficients were attained, the equation was transferred to a Lotus spreadsheet and the estimates for any value of the habitat variable were calculated. A graphical display of the curve and the observed preference values was also constructed in Lotus.

<u>CURVE VERIFICATION</u>

Habitat preference curves from other sources such as the U.S. Fish and Wildlife Service were compared graphically with those developed in this study.

GUILD IDENTIFICATION

In order to simplify selection of species life stages for the IFIM analysis, habitat-use guilds (groups of species life stages which have similar habitat preferences) were identified. For each river, habitat-use data of all species life stages, for which at least eight individuals were collected in at least three separate samples, were analyzed by cluster analysis. The CLUSTER module in SYSTAT (Wilkinson 1988) was used for these procedures. Thirteen variables (depth, velocity, dominant substrate, largest substrate, mean substrate diameter, vegetation, undercut bank, woody debris, flotsam, canopy, boulder, composite cover, and embeddedness) were used in the analysis. For each life stage, the mean of each habitat variable was calculated from all samples where the species was present. The means of the habitat variables for each species life stage were standardized (z value) to eliminate unit bias among variables. Depth and velocity were weighted by a factor of 11 so that their contribution to the analysis would be equivalent to the 11 channel index variables (substrates and covers), as they are in the Physical Habitat Simulation Model (PHABSIM).

A K-means approach was used to cluster the species. In this approach, the number of clusters was specified, and the program iterated to sort the cases until the between group variation was maximized relative to the within group variation. This routine was run eight times for each river with two to nine clusters specified.

Two criteria were used for choosing the number of clusters (guilds) which would adequately represent the fish community. First, the number of clusters was chosen which had significant ($\underline{P} < 0.05$) between group differences for the greatest number of input variables. Second, since the specification of large numbers of clusters may yield orphaned or single species life-stage clusters, minimization of these orphans was also a criteria in guild number determinations.

RESULTS

Habitat suitability data for 35,561 fish (63 species and 155 species life stages) were collected in this study (Appendix I). Fish densities varied among the five habitat types in the rivers (Figure 4). Densities were highest in riffles in the Zumbro and Yellow Medicine rivers, and in pools in the Snake River. Habitat preference curves were calculated for life stages of the three target species (walleye, channel catfish, and smallmouth bass), if sufficient observations were made. In addition, preference curves were calculated for representative species life stages of the habitat-use guilds. The coefficients for all habitat preference curves are found in Appendix III.

The generalized Poisson equation was used to fit all depth and velocity relationships. The logistic equation was tried for some depth relationships, but it yielded much higher least squares values than the Poisson and did not properly represent the collected data. We found that most species life stages, for which sufficient observations were made to calculate preference functions, invariably had low preference values for the deepest areas in the study sites. However, deep pool habitats were relatively rare, and this limited the observations of species life stages which preferred deep pool habitats.

POOLING OF MICROHABITAT DATA ACROSS RIVERS

Microhabitat data from fish species from the three streams were pooled when the peak preference values were well within that variable's range in all rivers. When a species life stage had a peak preference value for a habitat variable near the maximum available in the stream, that stream's data was not pooled. For example, because of the low water in the Yellow Medicine River in 1988, banded darter adults *Etheostoma zonale* were found in the swiftest water available. Rather than assume that the banded darters invariably preferred that velocity, habitat preference curves and histograms were constructed from the Zumbro River data, because the Zumbro River had the greatest range of values for depth and velocity and the greatest variety of substrate and cover types. Consequently, the Zumbro data was used exclusively for species life stages preferring high velocities or deep water.

WALLEYE

Walleye populations were small in the three primary study streams, as in similar medium-sized rivers. Observations of young-of-the-year, juvenile, and adult walleyes were not of sufficient numbers to enable computation of reliable habitat preference curves (N=19 young-of-the-year, 19 juveniles, and 1 adult). However, 266 spawning walleyes were observed below Stump Lake Dam in the upper Mississippi River, which has a large spawning walleye population. Habitat-use curves for depth and velocity were computed, and a histogram for substrate was prepared (Figures 5-7). Spawning behavior, such as close escort of a female by one or more males and side by side vibrations, were observed both during the day and at night. One-way analyses of variance were used to test the differences between day and night depth and velocity use. The average depth of spawning walleyes was greater in the day (68 cm or 2.23 ft) than at night (61 cm or 2 ft; $\underline{P} < 0.001$). There was no significant difference in velocity use between day and nighttime spawning walleyes.

When conducting Physical Habitat Simulation System (PHABSIM) procedures for simulations of walleye spawning habitat, we recommend the use of dominant substrate as the third input variable (in addition to depth and velocity). Cover does not appear to be an important variable for actively spawning fish, although cover may be important during prespawning activity.

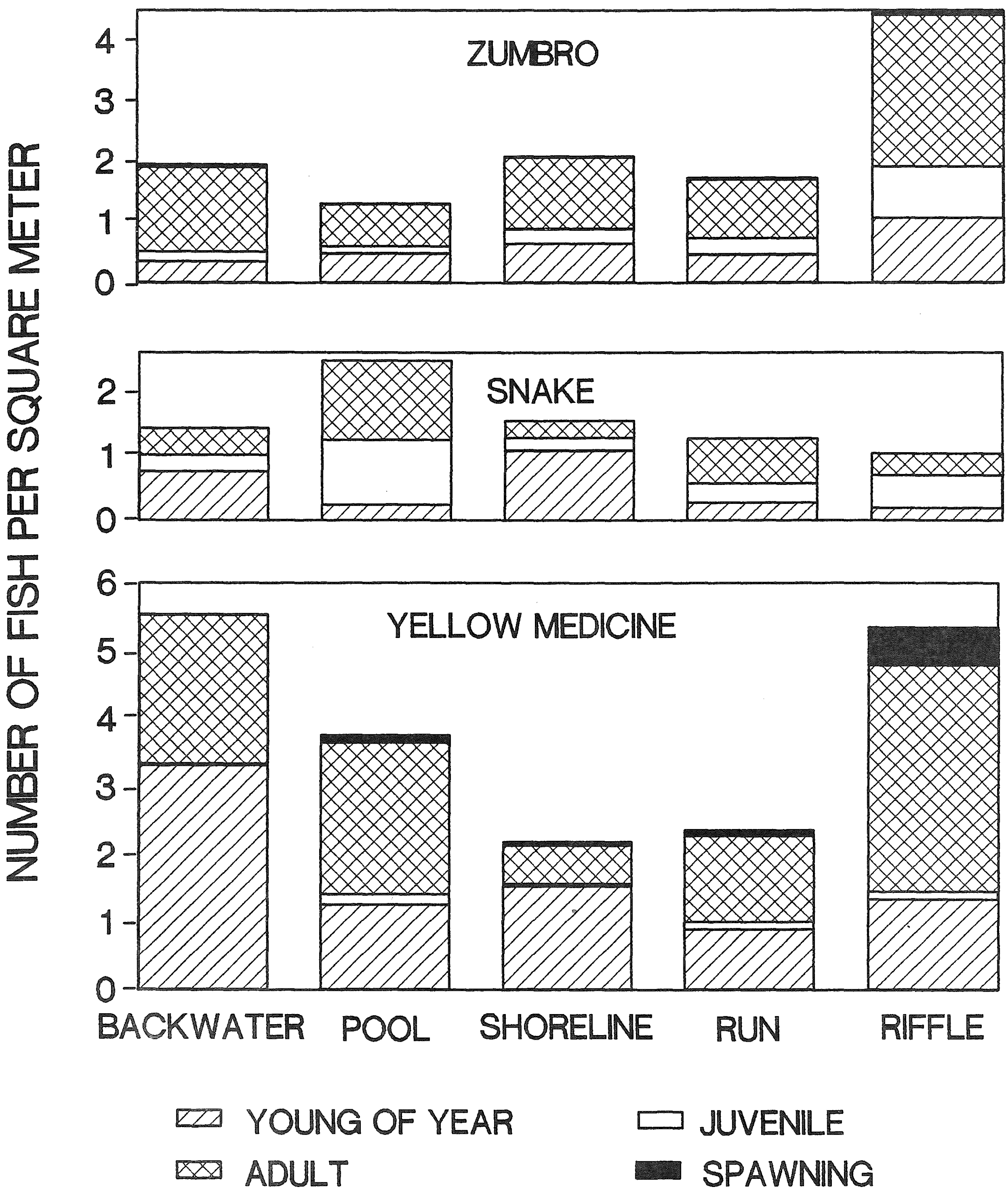


FIGURE 4. Total fish density in each habitat type in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

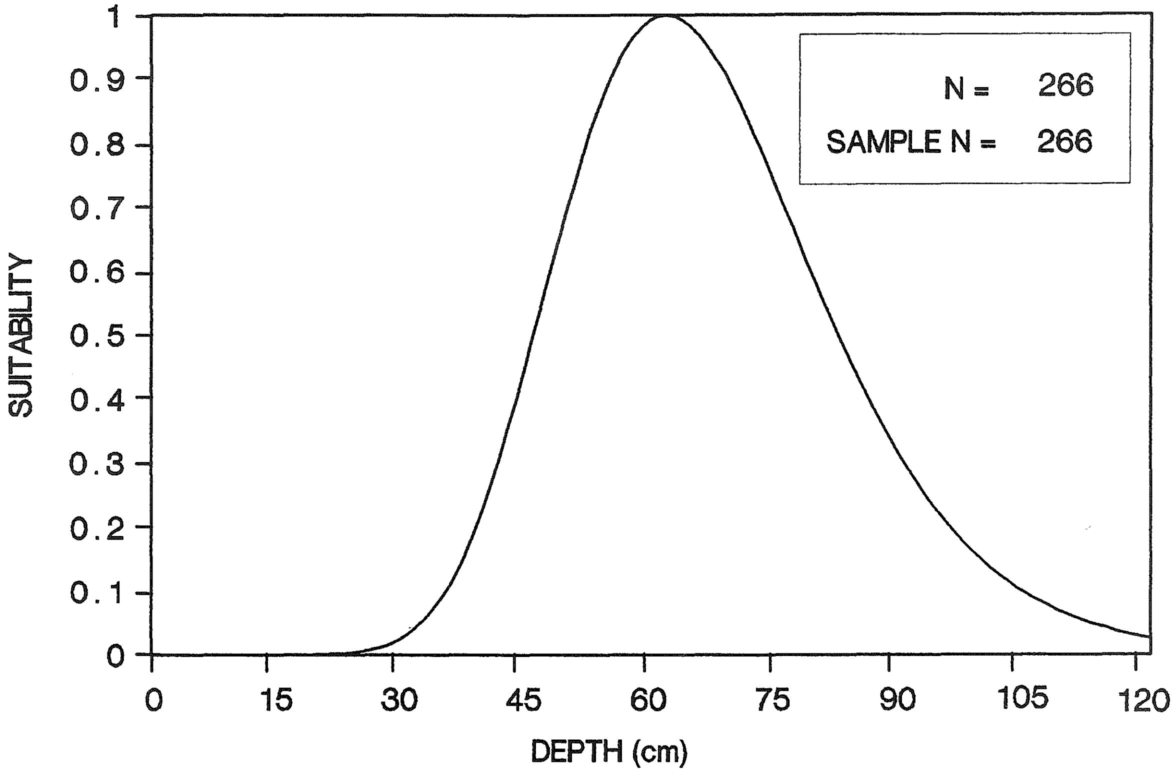


FIGURE 5. Spawning walleye depth utilization in the upper Mississippi River in Minnesota.

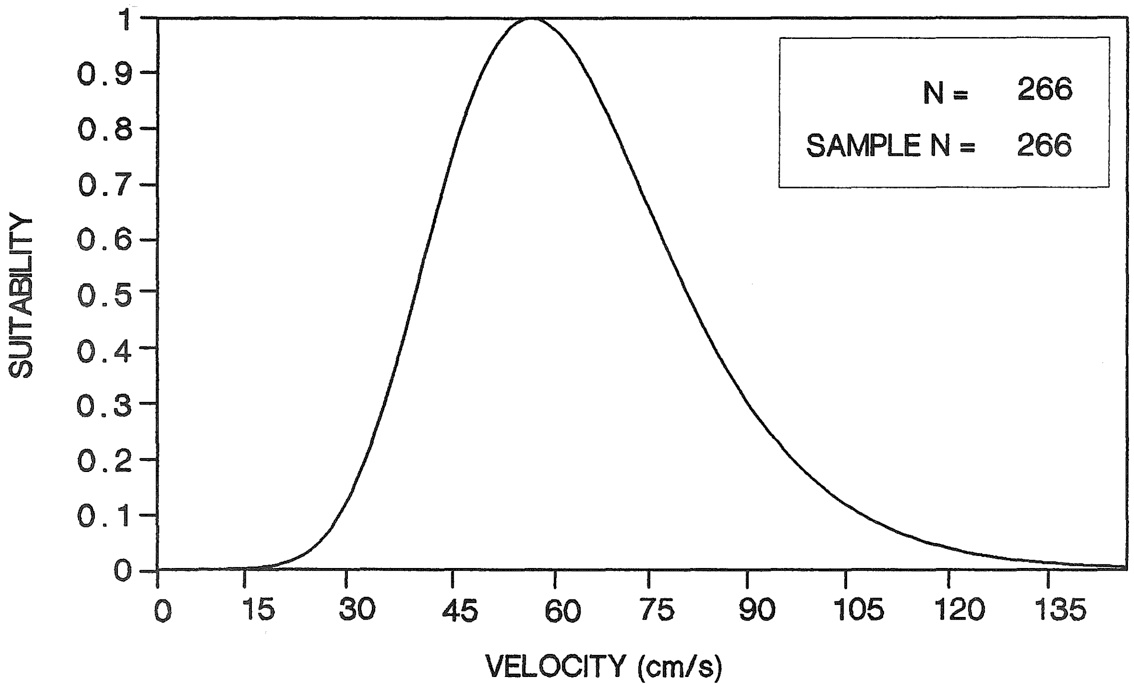


FIGURE 6. Spawning walleye velocity utilization in the upper Mississippi River in Minnesota.

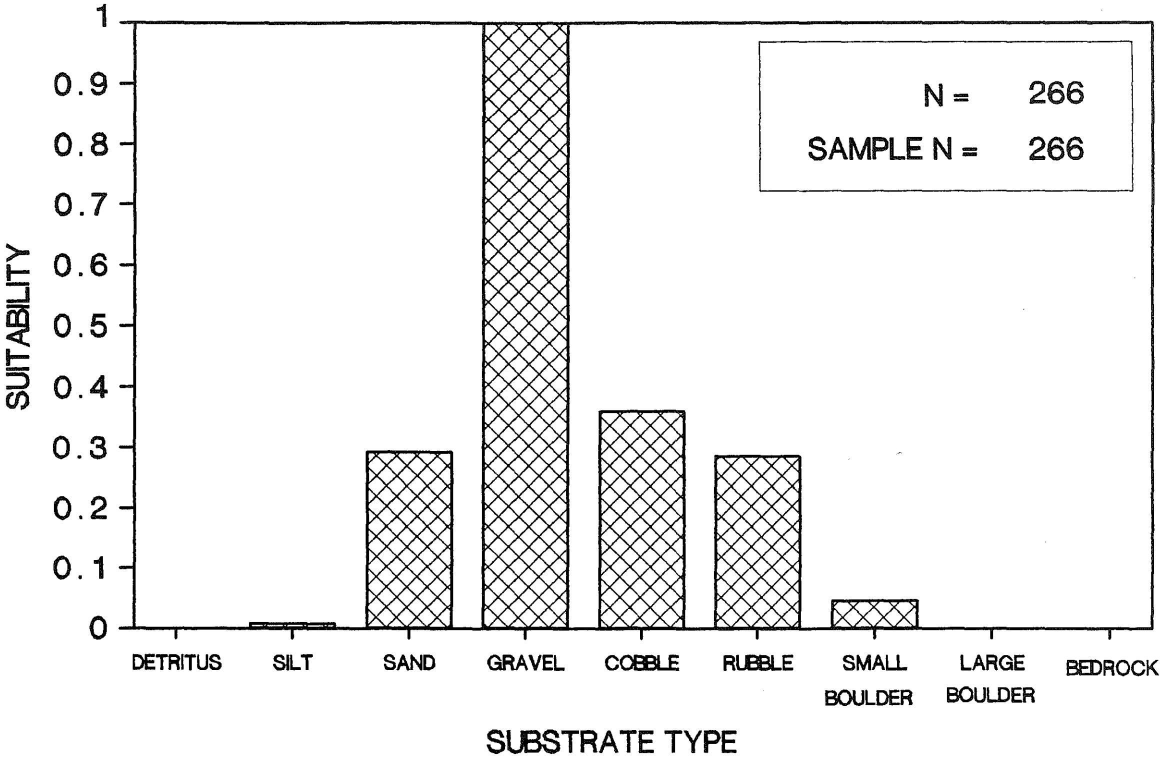


FIGURE 7. Spawning walleye dominant substrate utilization in the upper Mississippi River in Minnesota.

SMALLMOUTH BASS

The Snake and Zumbro rivers had excellent smallmouth bass populations, but the Yellow Medicine population was relatively low during the 1988 season. Habitat preference curves and histograms were developed for fry (<60 mm), fingerlings (61-99 mm), juveniles (100-189 mm), and adults (>189 mm) (Figures 8-23). Smallmouth bass fry were not collected from the Yellow Medicine River, so habitat preference curves and histograms (Figures 8-11) represent the composite of curves from the Zumbro and Snake rivers. Fingerling, juvenile, and adult habitat preference curves were constructed with data from the Yellow Medicine, Zumbro, and Snake rivers (Figures 12-23).

Young-of-the-year smallmouth bass were subdivided into fry and fingerling life stages due to obvious changes in habitat preference at approximately 60 mm (Figure 24). Nearly 99% of the smallmouth bass fry collected were taken in water flowing at less than 14 cm/s (0.5 ft/s). On the other hand, fingerlings were collected in water with velocities ranging from 0-90 cm/s (0-3 ft/s). The changes in habitat preference could have been associated with changes in food habits (Figure 25), tabulated from gut content analysis of 436 smallmouth bass. Fry and fingerling stomach samples were collected by flushing out the stomach contents with water from a squeeze bottle. Stomach samples of larger fish were collected by inserting a tube through the mouth into the stomach and creating a vacuum, thereby forcing the stomach contents into the tube when it was withdrawn. Stomachs were then flushed out with water.

Aquatic invertebrates found in the stomach samples were classified as either pool or riffle taxa based on descriptions found in Merritt and Cummins (1984). Species that were either terrestrial or hard to categorize (e.g. crayfish and leeches were found in almost all sampling locations in the Snake River) were considered 'other' taxa.

Several species of fish were also found in the stomach samples of smallmouth bass. The gut content analysis indicated that 46% of the fishes found in their stomachs were riffle species (Figure 26). Smallmouth bass from the Yellow Medicine River consumed the most fish; 65% (11 of the 17 smallmouth bass sampled) had fish in their stomachs. Thirteen percent (14 of 104) of the smallmouth bass stomachs sampled from the Zumbro River contained fish; and 4% (14 out of 315 smallmouth bass sampled) of the Snake River smallmouth bass had fish in their stomachs. These findings closely paralleled the overall densities of fish per square meter in study sites in each river. The Yellow Medicine River, with 65% of the sampled smallmouth bass piscivorous, had 14 fish per square meter (1.3 fish/m^2) in the study site sampled during low water in 1988 when smallmouth bass gut contents were sampled. The Zumbro River, in which 13% of the sampled smallmouth bass were piscivorous, had 2.3 fish per square meter (0.2 fish/ft^2) in the study sites. The Snake had 1.6 fish per square meter (0.15 fish/m^2) in the study sites, paralleling the low piscivory of sampled smallmouth bass (4%).

Habitat-use curves and histograms were developed for Zumbro River spawning smallmouth bass (Figures 27-30). Ninety-four nests were located during the 1988 spawning season, and smallmouth bass were frequently observed fanning the nests. Generally, smallmouth bass nests were located in silty areas where rooted macrophytes were abundant. Areas surrounding the nests were highly embedded with several centimeters of silt or sand over the larger substrates. The inside of the nests had been cleaned of silt and sand, and were composed of clean gravel, cobble, or rubble. All of the observed nests contained these larger substrates. Since substrate outside of the nest is most comparable to substrate observed when recording available habitat for PHABSIM, we recommend its use instead of within nest substrate suitability for spawning habitat simulations. Cover could also be used as an alternative to substrate for habitat simulations in some streams, since nests on the Zumbro river were invariably near rooted macrophytes.

Nests that had not been maintained invariably contained fungus-infected eggs or no eggs and were covered with silt and detritus. Frequently, these abandoned nests were located near actively guarded nests. Spawning areas usually did not have any measurable water velocity.

CHANNEL CATFISH

Channel catfish were most abundant in the Yellow Medicine River, although all three study streams had fishable numbers. Only 19 young-of-the-year and 22 adults were collected throughout the study, so reliable preference relationships could not be constructed. However, data from adult observations closely resemble the habitat-use data of juveniles. Habitat preference curves and histograms were developed for juveniles (Figures 31-34) from the Yellow Medicine River. Weighted data was used to construct the preference relationships because channel catfish were most abundant in a few pools with boulder or woody cover. In one location, which contained a large root crown roughly 3 m (9.8 ft) in diameter, 22 channel catfish were collected in a single sample; all of these were located very near or in the root crown. Food items found in 14 channel catfish collected in the Yellow Medicine River included: spotfin shiners (26), central stonerollers (5), common shiners (2), stonecat (1), largescale stoneroller (1), rainbow darter (1), northern hogsucker (1).

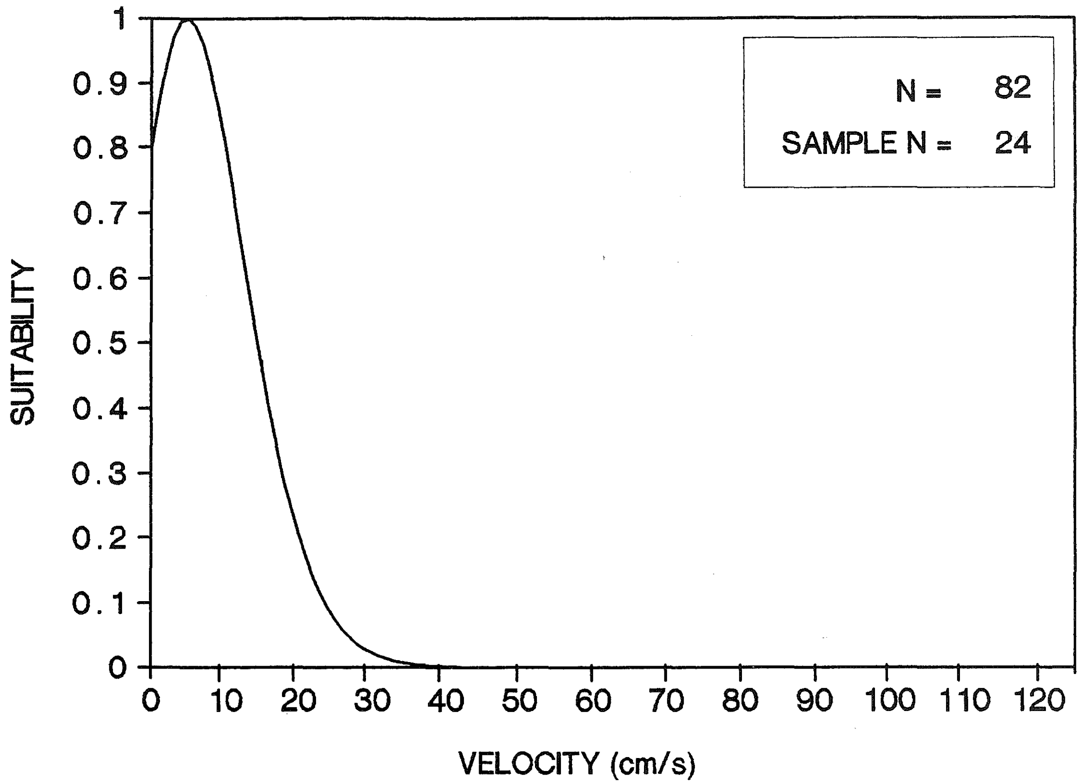


FIGURE 8. Velocity preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers in Minnesota (weighted data).

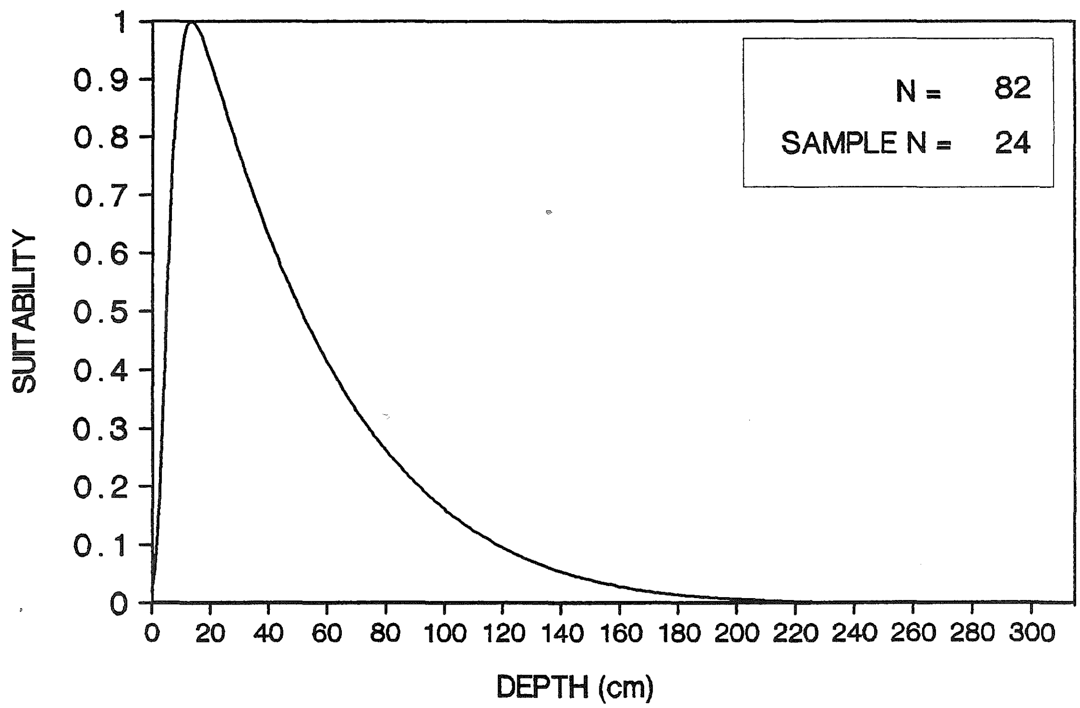


FIGURE 9. Depth preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers in Minnesota (weighted data).

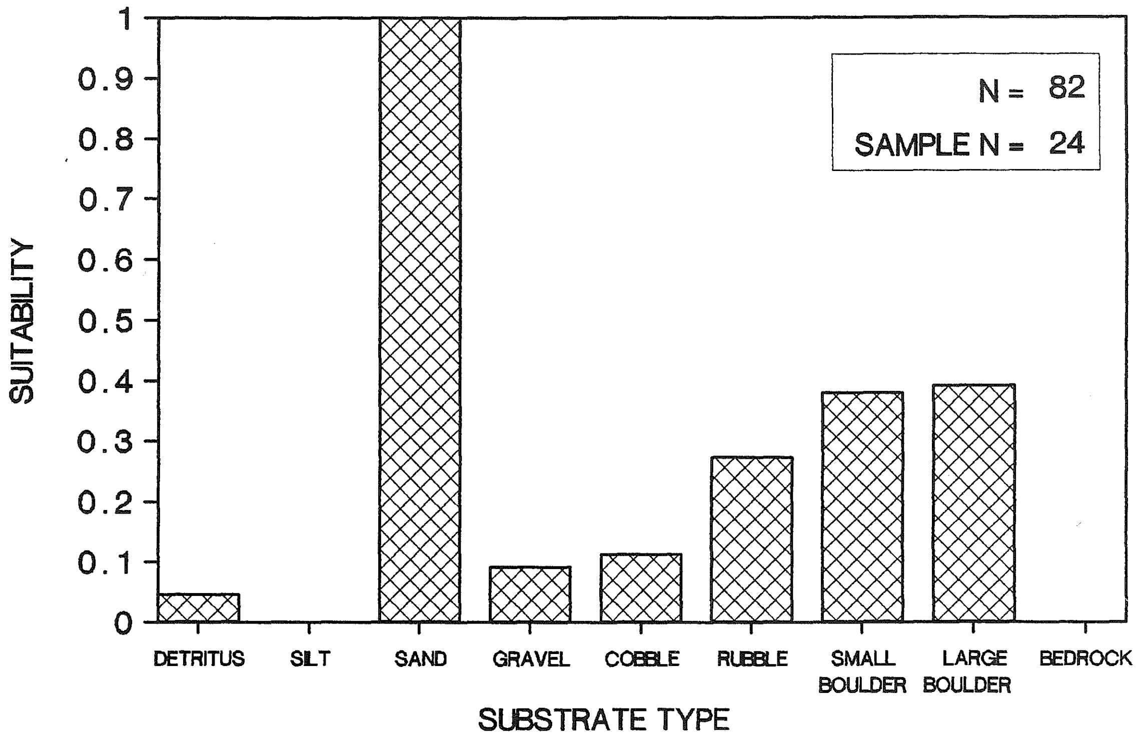


FIGURE 10. Dominant substrate preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers in Minnesota (weighted data).

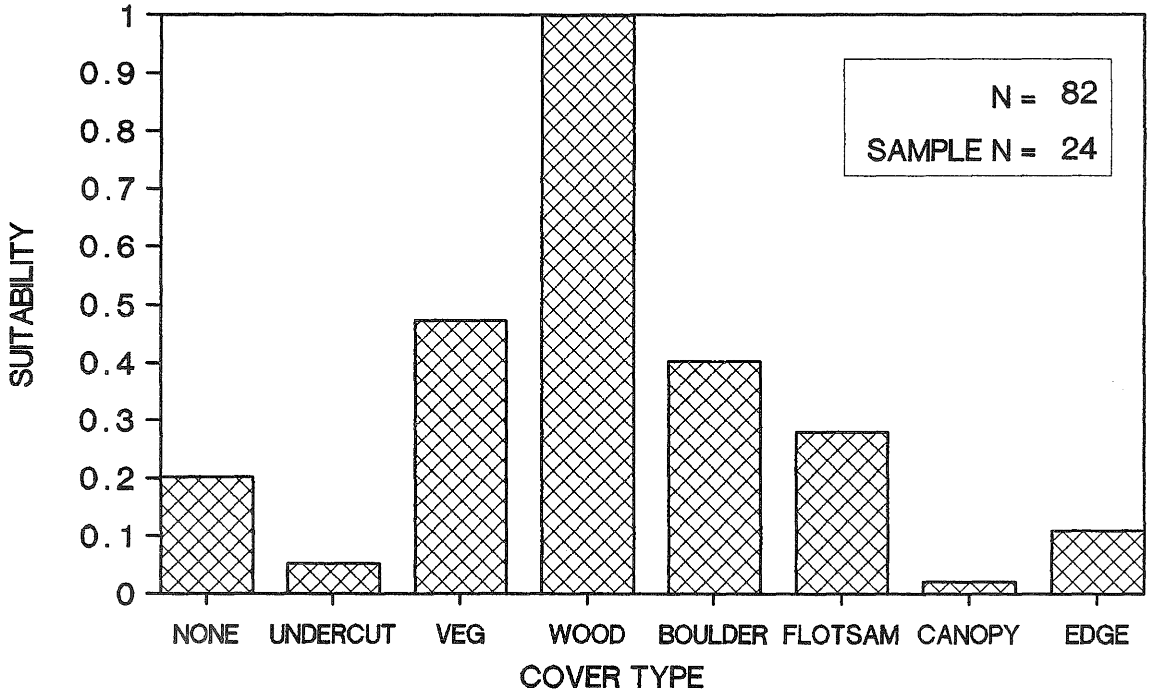


FIGURE 11. Cover preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers in Minnesota (weighted data).

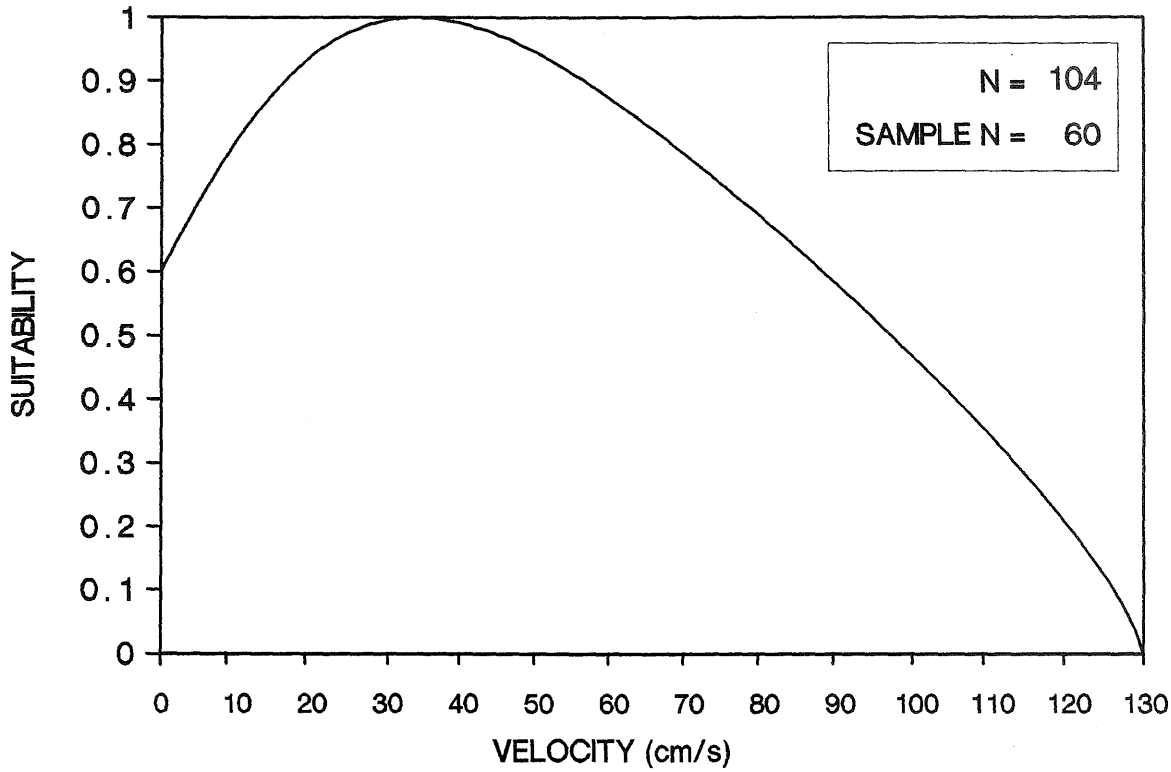


FIGURE 12. Velocity preference of smallmouth bass fingerlings (60–99 mm) in the Zumbro, Snake, and Yellow Medicine Rivers in Minnesota.

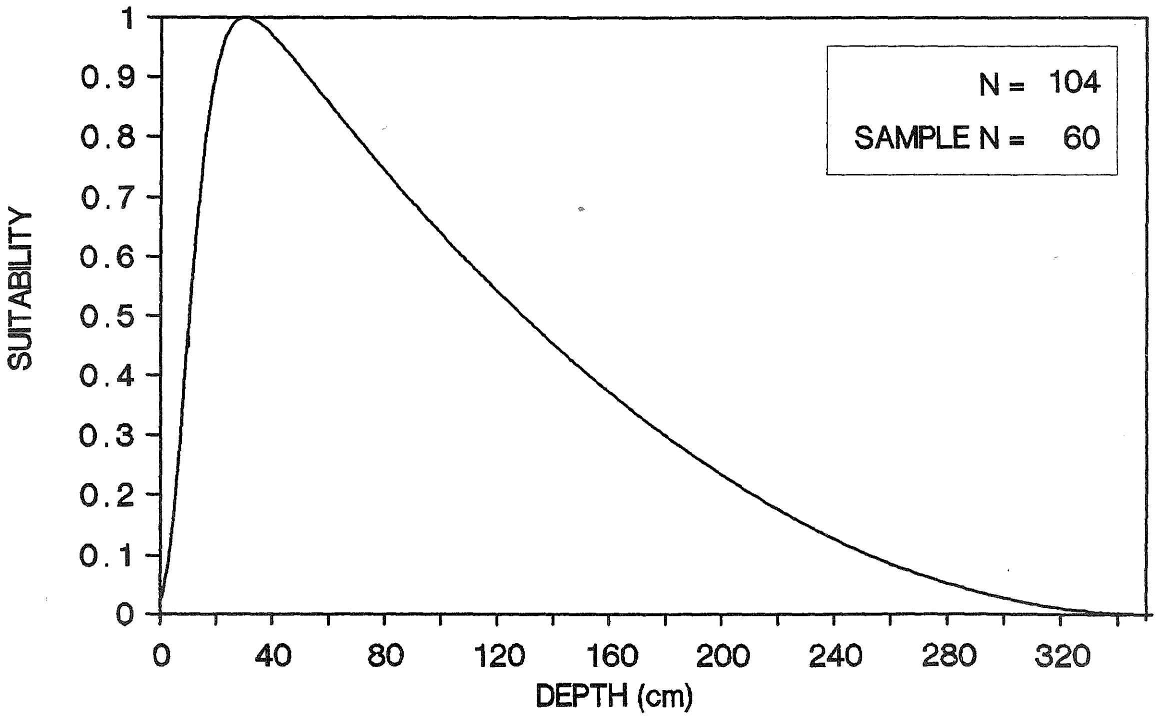


FIGURE 13. Depth preference of smallmouth bass fingerlings (60–99 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

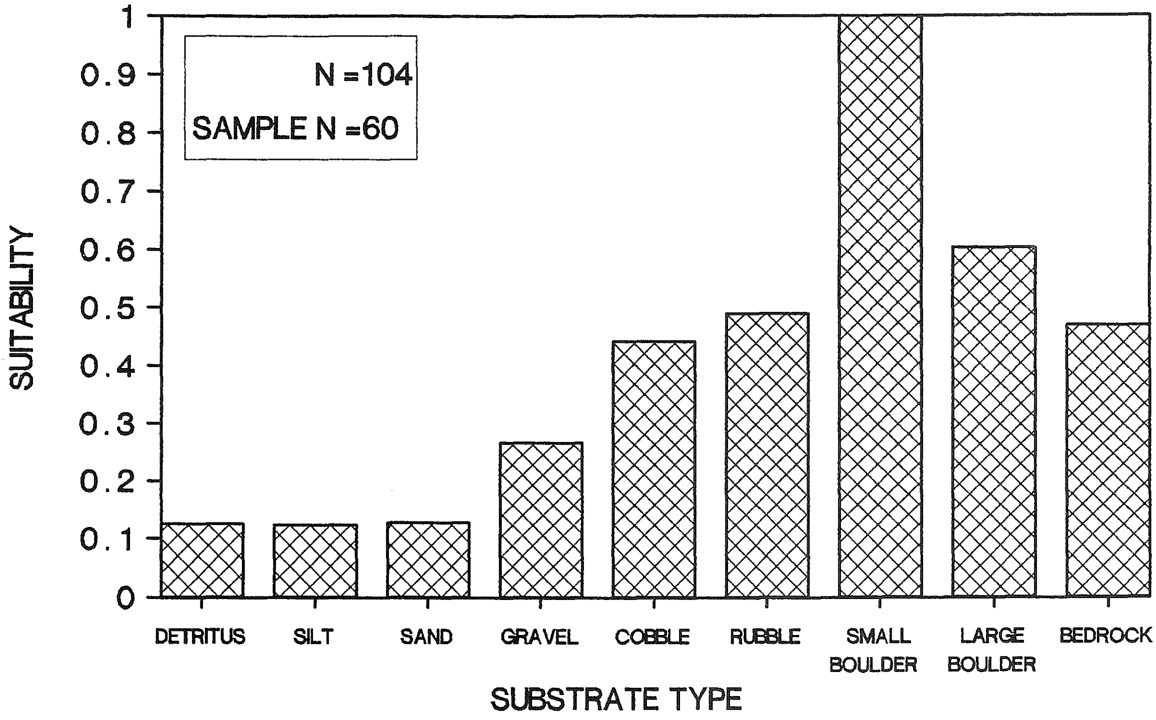


FIGURE 14. Dominant substrate preference of smallmouth bass fingerlings (60–99 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

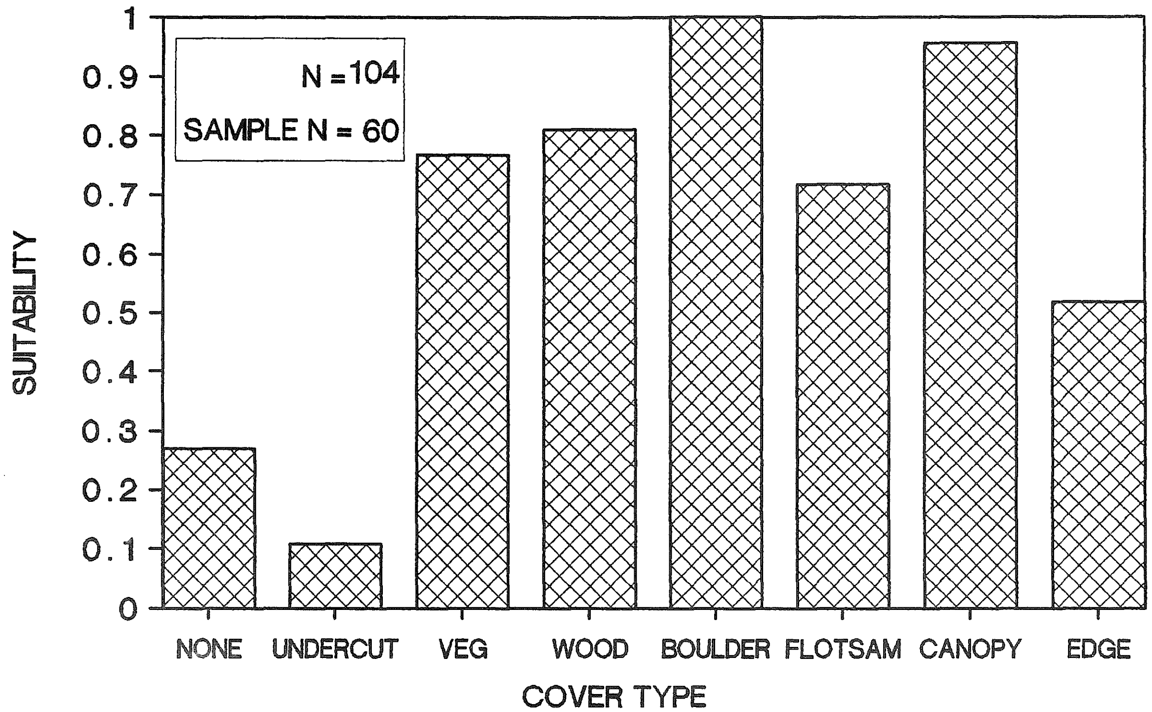


FIGURE 15. Cover preference of smallmouth bass fingerlings (60–99 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

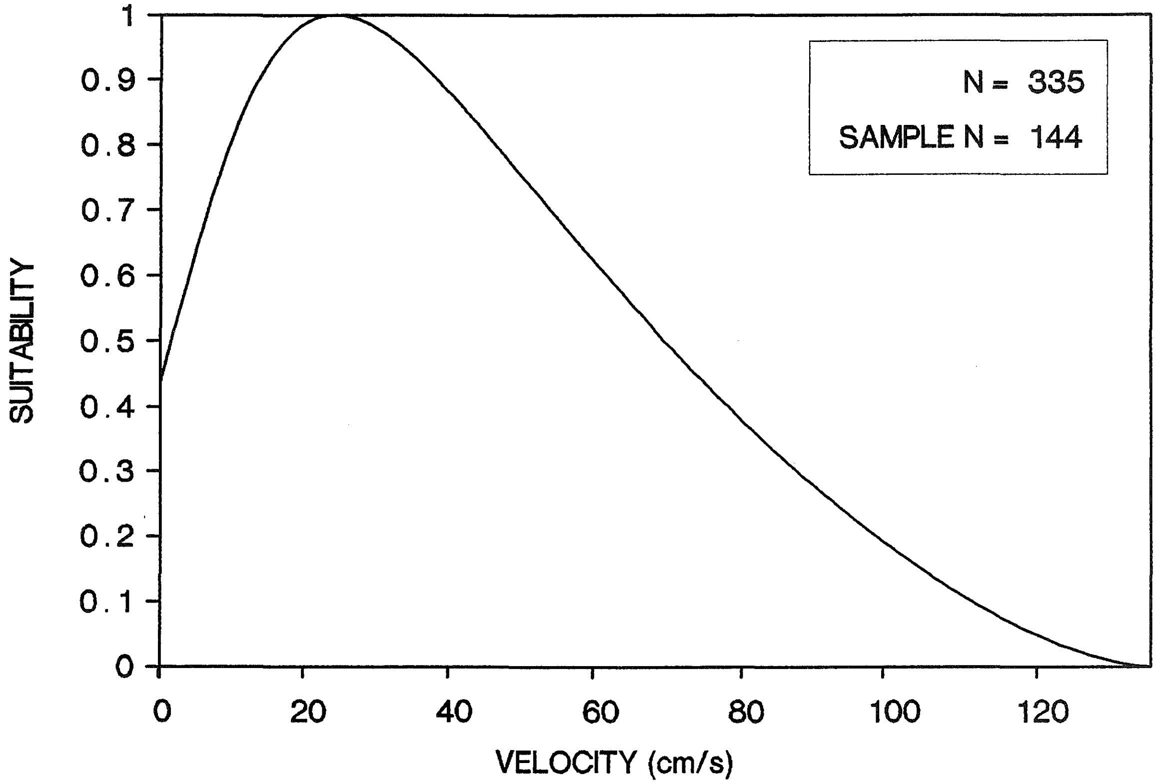


FIGURE 16. Velocity preference of juvenile smallmouth bass (100-189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

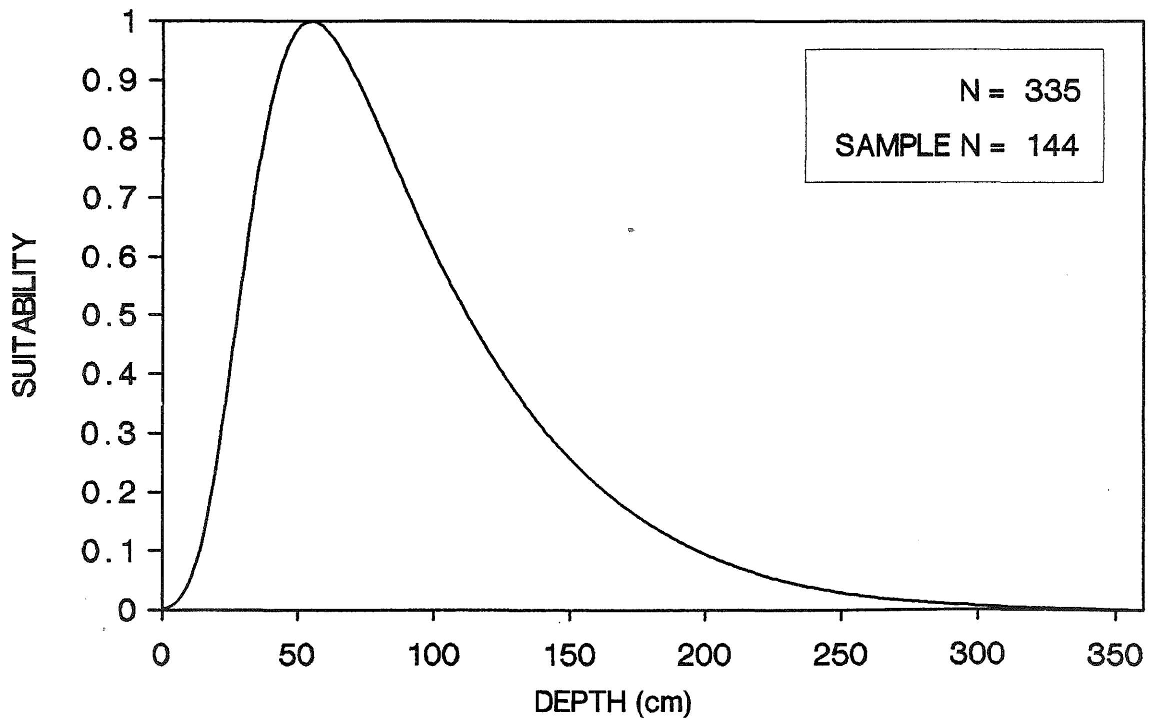


FIGURE 17. Depth preference of juvenile smallmouth bass (100-189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

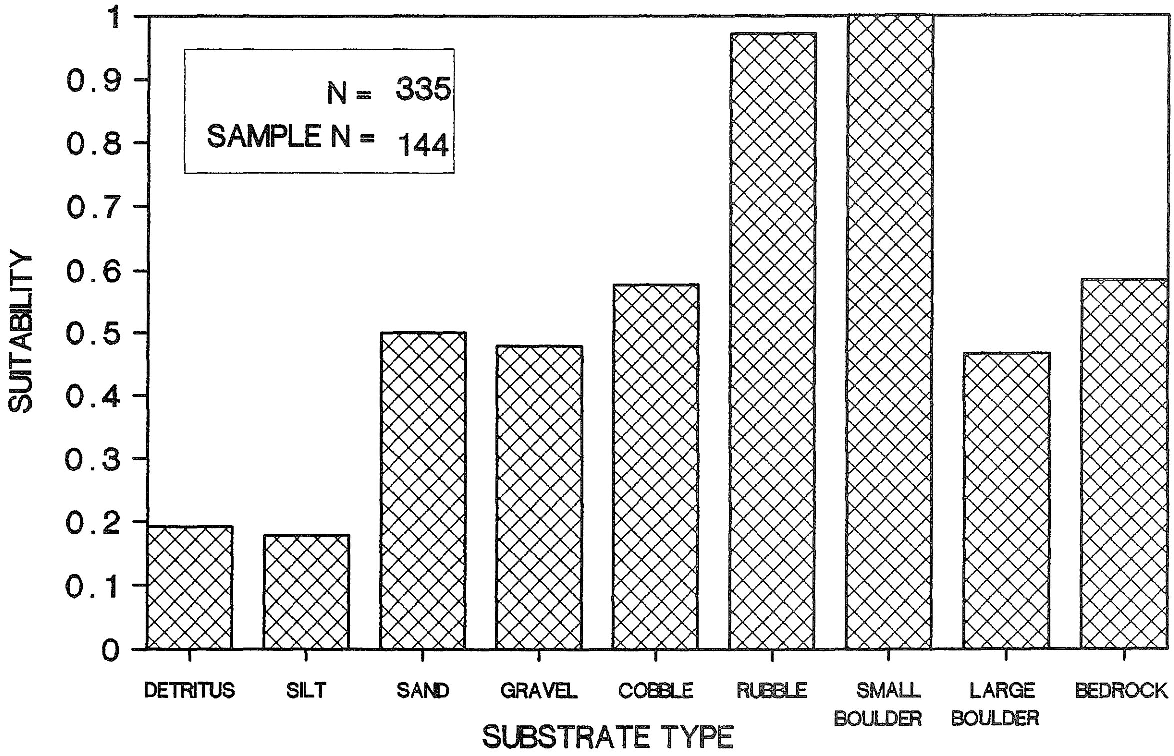


FIGURE 18. Dominant substrate preference of juvenile smallmouth bass (100–189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

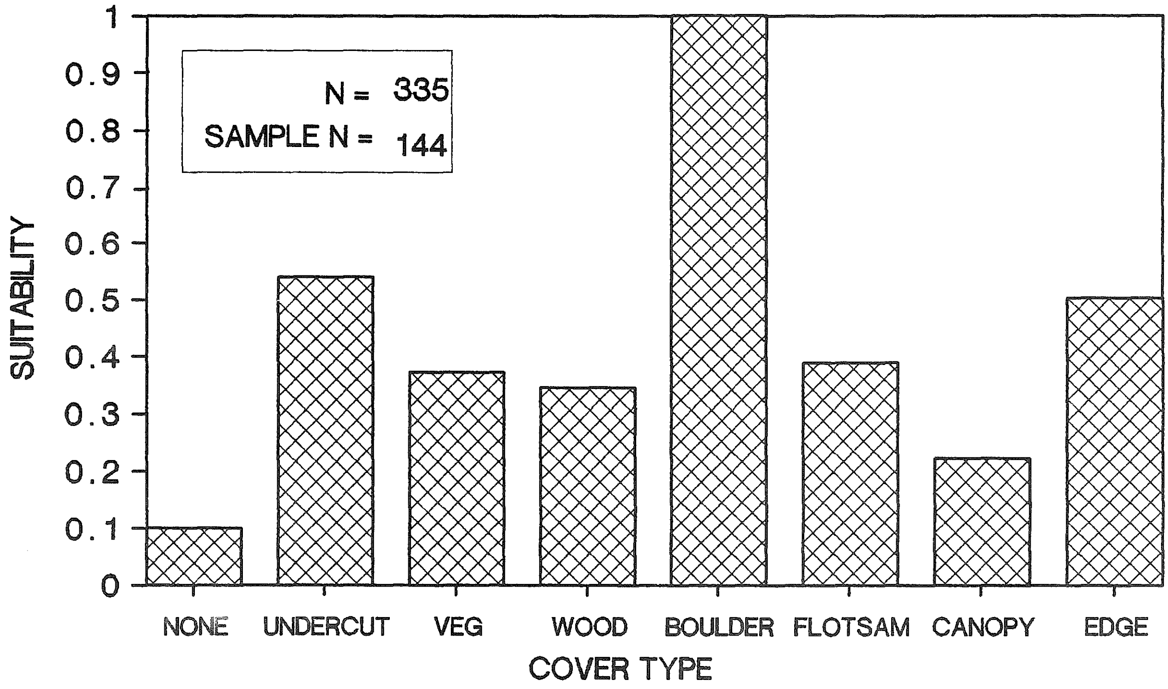


FIGURE 19. Cover preference of juvenile smallmouth bass (100–189 mm) in the Zumbro, Snake, and Yellow Medicine Rivers in Minnesota.

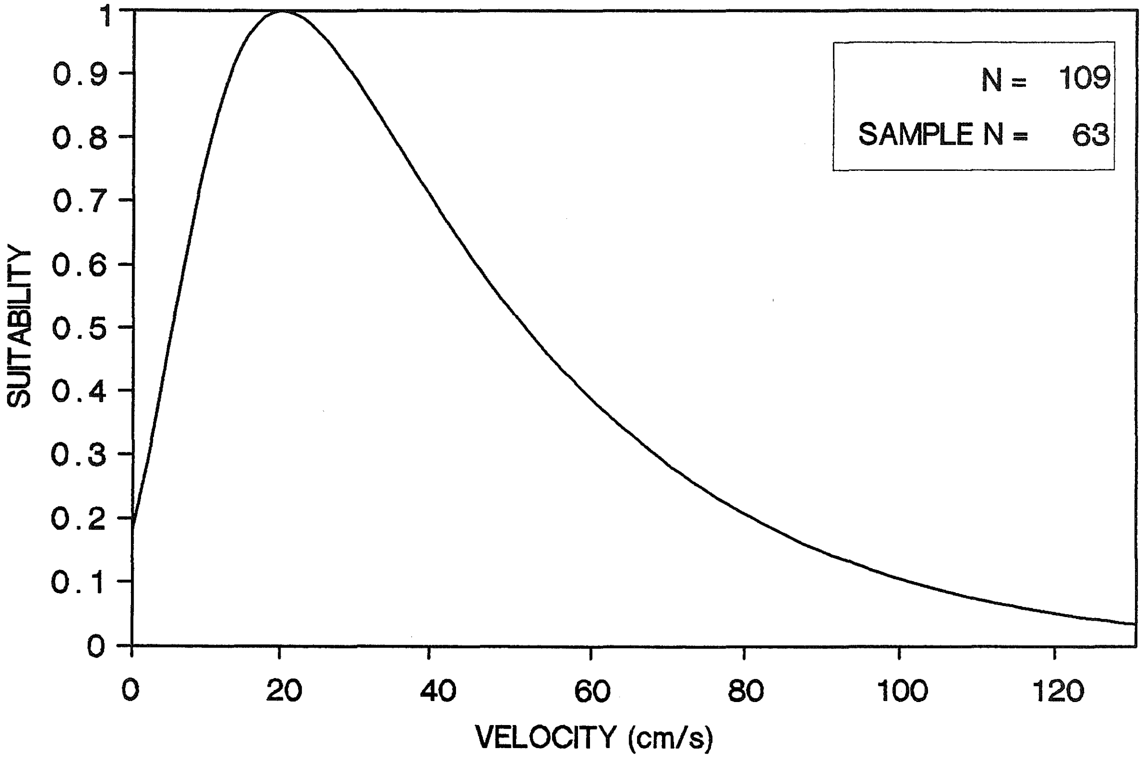


FIGURE 20. Velocity preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

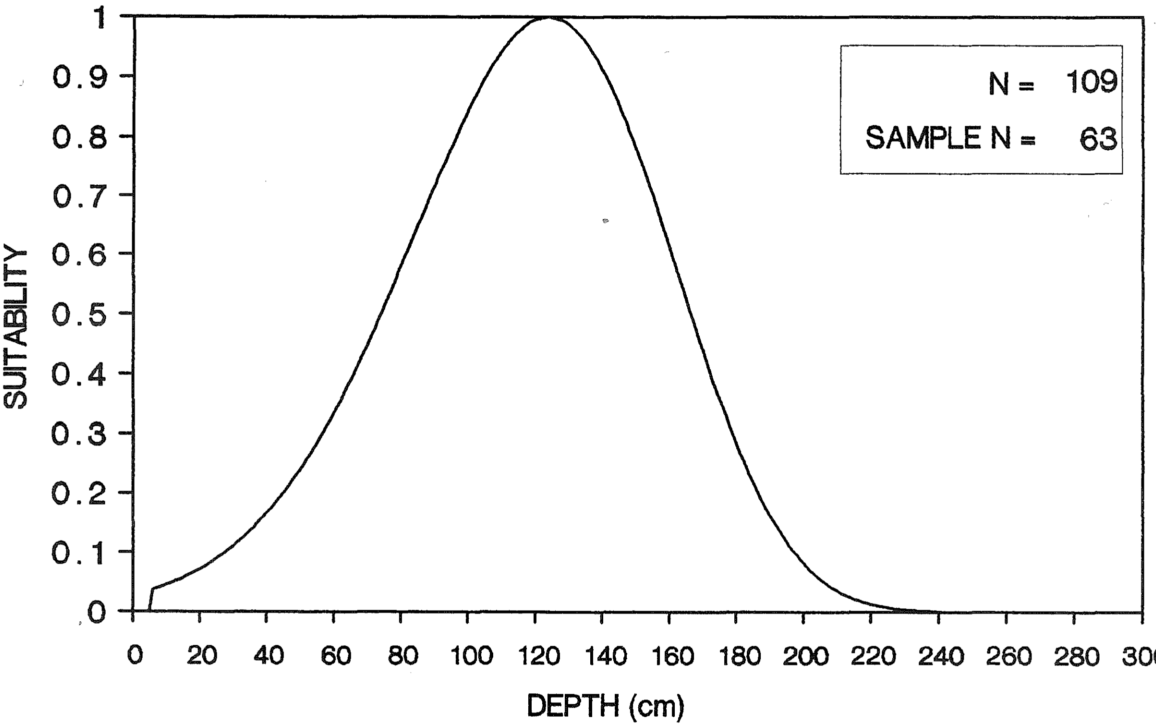


FIGURE 21. Depth preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

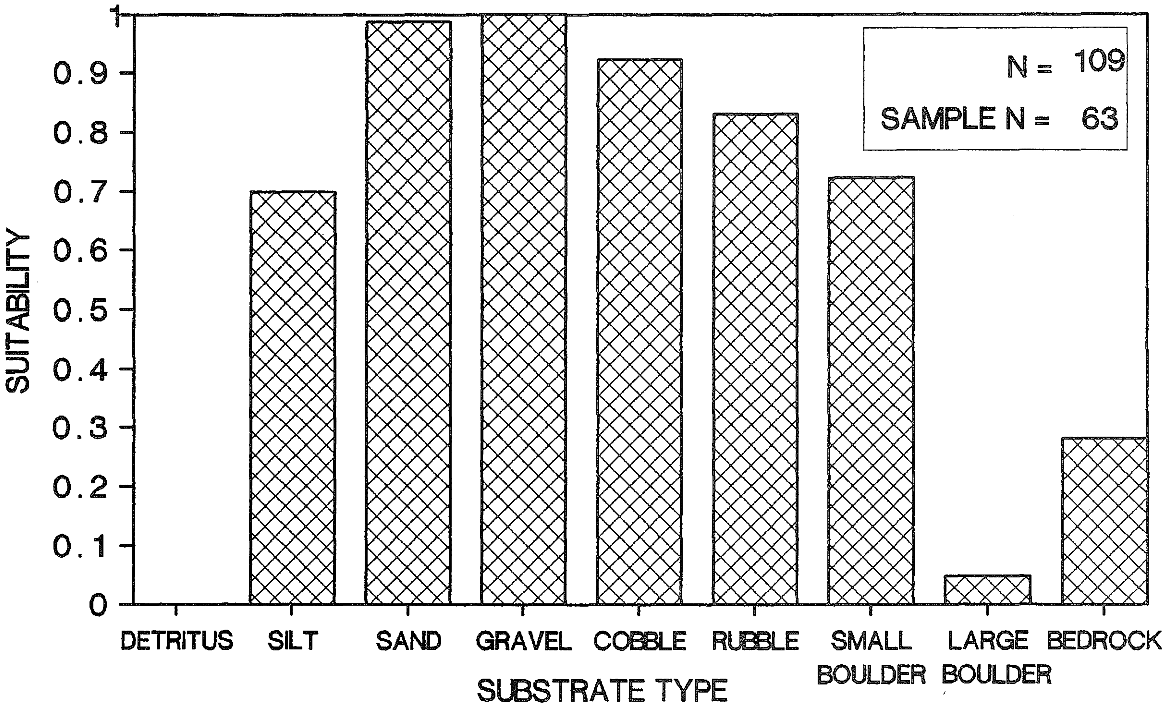


FIGURE 22. Dominant substrate preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

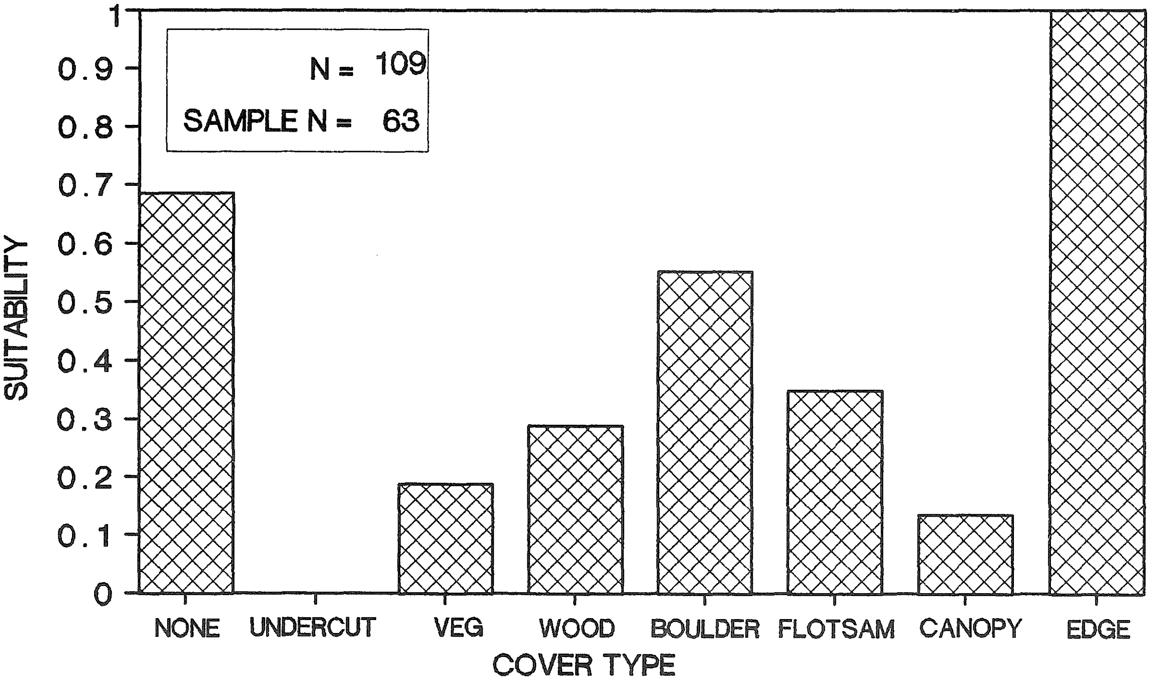


FIGURE 23. Cover preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota.

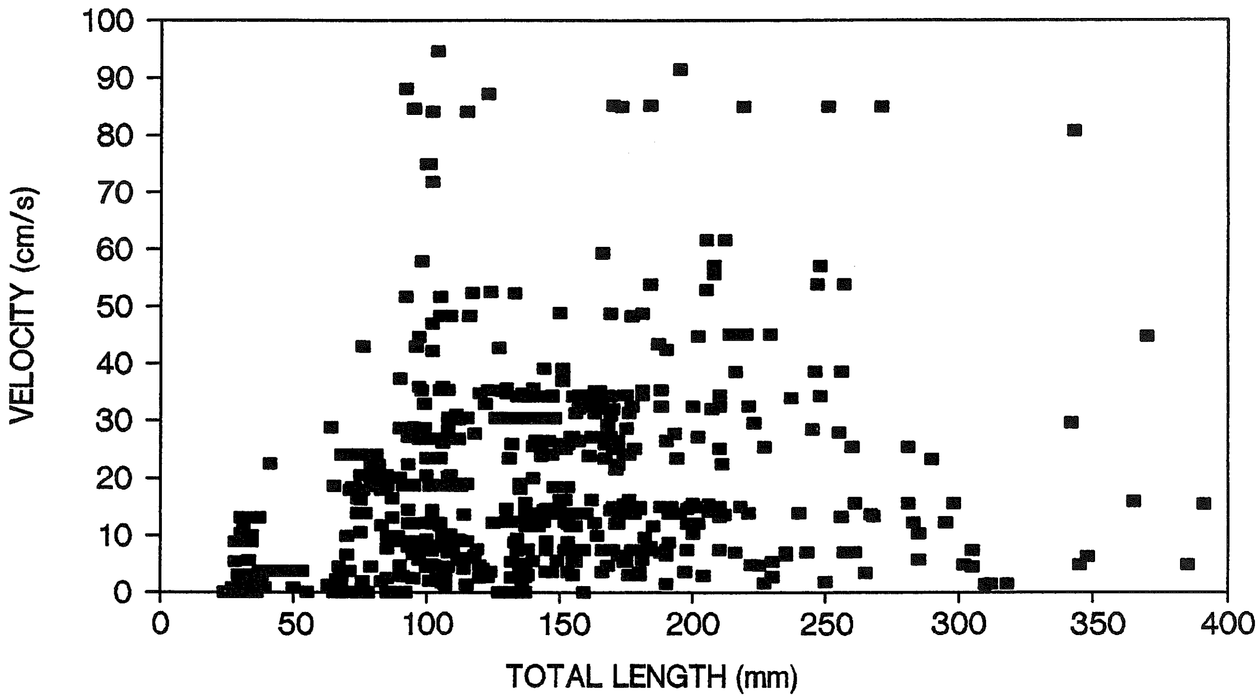


FIGURE 24. Velocity used by Zumbro, Snake, and Yellow Medicine smallmouth bass as a function of total length.

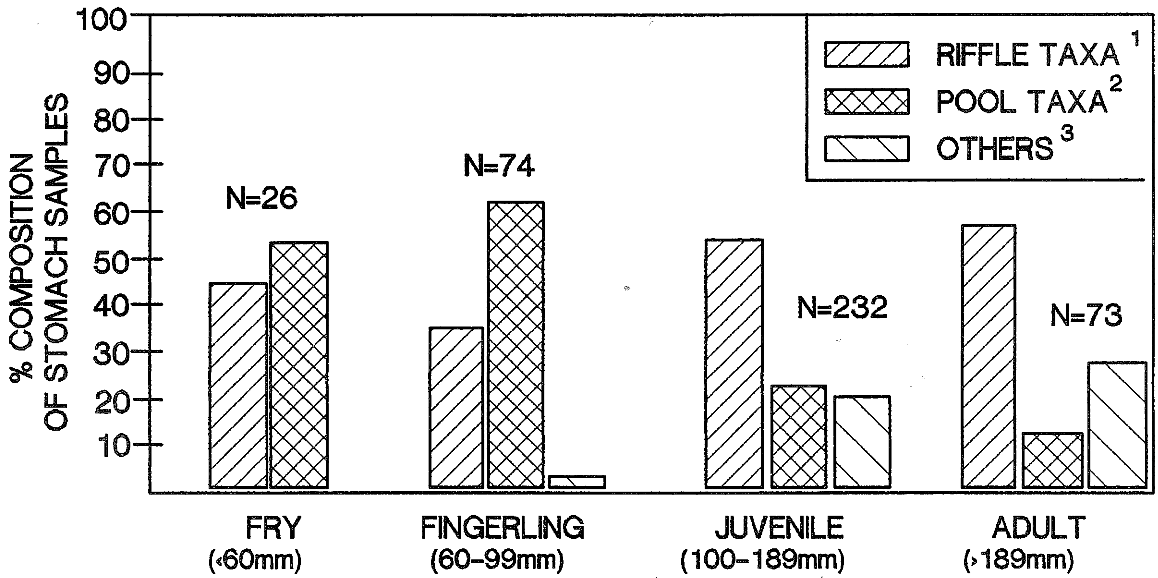


FIGURE 25. Invertebrate food selection of Zumbro, Snake and Yellow Medicine river smallmouth bass (determined by numbers in stomachs).

[1] Mayfly, caddisfly, stonefly, megaloptera, water penny

[2] Diptera, water boatmen, backswimmer, Hemipteran, damselfly & dragonfly, Chironomid, tipulid, cladoceran, amphipod, Gerridae, ostracod, plenaria, Hexagenia

[3] Crayfish, leeches, deerfly, ants, terrestrial spiders & insects, Coleoptera

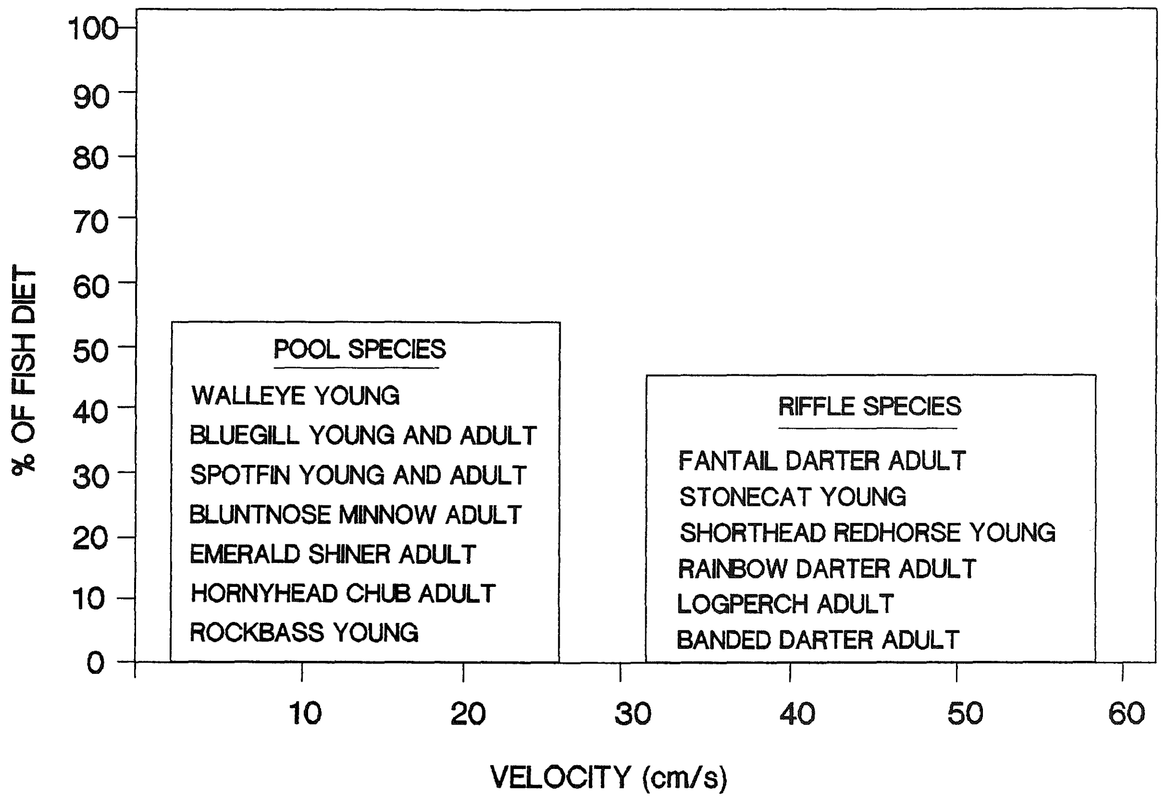


FIGURE 26. Average velocities utilized by fish species found in the diets of Zumbro, Snake, and Yellow Medicine river smallmouth bass.

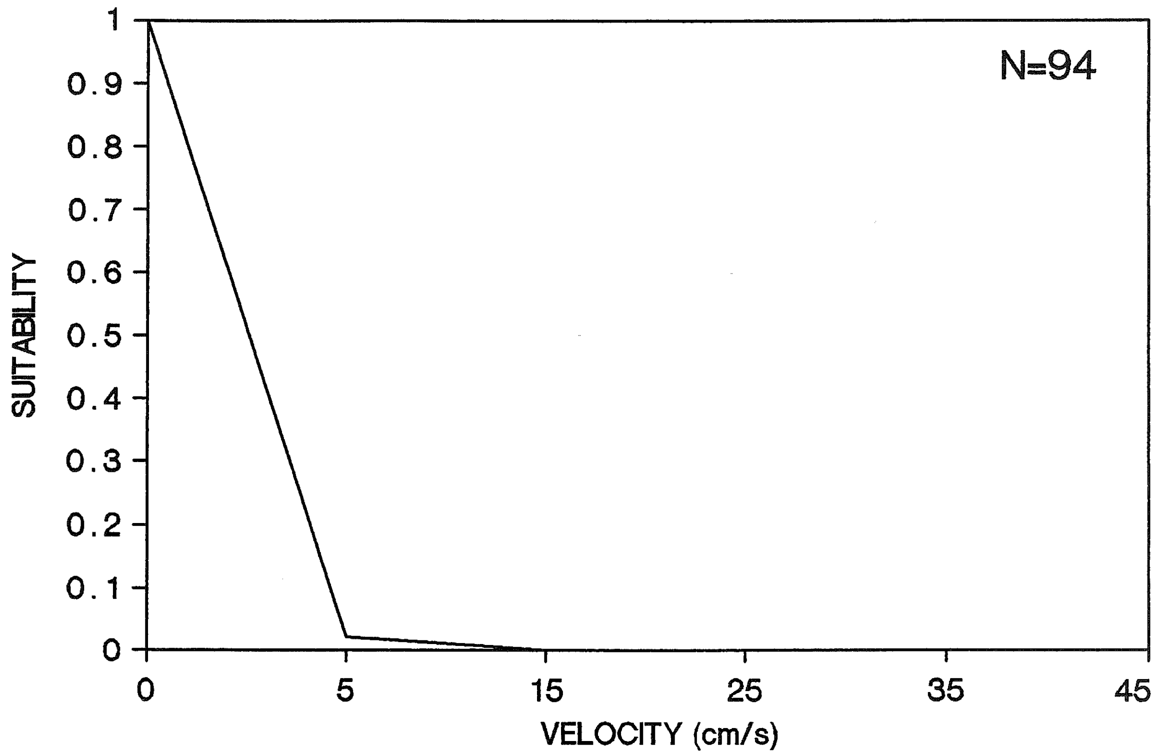


FIGURE 27. Zumbro River spawning smallmouth bass velocity utilization.

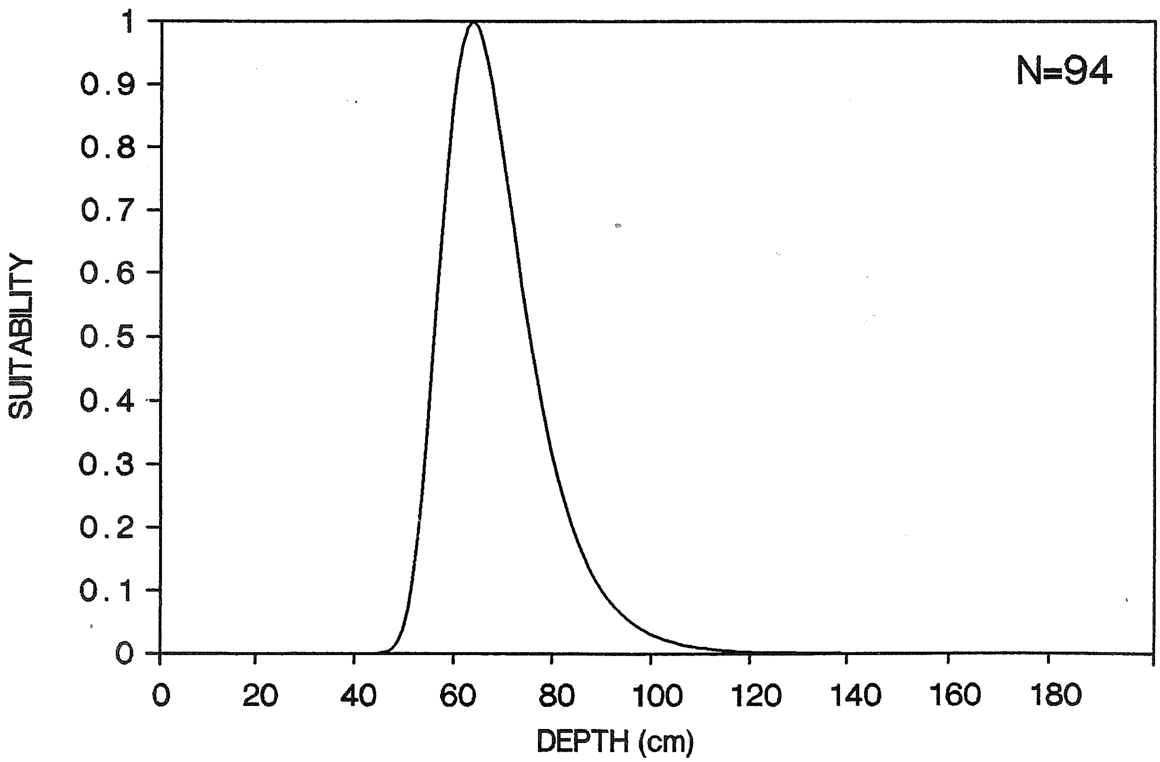


FIGURE 28. Zumbro River spawning smallmouth bass depth utilization.

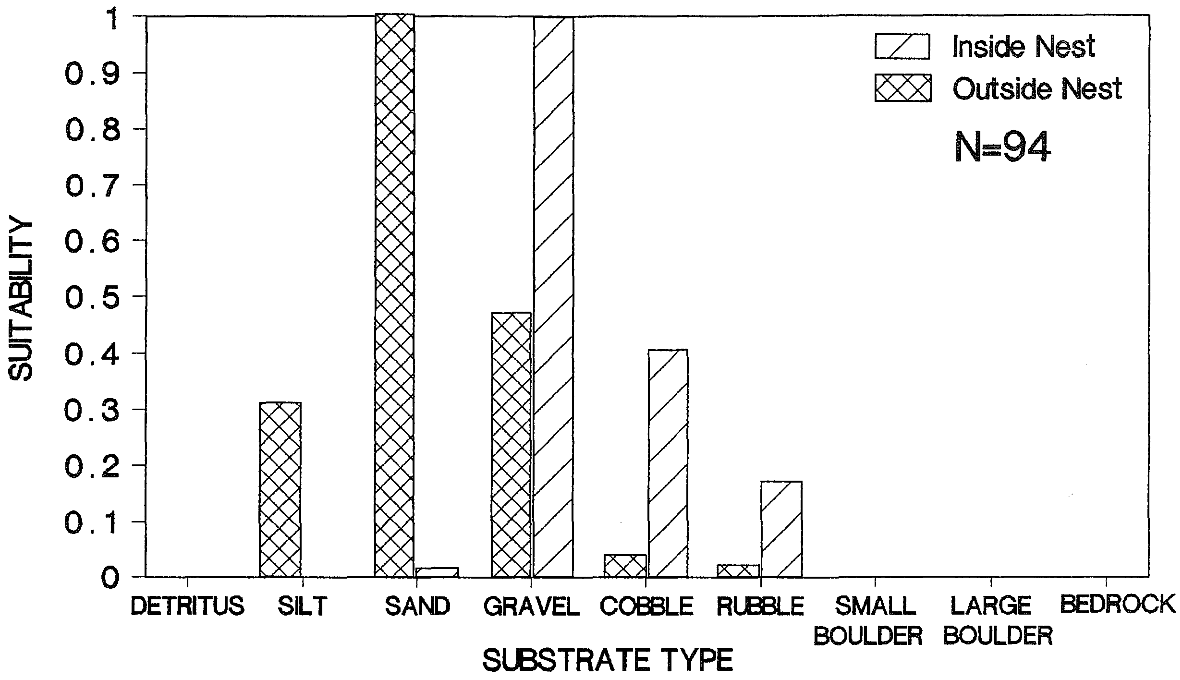


FIGURE 29. Zumbro River spawning smallmouth bass dominant substrate utilization.

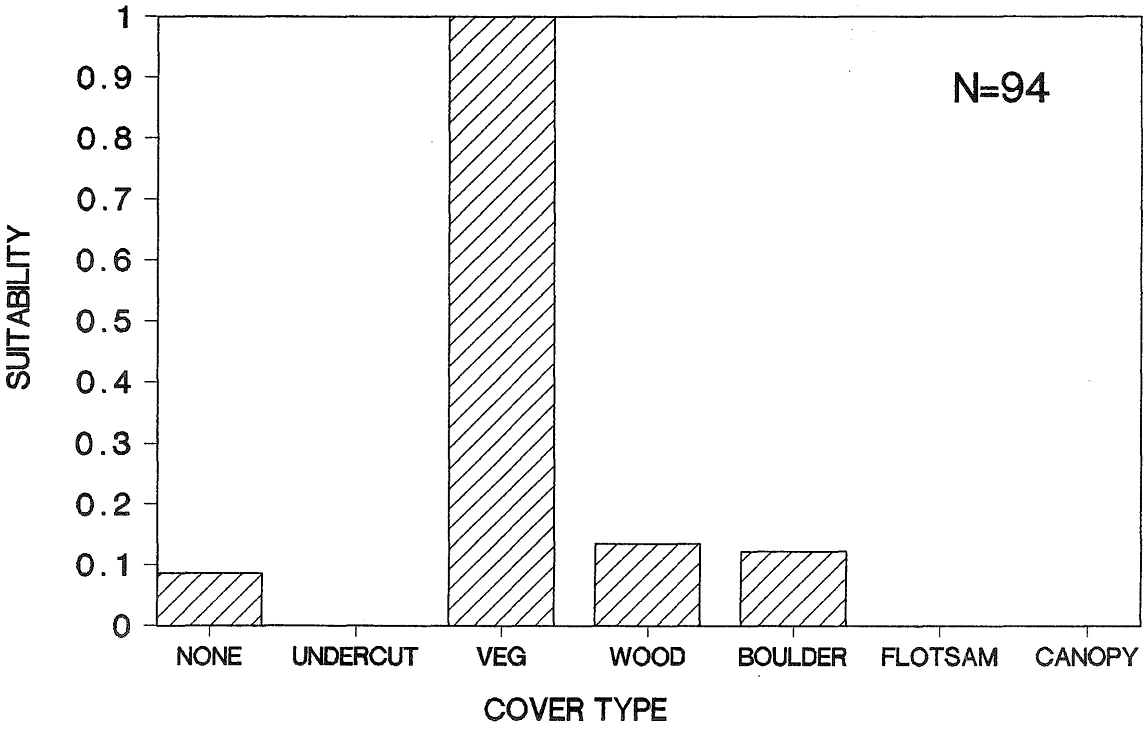


FIGURE 30. Zumbro River spawning smallmouth bass cover utilization.

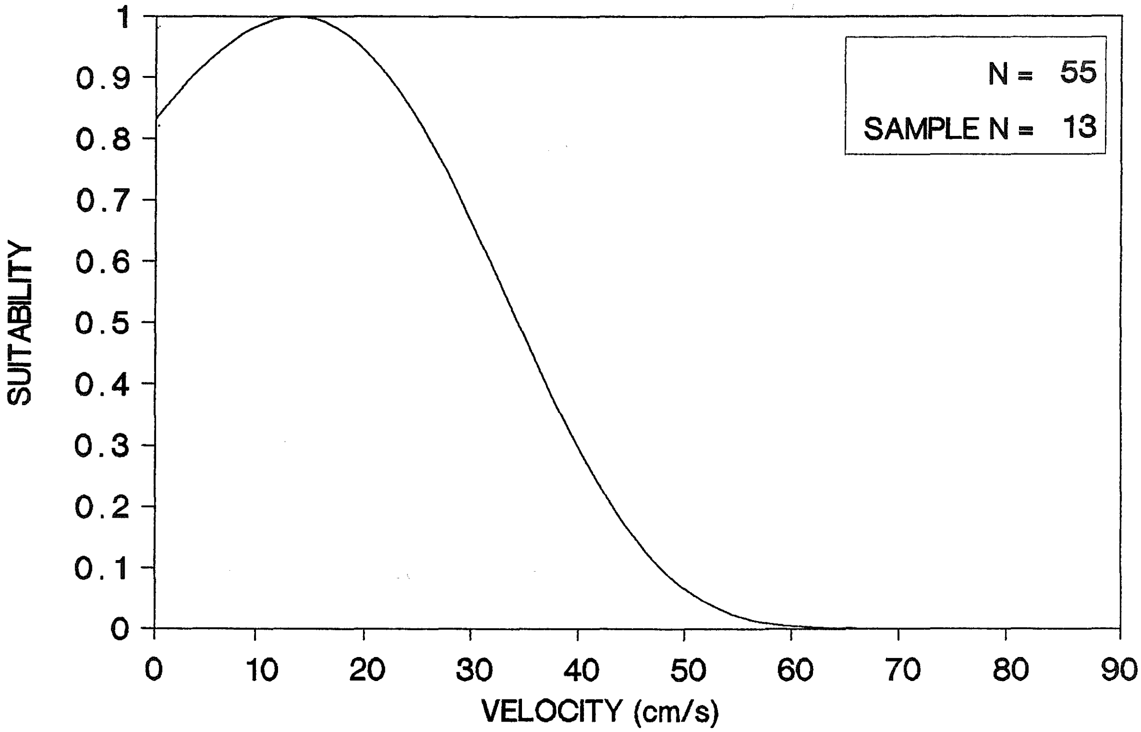


FIGURE 31. Velocity preference of juvenile channel catfish (80-309 mm) from the Yellow Medicine River (weighted data).

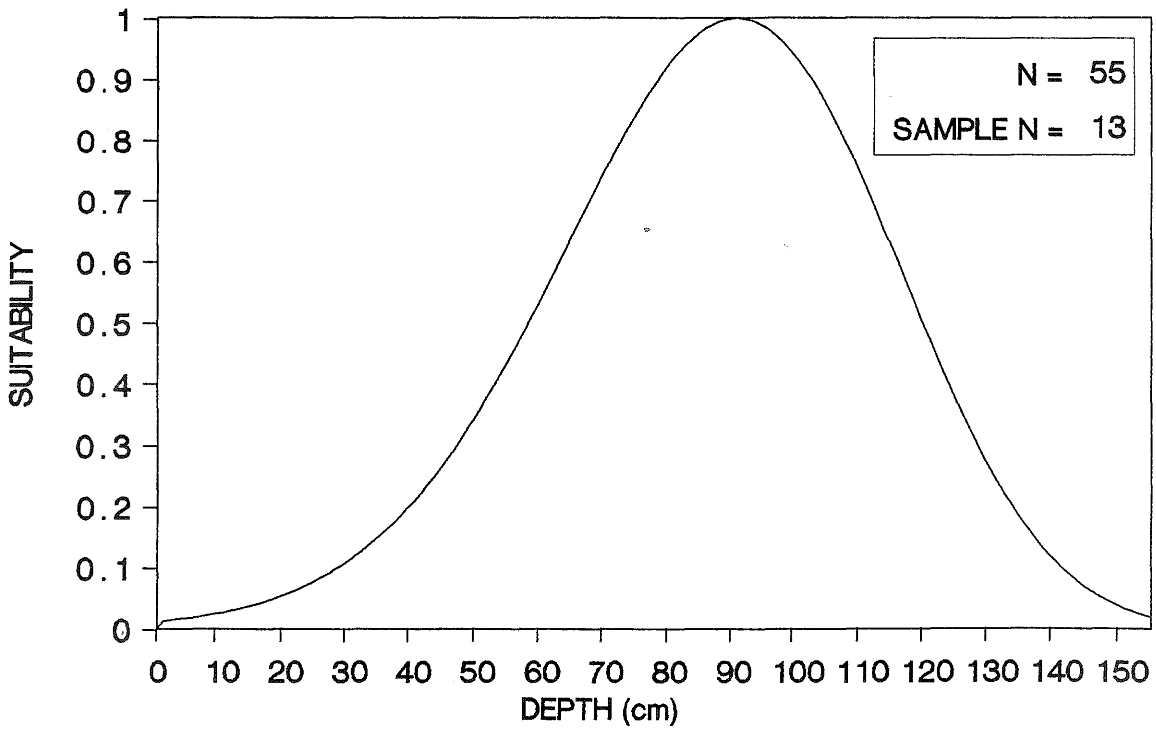


FIGURE 32. Depth preference of juvenile channel catfish (80-309 mm) from the Yellow Medicine River (weighted data).

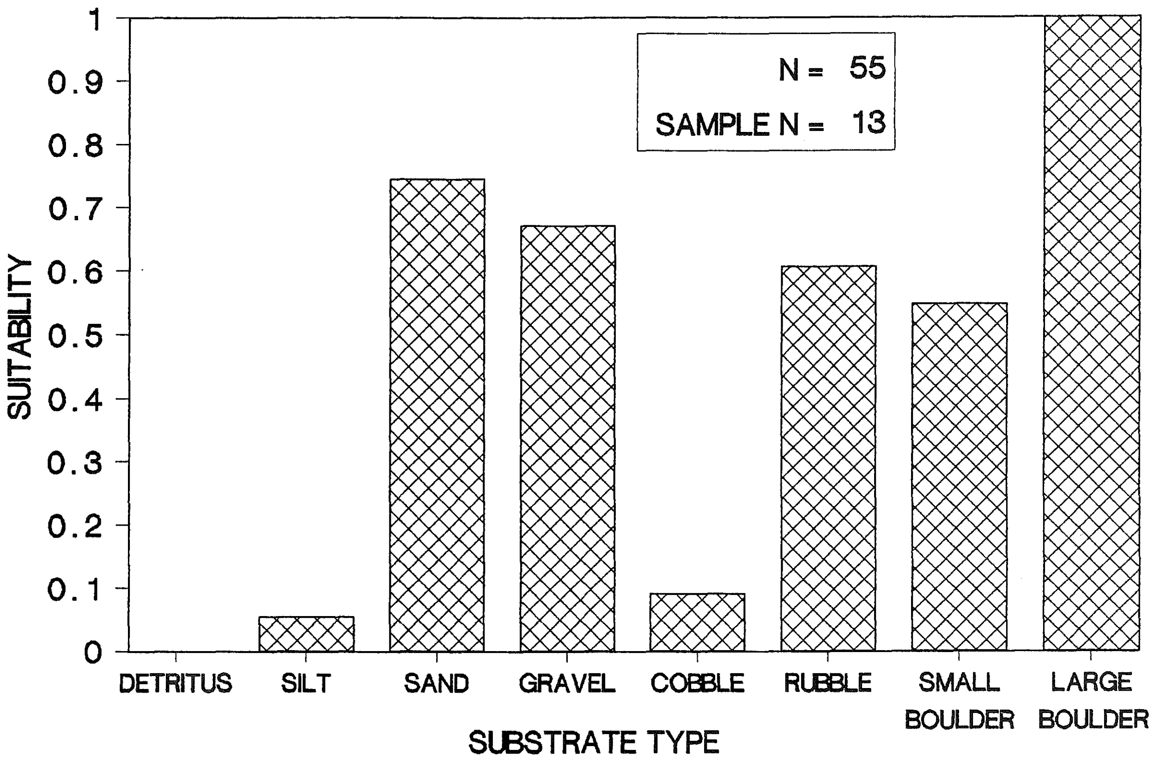


FIGURE 33. Dominant substrate preference of juvenile channel catfish (80-309 mm) from the Yellow Medicine River (weighted data).

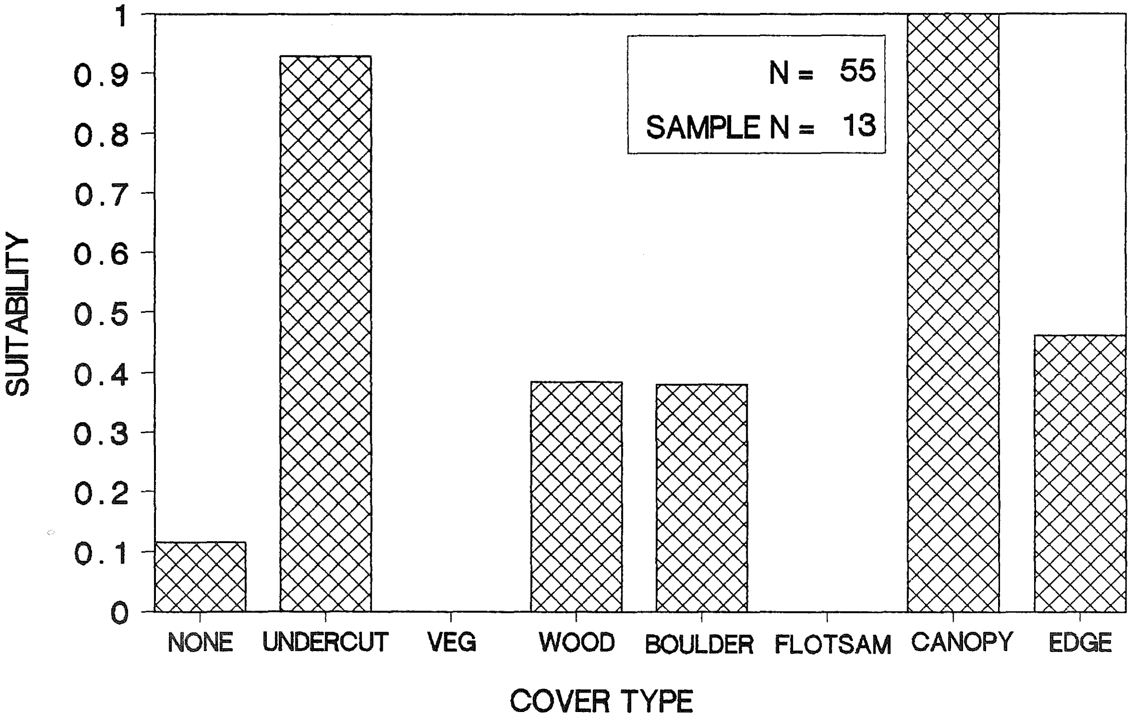


FIGURE 34. Cover preference of juvenile channel catfish (80-309 mm) from the Yellow Medicine River (weighted data).

HABITAT-USE GUILDS

Six habitat-use guilds were identified in the three study streams using the K-means approach to the cluster analysis: shallow pool, pool, deep pool, run, riffle, and fast riffle (Table 4). The species life-stage assemblages within each guild type were very similar in the three rivers and common species life stages clustered into the same guild 57% of the time. For the Zumbro River, between guild differences were significant for all 13 variables ($P<.05$) at this level of cluster specification. Between guild differences were significant ($P<.05$) for all variables except boulder and flotsam for the Yellow Medicine River. These two variables are probably poor predictors of species assemblages for the Yellow Medicine since boulder was so abundant (53.6% of the samples) and flotsam was so rare (1.3% of the samples). For the Snake River, between guild differences were significant ($P<.05$) for all variables except undercut bank (which was present in only one sample) and canopy.

Cluster analysis of the Zumbro River data was considered to be the most reliable and transferable because the Zumbro River had the greatest habitat variation, was the least affected by the 1988 drought, and was sampled the most extensively. Due to low water conditions in the Yellow Medicine and Snake rivers, fast water areas were rare or not available during the summer sampling periods. The compressed range of velocity and depth in these two rivers apparently affected habitat use by some species life stages and the species assemblages with which they were associated. Some species life stages, adult golden redhorse for example, which preferred fast run areas in the Zumbro River, were found in pool areas in the Yellow Medicine River; runs were non-existent, and riffles were very shallow. Longnose dace which preferred fast riffle areas in the Zumbro River, were found in similar areas in the Snake River, but velocities there were much lower. Representatives of each habitat-use guild were chosen for use in the IFIM study based on their relative abundance in the three study streams and their distribution in Minnesota (Table 5).

TABLE 4. Microhabitat variable means and ranges (in parentheses) of six habitat-use guilds identified by cluster analysis of Zumbro River habitat suitability data.

Habitat Use Guild Guild	Velocity (cm/s)	Depth (cm)	Dominant Substrate
shallow pool	17 (4-32)	30 (14-48)	sand (silt-cobble)
pool	15 (0-27)	77 (53-108)	gravel (sand-rubble)
deep pool	8 (6-10)	147 (120-173)	sand (sand-sand)
run	37 (26-47)	66 (48-89)	cobble (gravel-cobble)
riffle	46 (32-64)	28 (15-47)	gravel (gravel-cobble)
fast riffle	88 (79-94)	41 (25-60)	cobble (gravel-rubble)

TABLE 5. Representative fish species of Zumbro River habitat-use guilds identified by cluster analysis. Species abbreviations are defined in Appendix 1; the last letter of the abbreviation refers to life stage: FR = Fry, FI = Fingerling, Y = young-of-the-year, J = juvenile, A = adult, S = spawning adult. Species with an asterisk (*) are the guild representatives suggested for the IFIM analysis.

Shallow Pool	Pool	Deep Pool	Run	Riffle	Fast Riffle
BNM-A	BLC-J	BLC-A	CSH-A	**BDD-A***	LGP-S
BNM-Y	BLC-Y	BLG-J	GIS-Y	BDD-S	LND-A
BSD-A	CAP-A	**CCF-J***	GLR-A	BDD-Y	**LND-J***
BSD-Y	GIS-A	YEP-A	GLR-S	CSR-A	SHD-S
CAP-Y	LMB-J		LGP-A	CSR-J	
CRC-A	LMB-Y		NHS-A	CSR-S	
CRC-J	SMB-A		**SHR-A***	CSR-Y	
CRC-Y	**SMB-J***		SHR-J	LGP-Y	
CSH-J	SMB-S			LND-S	
EMS-A	SMB-FI			NHS-J	
EMS-Y	WHB-J			NHS-S	
GLR-Y	WHB-Y			RBD-A	
GSF-A	WTS-A			SDS-A	
GSF-Y	YEP-J			SDS-S	
JND-A				SHD-A	
JND-Y				SHR-Y	
MMS-A				WTS-J	
NHS-Y					
RVS-A					
RVS-Y					
SDS-Y*					
SFS-A					
SFS-S					
SFS-Y					
SLR-Y					
SMB-FR					
SPO-A					
SPO-Y					
WTS-Y					

Shallow pool guild

The shallow pool guild was made up largely of shiners (Notropis spp.), young-of-the-year suckers (Catostomidae), and sunfishes (Centrarchidae; Table 5). The shallow pool habitat used by these fishes was usually found along the channel margin in slow, shallow water (Table 4).

The shallow pool guild is best represented by young-of-the-year sand shiners which were an abundant prey species in all three study streams. Young-of-the-year sand shiners preferred sandy, shallow areas with extensive filamentous algae growth (Figures 35-38). Because the sand shiners preferred shallow, low velocity areas which were available in all three study streams, data from the study streams was pooled to construct the preference curves and histograms.

Pool guild

The pool guild consisted of sunfishes, carpsuckers (*Carpoides* *spp*.), adult shiners and most of the predatory fishes (Table 5). Members of this guild used slow moderately deep water (Table 4).

Habitat preferences of smallmouth bass juveniles best represented the pool guild, because they were collected in all three streams and typically found in deep areas with low velocity and larger substrates. Composite preference curves were created from data collected in all three study streams (Figures 16-19). Smallmouth bass juveniles were observed more frequently than adults, fry or fingerlings in all study streams.

Deep pool guild

Members of the deep pool guild included young-of-the-year common shiner, sunfishes and channel catfish (Table 5). These fish used the deepest pools available (Table 4).

Since the other representatives of the deep pool guild from the Zumbro River are species which do not normally occur in streams without lake influence, channel catfish are suggested as the deep pool guild representative. Curves were developed for juvenile channel catfish collected from the Yellow Medicine River (Figures 31-34). Channel catfish were not taken in sufficient numbers in the Zumbro and Snake rivers to meet the criteria for inclusion into the cluster analysis described previously. An expanded version of the analysis for these two rivers, which included all species life stages regardless of sample size, placed juvenile and adult channel catfish in the deep pool guild, as did the Yellow Medicine River cluster analysis. Ideally, adult channel catfish should be the representatives for this guild, but use of curves developed in other states or further work in Minnesota would be necessary.

Run guild

The run guild was dominated by juvenile, adult, and spawning suckers (northern hog sucker and *Moxostoma* *spp*.). These fishes used areas which had moderate velocities, moderate depth and large substrates (Table 4).

Shorthead redhorse best represented the run guild because they were abundant and probably comprised the highest biomass of any species in the three study streams. Preference relationships were developed from Zumbro River data because, as discussed previously, run areas were lacking in the Yellow Medicine River, and velocities were much lower in the Snake River. Weighted data was used to construct the preference curves and histograms, because adults were localized in run areas with moderate velocities and large substrates (Figures 39-42).

Riffle guild

The riffle guild was dominated by darters (Etheostoma spp), stonerollers (Campostoma spp.), and stonecats. The habitat used by these fishes was shallow with moderate to high velocities, and gravel, cobble, or rubble substrate (Table 4).

Adult banded darters were chosen as the riffle guild representative because they were the most common riffle species in the Yellow Medicine and Zumbro rivers. They were not present in the Snake River, as it is just north of their range. Habitat preference curves were created from Zumbro River data because banded darter adults were found to prefer shallow water areas with moderate to high velocities (Figures 43-46), and the Zumbro River had the widest ranges of velocity and depth.

Fast riffle guild

The fast riffle guild consisted of juvenile and adult longnose dace (in the Zumbro River), and adult and spawning darters. These species life stages were found in the fastest velocity areas which were shallow and had cobble or rubble substrates (Table 4).

Longnose dace were abundant in the Zumbro and Snake Rivers, and their habitat preferences best represented the fast riffle guild (Table 5). Because of the wider range of velocities sampled in the Zumbro River, all preference relationships were constructed from Zumbro River data. Longnose dace juveniles preferred the high velocity, fast riffle areas (Figures 47-50).

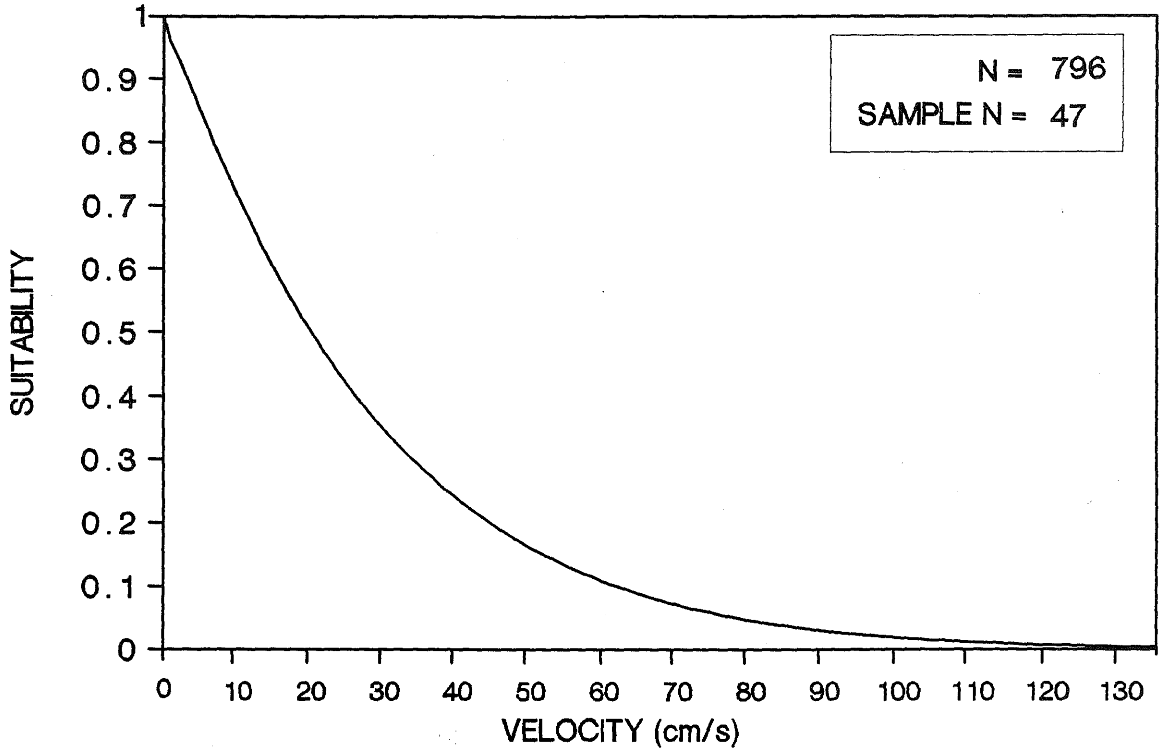


FIGURE 35. Velocity preference of young-of-the-year sand shiners (<40 mm) from the Zumbro and Yellow Medicine rivers.

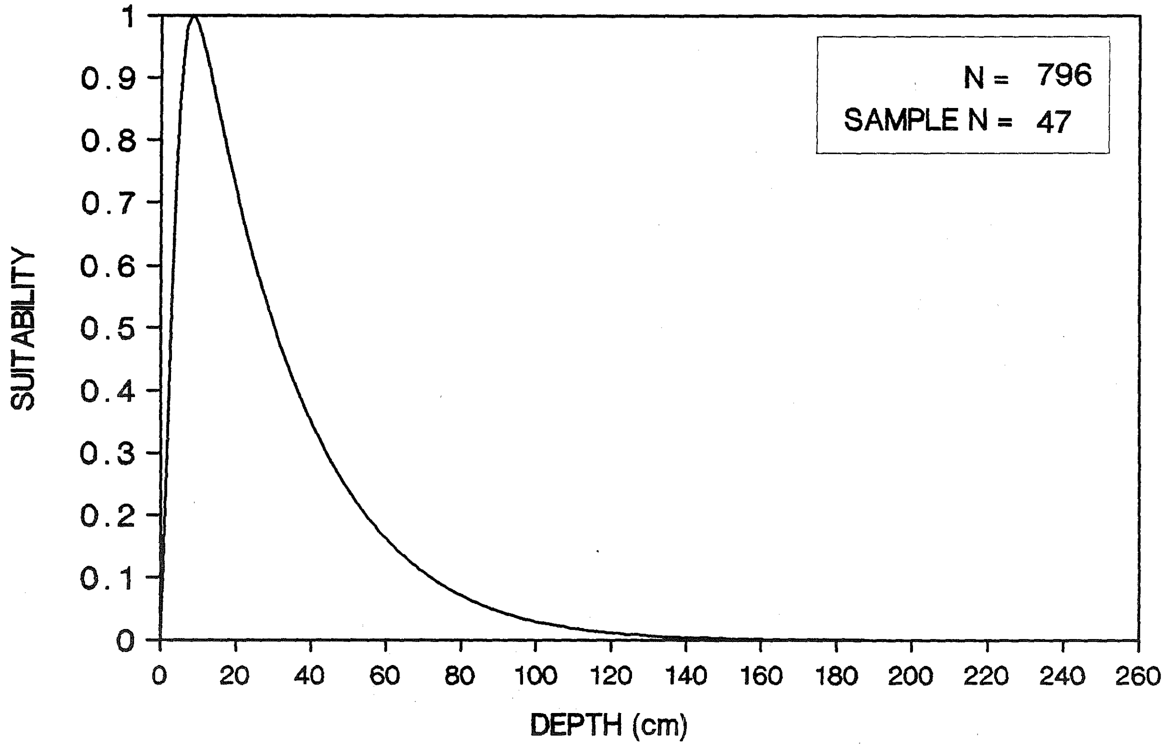


FIGURE 36. Depth preference of young-of-the-year sand shiners (<40 mm) from the Zumbro and Yellow Medicine rivers.

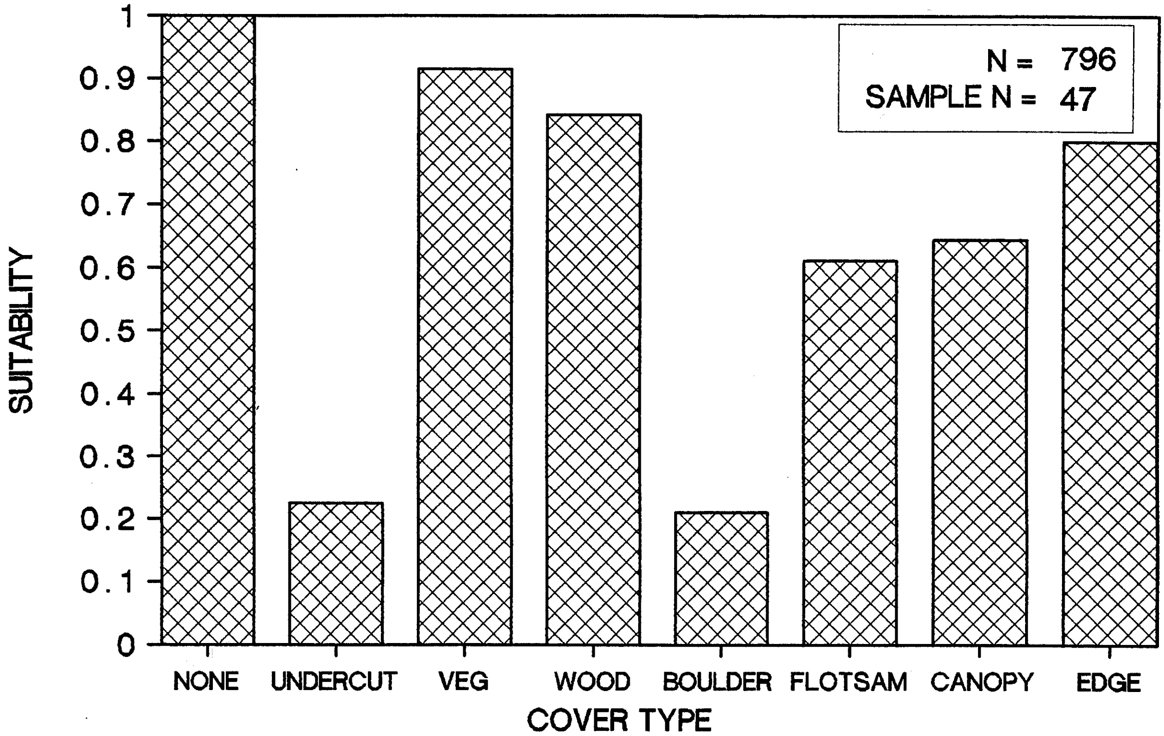


FIGURE 37. Cover preference of young-of-the-year sand shiners (<40 mm) from the Zumbro and Yellow Medicine rivers.

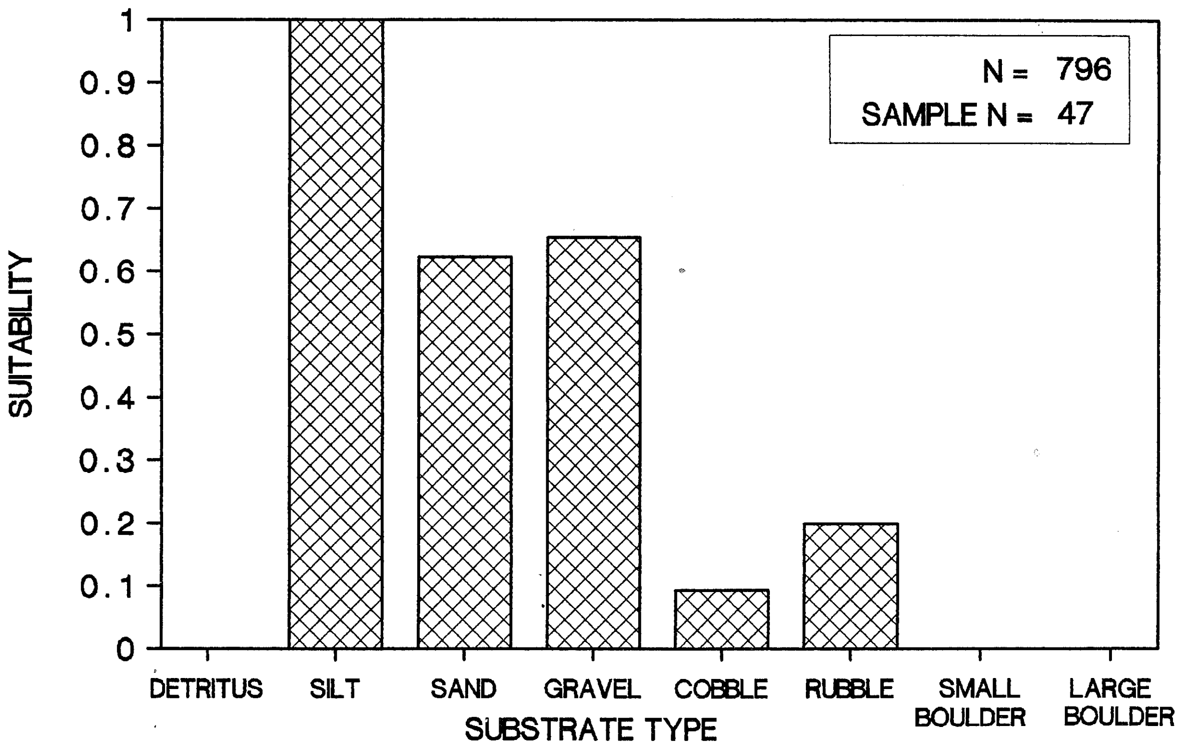


FIGURE 38. Dominant substrate preference of young-of-the-year sand shiners (<40 mm) from the Zumbro and Yellow Medicine rivers.

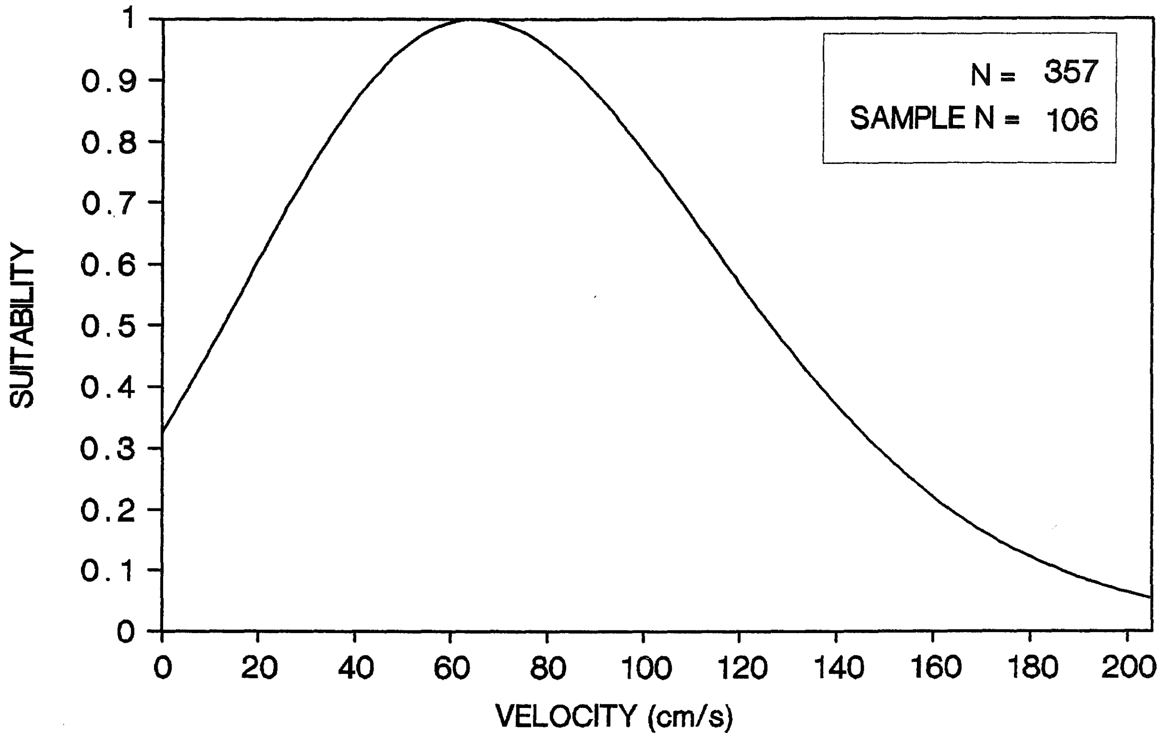


FIGURE 39. Velocity preference of Zumbro River adult shorthead redhorse (›250 mm; weighted data).

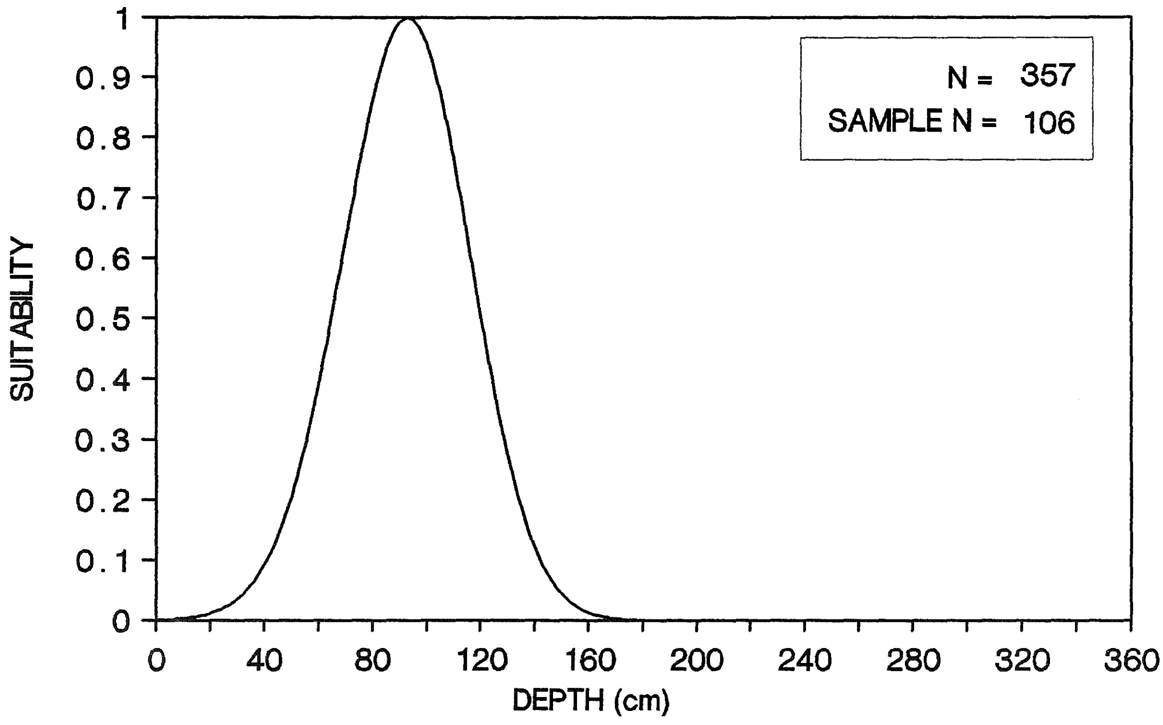


FIGURE 40. Depth preference of Zumbro River adult shorthead redhorse (›250 mm; weighted data).

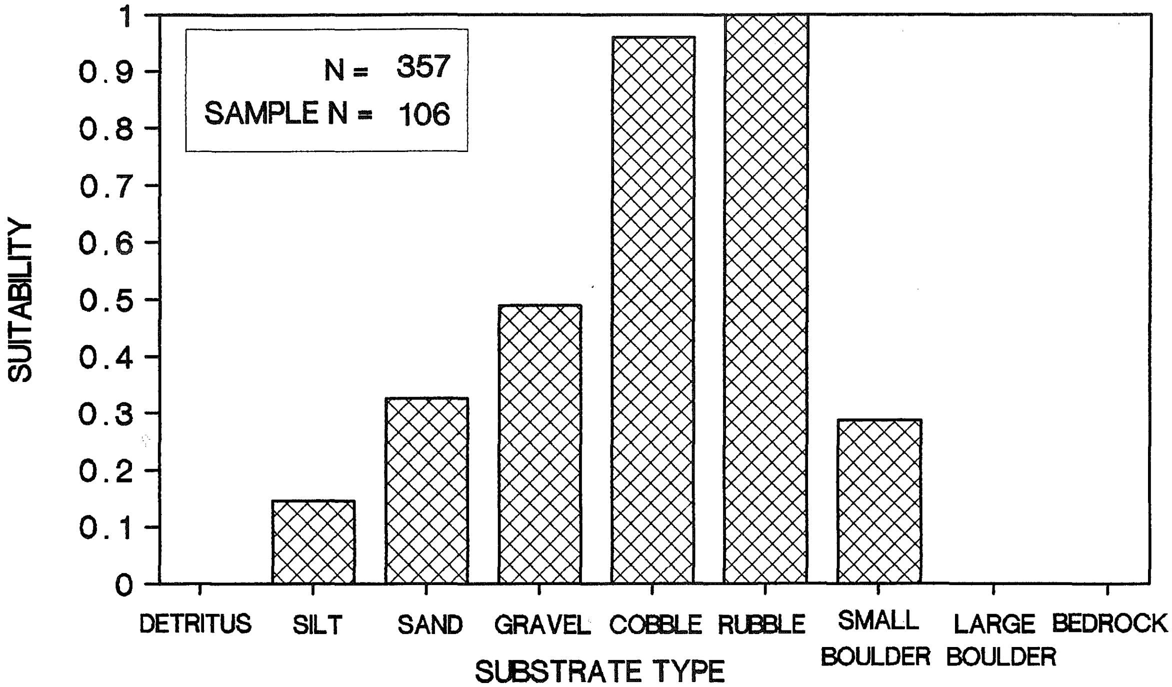


FIGURE 41. Dominant substrate preference of Zumbro River adult shorthead redhorse (›250 mm; weighted data).

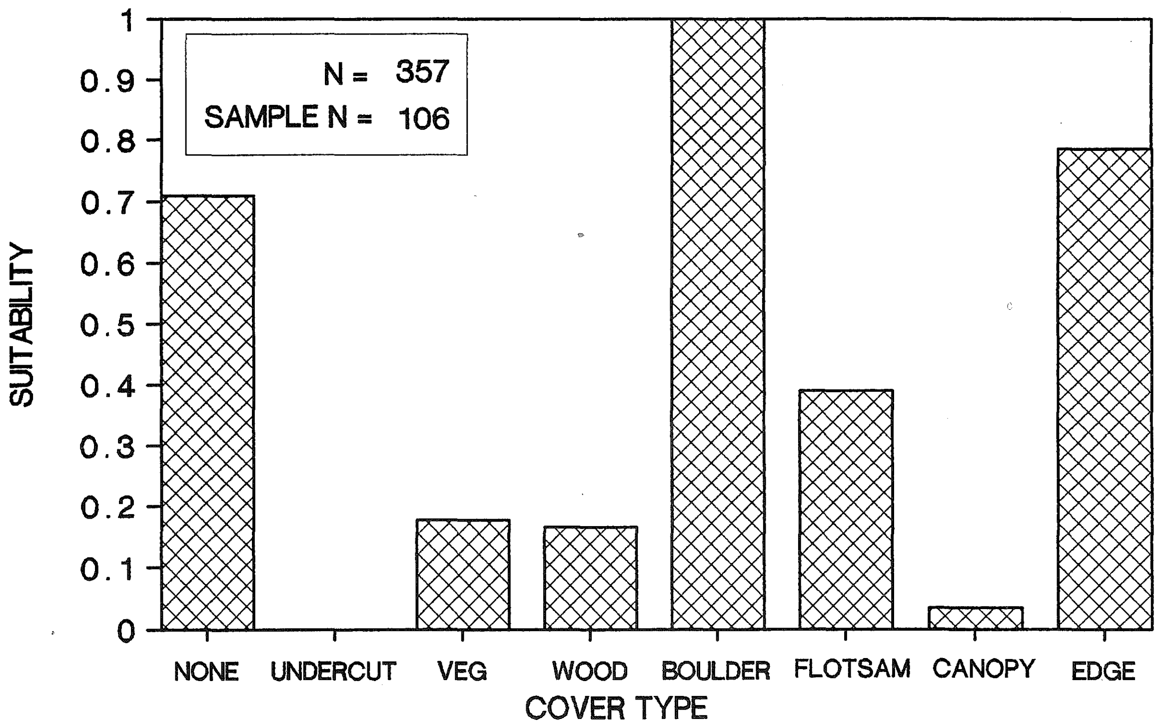


FIGURE 42. Cover preference of Zumbro River adult shorthead redhorse (›250 mm; weighted data).

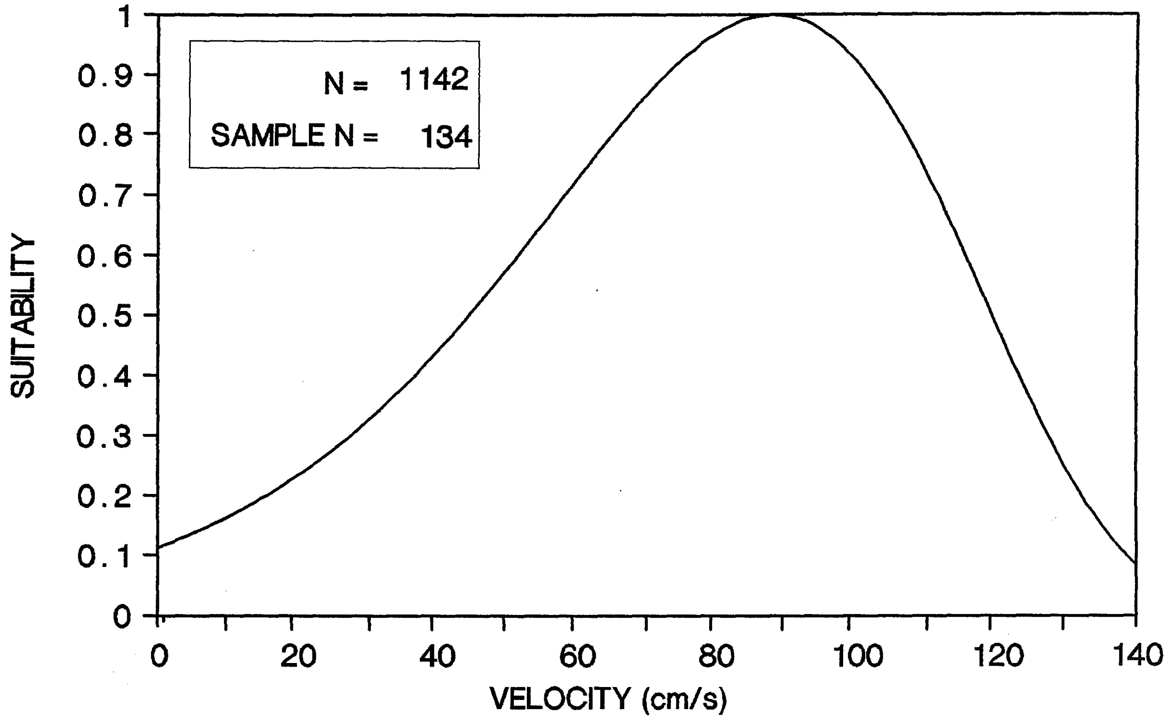


FIGURE 43. Velocity preference of Zumbro River adult banded darters (>38 mm).

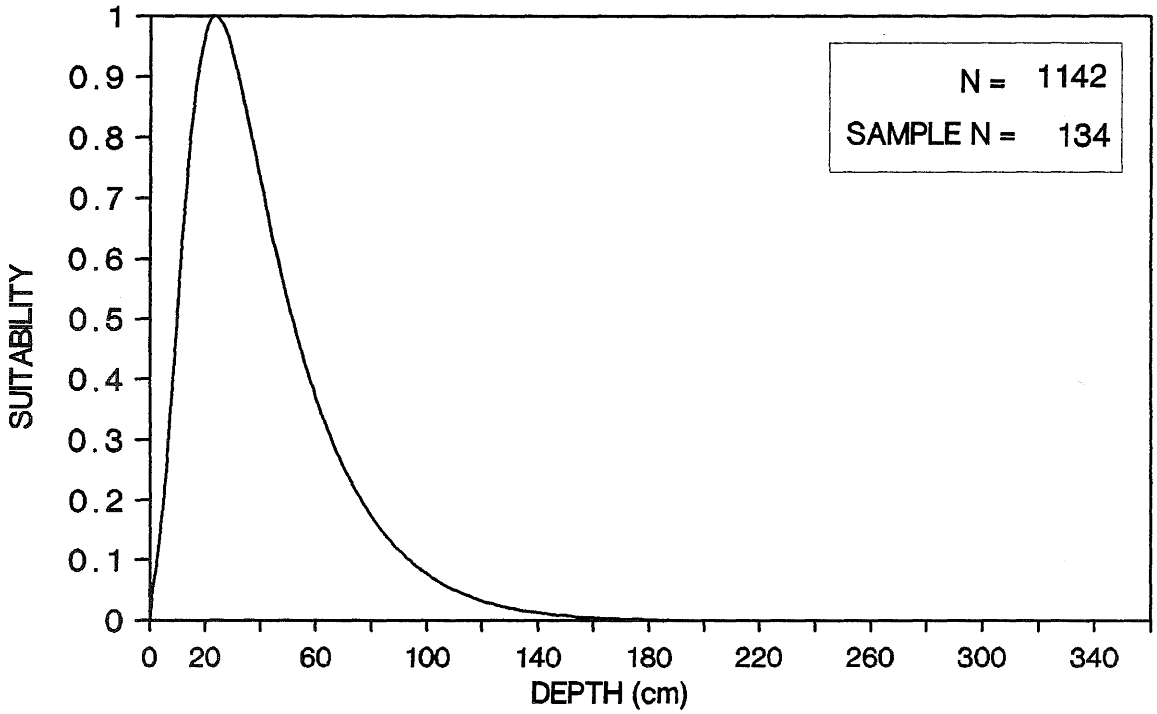


FIGURE 44. Depth preference of Zumbro River adult banded darters (>38 mm).

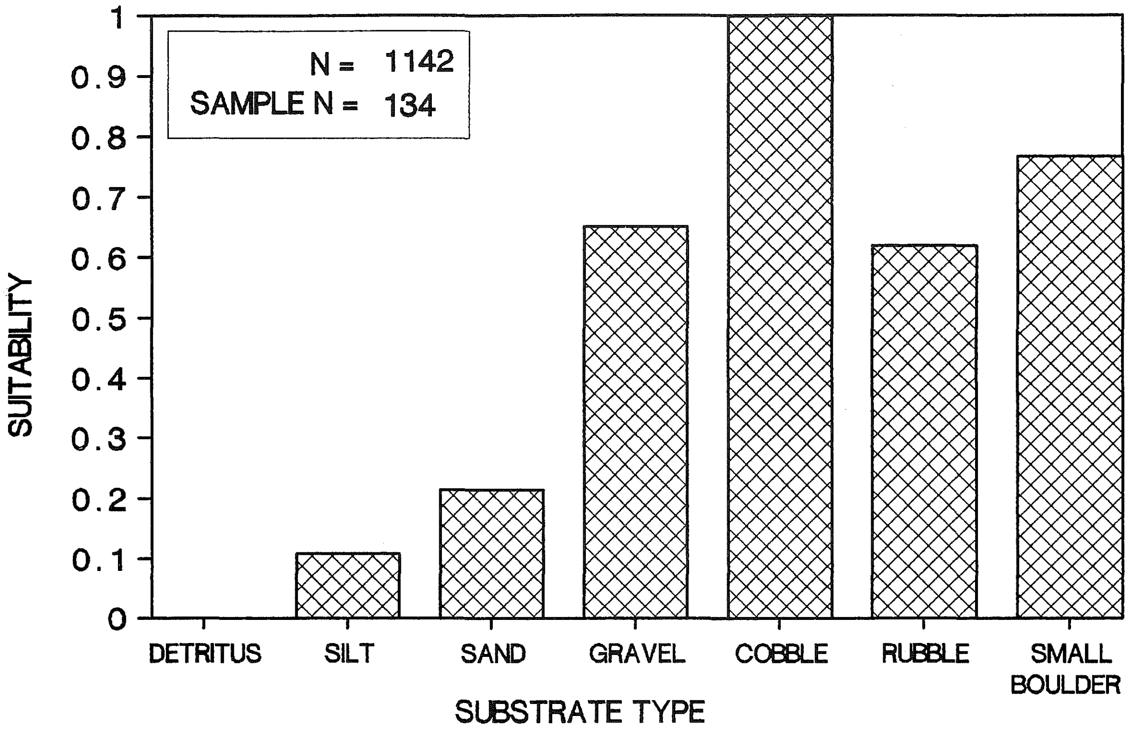


FIGURE 45. Dominant substrate preference of Zumbro River adult banded darters (>38 mm).

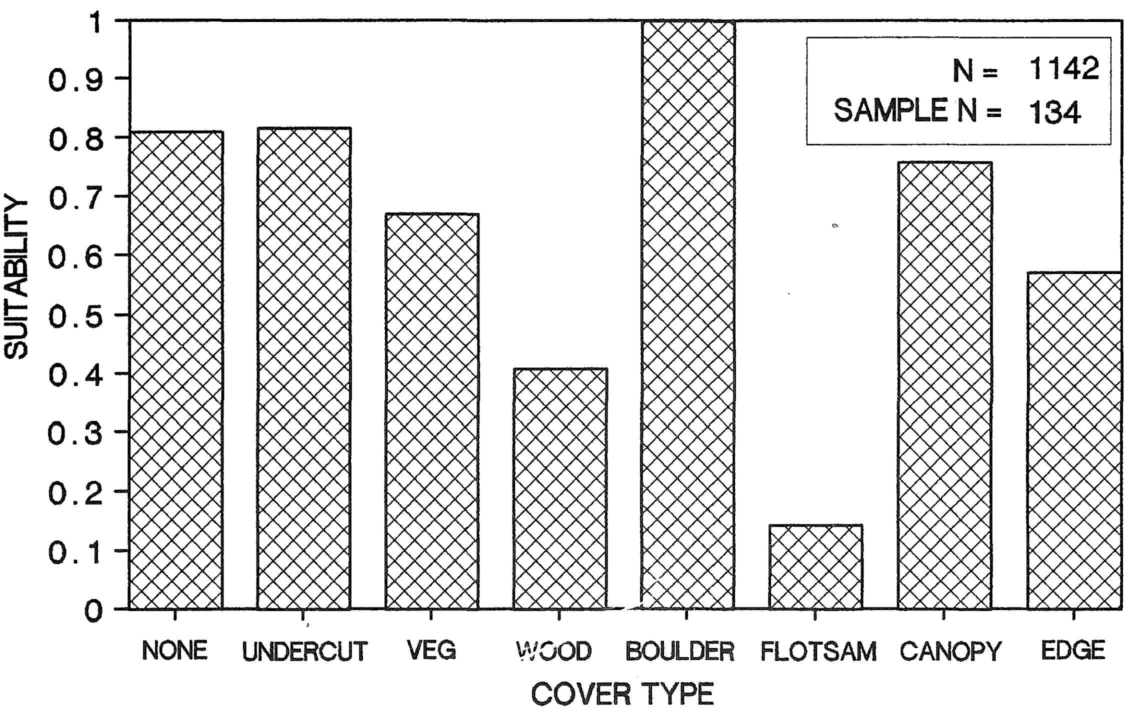


FIGURE 46. Cover preference of Zumbro River adult banded darters (>38 mm).

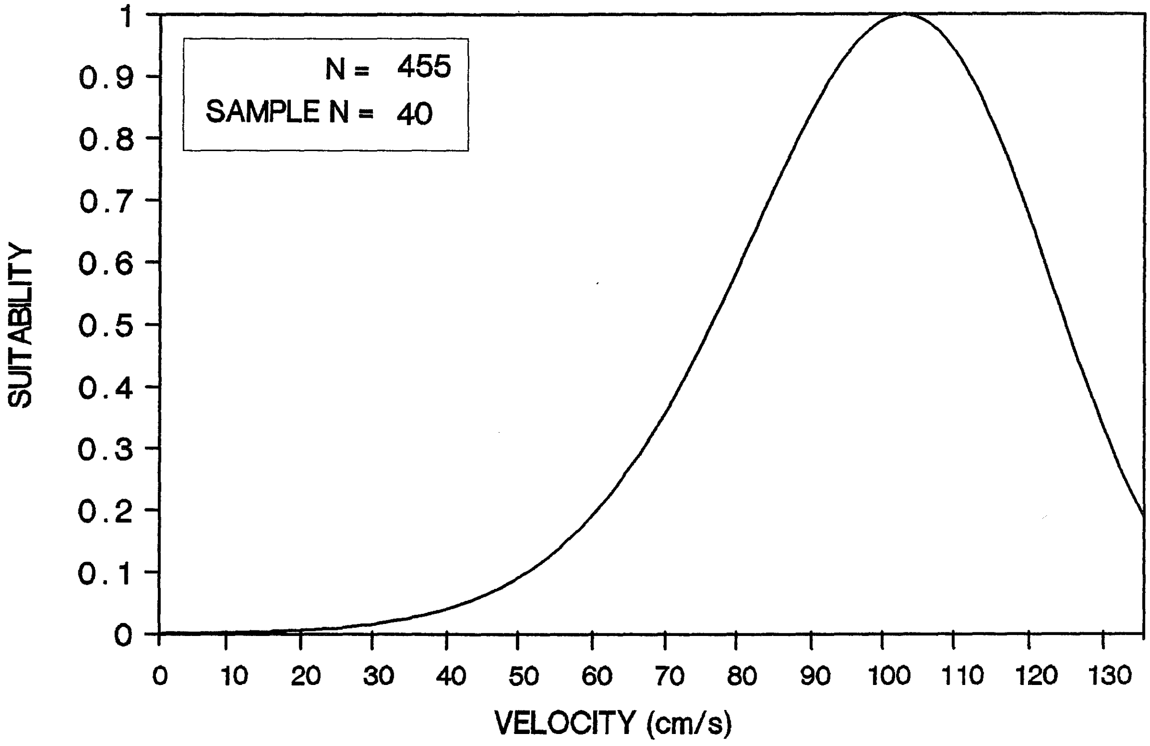


FIGURE 47. Velocity preference of Zumbro River juvenile longnose dace (40-79 mm).

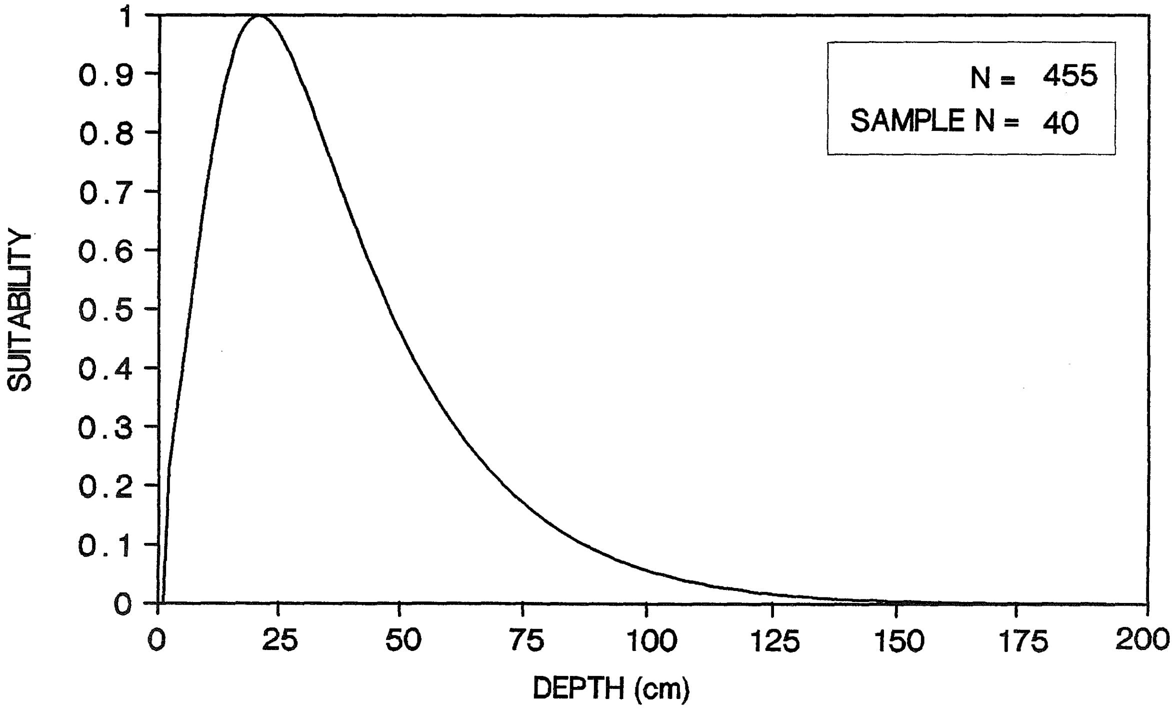


FIGURE 48. Depth preference of Zumbro River juvenile longnose dace (40-79 mm).

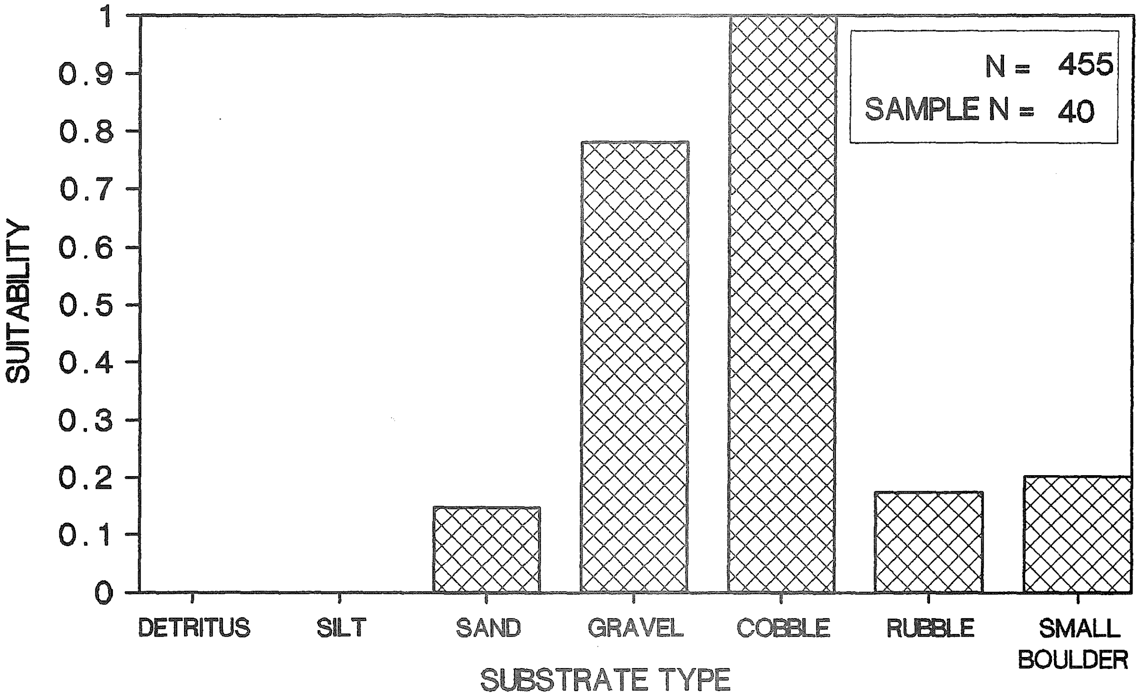


FIGURE 49. Dominant substrate preference of Zumbro River juvenile longnose dace (40-79 mm).

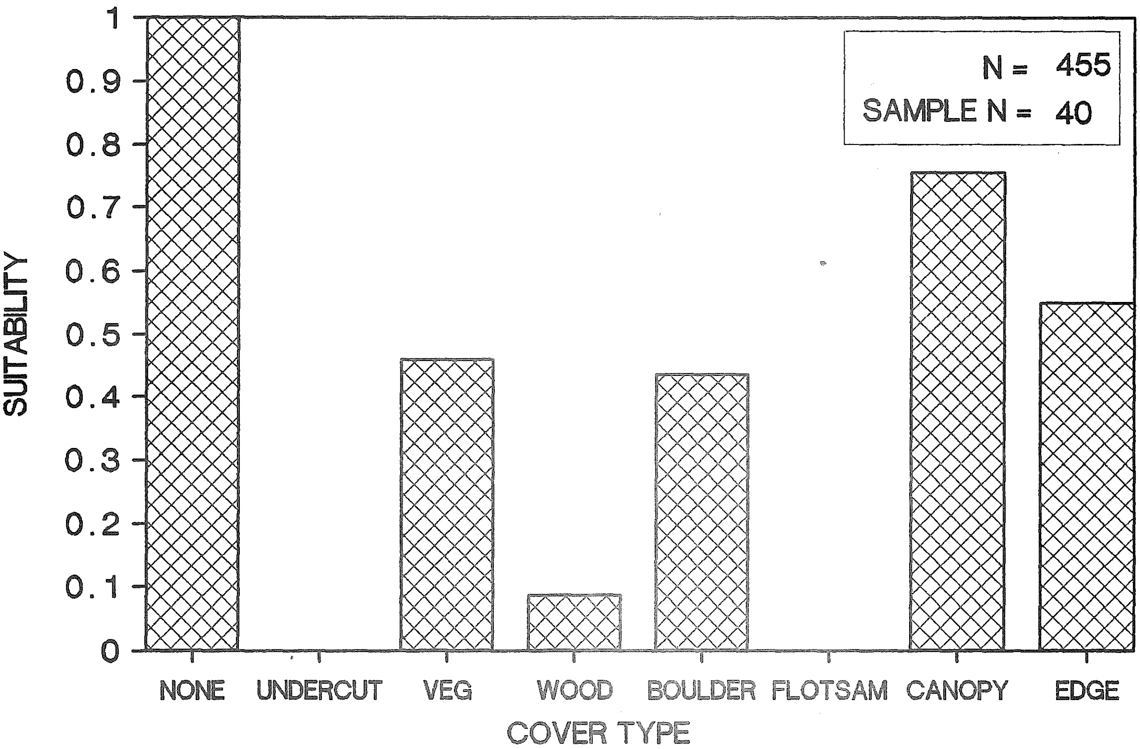


FIGURE 50. Cover preference of Zumbro River juvenile longnose dace (40-79 mm).

DISCUSSION

CURVE TRANSFERABILITY

Graphical comparisons of habitat preference curves developed in this study with those from the Instream Flow Group's (IFG) FISHFIL in Fort Collins, Colorado showed pronounced differences for some species life stages. For instance, IFG velocity preference curves for smallmouth bass adults indicate that zero velocity water is the most suitable and that velocities over 16 cm/s (0.52 ft/s) have suitability index values of less than 0.2. Suitability index curves created from our data show a peak velocity preference of 23 cm/s (0.75 ft/s), with a velocity of 80 cm/s (2.62 ft/s) having a suitability index value of 0.2 (Figure 51). We found similar inconsistencies with curves for other smallmouth bass life stages (Figures 52-56). Wiley et al. (1987) found similar discrepancies in habitat preference values for many of the species life stages they compared.

There are several possible explanations for the discrepancies between IFG habitat suitability curves and the preference curves developed in this study. Habitat suitability curves have been created by a variety of techniques. Many of the available curves were developed using the Delphi Technique (category I curves) or similar methods which do not employ empirical data (Figures 53-56). These techniques could permit generalizations which lead to conclusions different from those which are derived with empirical data. For instance, the presence of a species in lentic habitats may be incorrectly considered as evidence that zero velocity water in lotic habitats is highly suitable for that species.

Geographic differences and the lack of adequate variable ranges in the stream where habitat suitability criteria are developed could also affect the outcome of the criteria. For instance, if a species life stage preferred higher water velocity than that available in a stream, velocity preference curves developed on that stream would be incomplete. Also, interaction biases could occur between variables, like depth and velocity, and would be most evident in streams lacking adequate habitat. For example, fish such as shorthead redhorse, which prefer high velocity areas, but also prefer relatively deep water, may be found in shallow riffles if fast, deep areas do not exist. Even category III habitat suitability criteria developed in such a stream would be biased because of the lack of adequate velocity in deep areas. These interactions can only be corrected for by developing multivariate criteria, which are cost prohibitive. In this study, however, the Zumbro River contained a wide range of habitat types, velocities, depths, substrates, and cover types. The development of category III (preference) curves in this stream allowed us to minimize the effects of these biases.

Biotic interactions could also cause differences in habitat preference curves. Werner and Mittelbach (1981) and Schlosser (1987) have shown that predation and competition can cause changes in habitat use by fishes. Consequently, regional differences in species assemblages may also explain differences in habitat suitability curves. For these reasons, it is preferable that curves used in IFIM studies are developed in streams similar to those being assessed, and that species selection for the IFIM simulations are specific to the river section being studied.

Another factor limiting the value of curve comparisons is the lack of adequate documentation of available curves. Explicit methods, length breaks of life stages, and exact sources of criteria information are largely unavailable in the IFG FISHFIL. Consequently, development of suitability criteria within Minnesota appears to be a more appropriate option than verification of curves developed in other areas of North America.

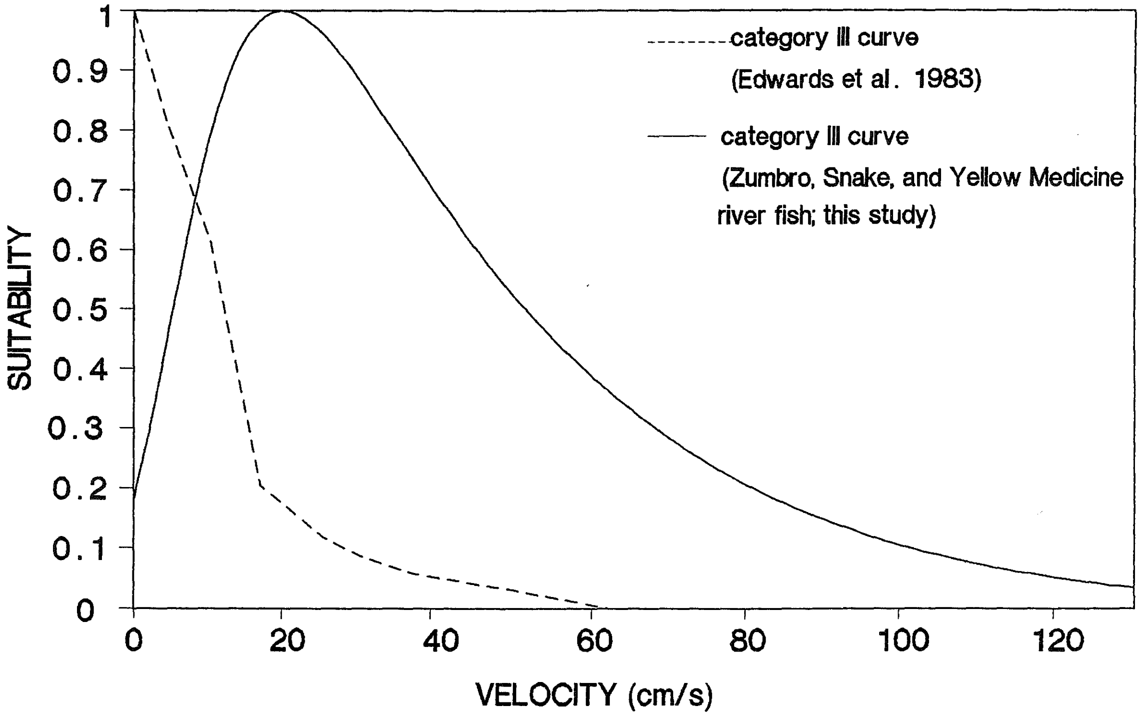


FIGURE 51. Comparison of category III velocity suitability curves for adult smallmouth bass.

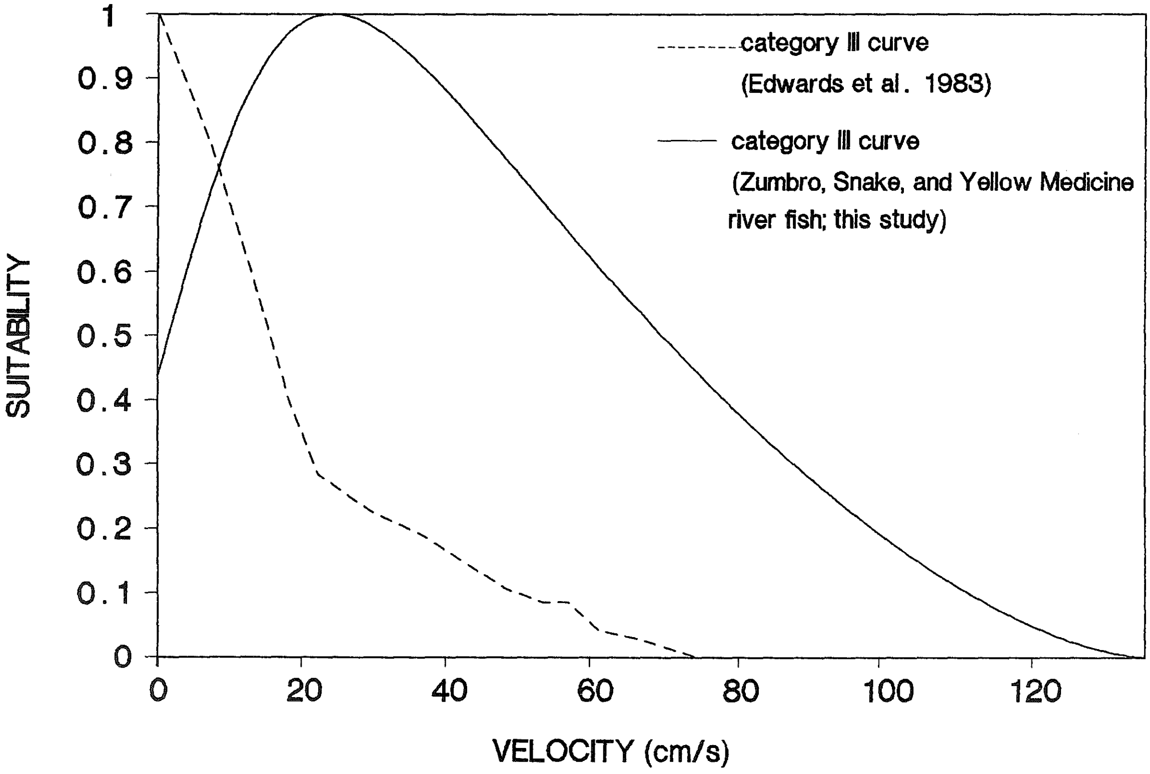


FIGURE 52. Comparison of category III velocity suitability curves for juvenile smallmouth bass.

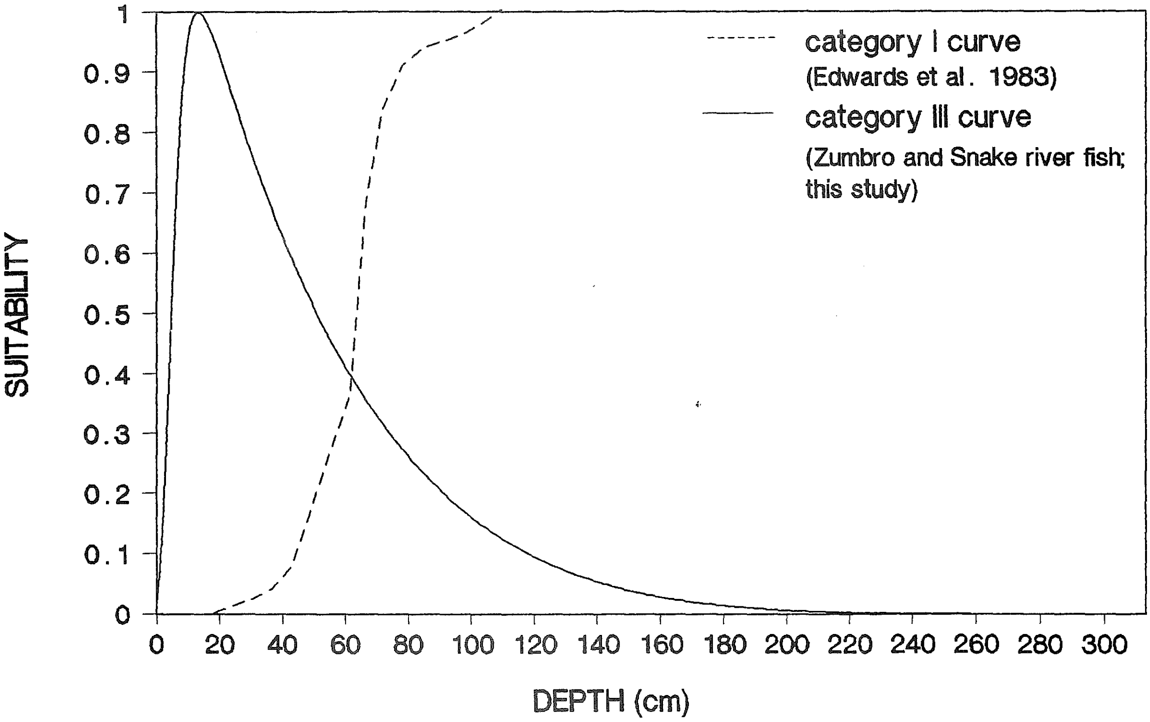


FIGURE 53. Comparison of category I and III depth suitability curves for smallmouth bass fry.

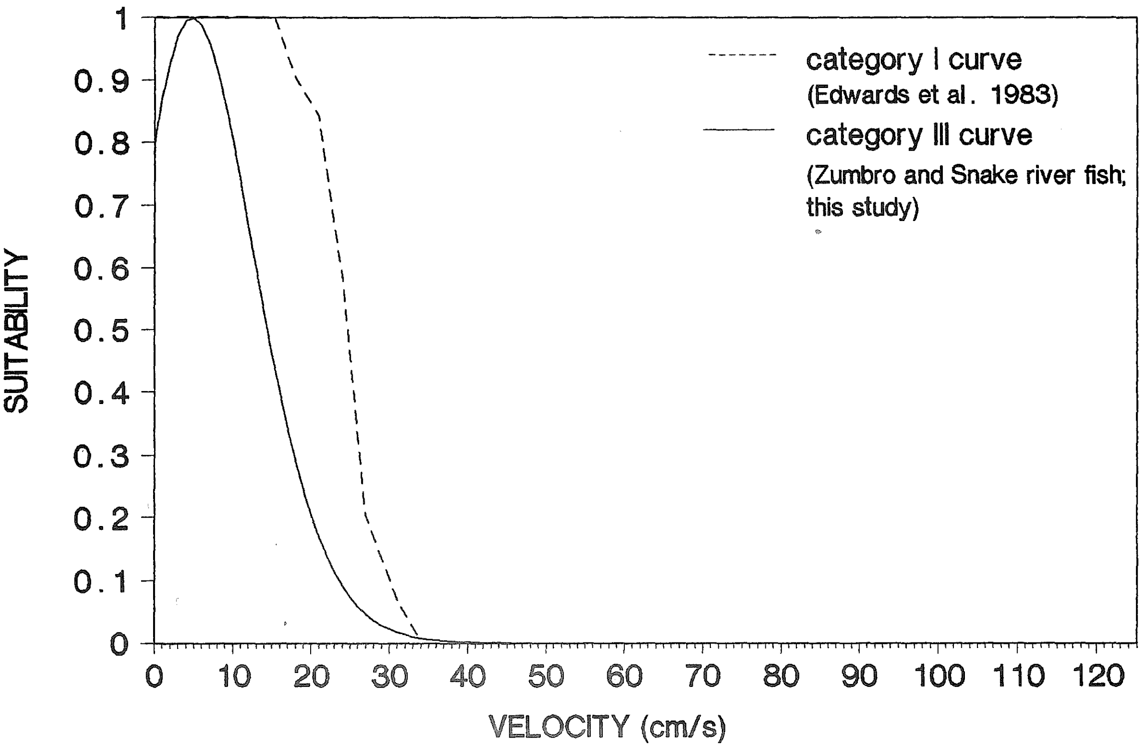


FIGURE 54. Comparison of category I and III velocity suitability curves for smallmouth bass fry.

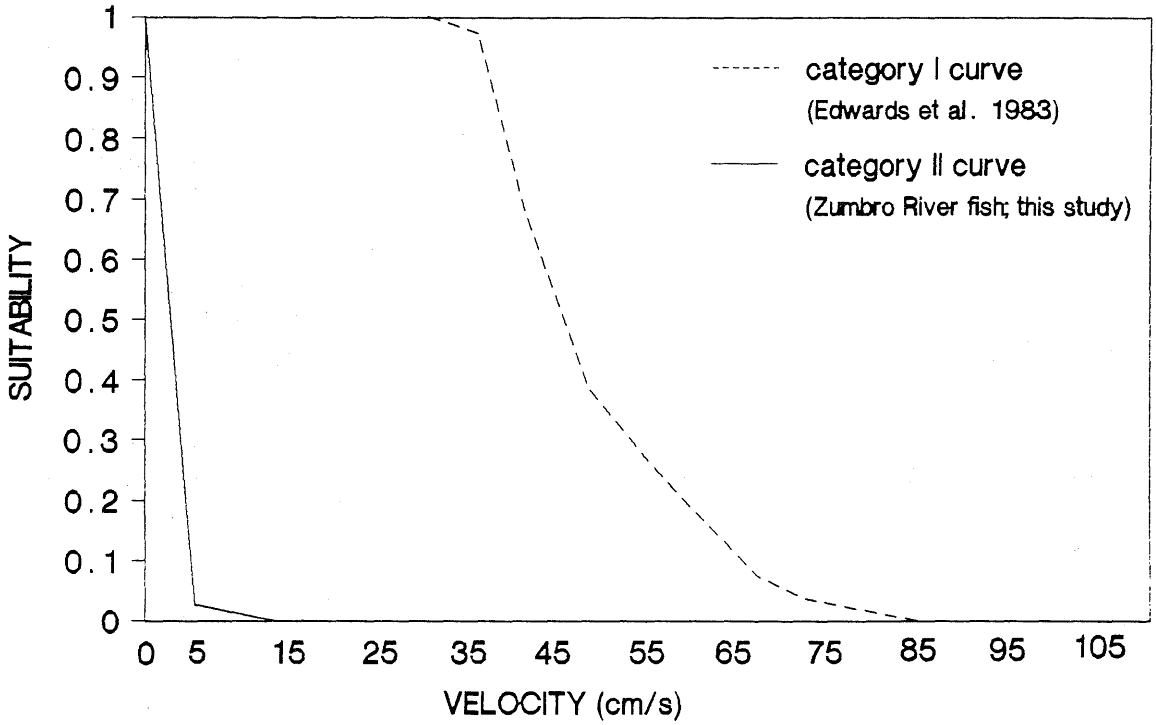


FIGURE 55. Comparison of category I and II velocity suitability curves for spawning smallmouth bass.

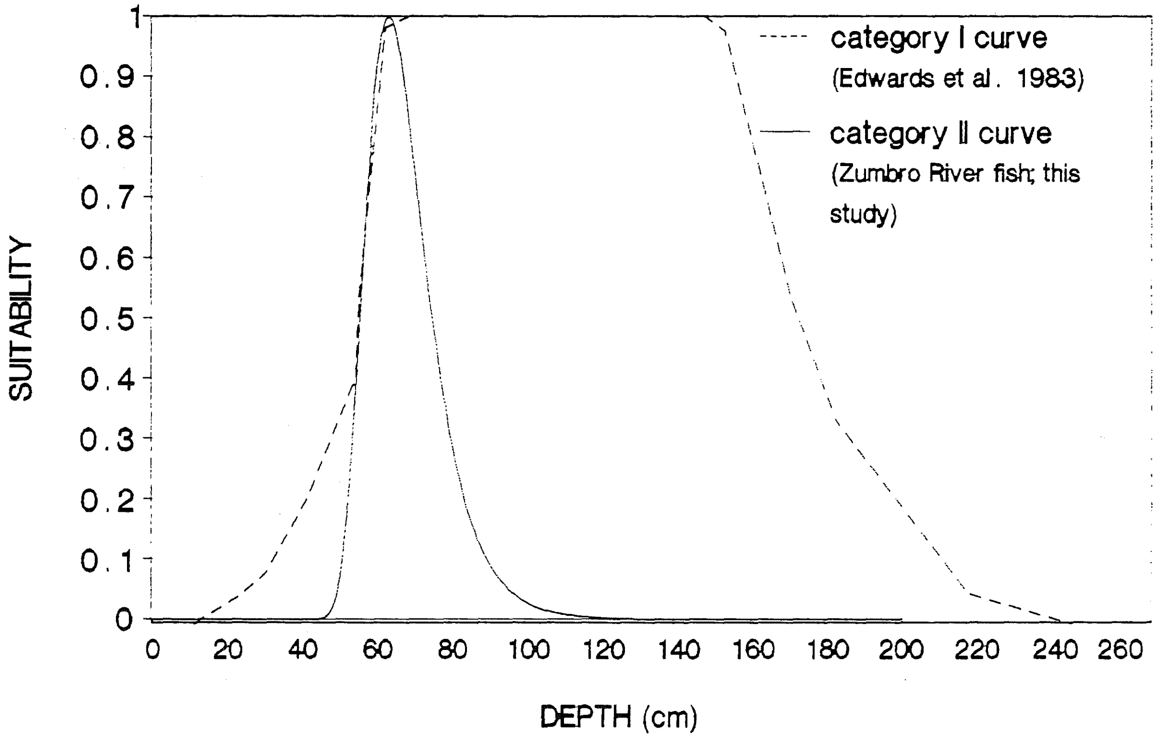


FIGURE 56. Comparison of category I and II depth suitability curves for spawning smallmouth bass.

WEIGHTED VERSUS UNWEIGHTED CURVES

The quantitative sampling techniques used in this study allow the calculation of both weighted (by numbers of individuals collected in a single sample) and unweighted (wherein all samples count equally regardless of the number of individuals collected) preference curves. Assumptions made when using weighted curves include: 1) areas which hold the greatest concentrations of individuals of a species life stage have the most desirable combination of microhabitat parameter values; 2) individuals collected in the sample are present independently rather than due to schooling tendencies; and 3) use of a weighted curve eliminates the effects of loner fish which are passing through an area or otherwise misrepresent the habitat preferences of the species life stage. Assumptions made when using unweighted curves include; 1) areas which hold the greatest concentrations of individuals do so because of schooling tendencies rather than the suitability of the habitat parameters and 2) these schools are constantly moving and numbers collected in a particular sampling location would be highly variable.

Both unweighted and weighted data were used in habitat preference calculations in this study. Unweighted curves were preferred when large numbers (>75) of samples containing at least one individual of a species life stage were taken, and when the species life stage was known to school. Weighted curves were used only for species life stages which were consistently concentrated in localized areas. For instance, large numbers of channel catfish adults and juveniles were consistently found in relatively deep areas which had woody debris or boulder cover. Spawning shorthead redhorse were highly concentrated in high velocity gravel bottomed run areas where they were observed spawning; a few ripe individuals were also found in pool areas but were not seen spawning. The use of unweighted curves in these instances was considered to be inappropriate.

A COMMUNITY ORIENTED APPROACH FOR IFIM IN MINNESOTA

Most studies using the Instream Flow Incremental Methodology (IFIM) have simulated relationships between flow regime and weighted useable area (WUA) for a single species or a few species of special interest. Subsequently, flow recommendations based on these simulations are made. Although this approach may be appropriate for certain cold water streams with low species diversities, it is not adequate for warm water streams. The energetics of warm water streams are very complex and an over-simplified approach (single or few species approach) to complex fisheries management may overlook vital components of the system (Lyons et al. 1988).

Frequently, the species of special interest in IFIM studies are game fish. Game fish are almost always predatory and often piscivorous. Predatory fish spend only a small fraction of their time feeding; most of their time is spent resting and digesting meals (Klauda 1975; Diana 1979). This disproportion in activity will cause habitat preference curves to be biased towards the resting phase of a piscivore's behavior. For instance, habitat preference data for smallmouth bass, collected in this study, suggested that smallmouth bass are basically a pool species throughout their lifetime, yet, food habits of 496 smallmouth bass indicated that 46% of the fishes found in their stomachs were riffle species (Figure 26). Smallmouth bass were frequently observed chasing schools of central stonerollers and shiners _Notropis_ spp. in riffle areas so shallow that smallmouth bass backs were out of the water. On several occasions this feeding behavior was so voracious that fleeing baitfish beached themselves. These incidents happened very quickly, however, so the probability of actually sampling smallmouth bass in the act of feeding is relatively small. If the habitat simulations were conducted, and flow recommendations for increasing smallmouth bass WUA were made based on only their habitat preference data, the simulations might indicate that dewatering riffle areas to produce low velocity water, or flooding out riffle areas to produce deep water would produce more smallmouth bass habitat. Either flow regime could be detrimental to smallmouth bass by reducing food producing areas. Relationships between WUA and standing stock of a fish species are likely to be greatest for fishes which use similar habitat for all aspects of their behavior and are least dependent on other areas. For example, a study evaluating IFIM in Oklahoma showed no correlation between WUA and standing stock of adult and juvenile smallmouth bass during any season, but showed significant correlations for freckled madtom _Noturus_ _nocturnus_, central stoneroller, and orangebelly darter _Etheostoma_ _radiosum_ which are non-piscivorous species (Orth and Maughan 1982).

In the present study, habitat suitability data were collected from over 36,000 fish, which were clustered by species into six habitat-use guilds. These guilds describe the relationships between certain types of habitat (represented by the variables of velocity, depth, substrate, cover), and the presence or absence of fish species. The guilds also exemplify the habitat-use relationships among fish. Therefore, to ensure adequate protection of the aquatic habitat in Minnesota, habitat-flow relationships should be simulated for representatives of these prevalent habitat-use guilds. The habitat-flow relationships will probably be different for each of the guild representatives, so interpretation of the habitat simulation will requires a good understanding of the community dynamics and management objectives of the stream.

Species selection for the IFIM simulations should be specific to the river section being studied. Streams typically exhibit a gradient of physical characteristics from headwaters to large rivers (Leopold et al. 1964; Horowitz 1978; Vannote and Sweeney 1980) and these changes are also associated with changes in species assemblages (Cummins 1975; Vannote et al. 1980; Schlosser 1982). Guild representatives identified in this study are appropriate for habitat simulations on the Zumbro River and other rivers of similar order and gradient, but may not be appropriate on streams such as the Minnesota River, which are morphologically dissimilar to the Zumbro. Also, some species of fish are more sensitive to changes in flow than others. Therefore, the habitat-use guild representative which is most sensitive to changes in flow should be weighted most heavily in the interpretation of habitat simulations. For these reasons, we advocate a community-oriented approach to IFIM and to subsequent protection of important habitat types.

Information gathered during the past two years has greatly improved our understanding of the habitat requirements of a number of stream fishes. The habitat suitability curves developed in this study will improve the DNR's ability to respond to appropriation permits, hydropower licensing and relicensing applications, water diversion projects, and reservoir operation plans (i.e. flood control, recreation, navigation). Some of this information has already been applied in negotiating stream flows below hydropower facilitates on the upper Mississippi and Ottertail rivers.

The availability of reliable habitat preference data has often limited the use of the IFIM in warm and cool water streams. Techniques which are not based on biological needs are relied upon, although they are unproven for use on warm water streams, and are difficult to defend in appropriation hearings. Sampling techniques and analytical procedures that have been developed or refined for use in Minnesota should greatly reduce the cost of subsequent instream flow investigations and permit more detailed analysis.

The library of habitat suitability curves that has been compiled during the past two years is by no means complete. There are many species for which insufficient data was collected to develop reliable suitability curves. Of the more than 150 species known to inhabit the streams and rivers of Minnesota, only 63 were collected from the Snake, Yellow Medicine, and Zumbro rivers. There remains a great deal to learn about the specific life-stage requirements of these species. Detailed information is especially needed for game fishes since their welfare is often dependent on complex community interactions.

Unlike many states in the western and eastern United States, Minnesota has a strong legal framework for protecting instream flow values. A tremendous opportunity exists to use the existing legal authority to protect and enhance Minnesota streams and rivers. Until now, we have been unable to take full advantage of this opportunity due to a lack of knowledge concerning habitat requirements of stream fishes and uncertainty as to which instream flow assessment techniques are appropriate for use in Minnesota. In the past two years we have accomplished a great deal towards filling this knowledge void. The momentum that has been gained through the LCMR Water Allocation and Conservation project has established Minnesota as a leader in the Midwest in the field of instream flow research. The accomplishments of this program have been recognized both within the state and nationally. Every effort should be made to continue this program for the protection of Minnesota's stream resources.

RECOMMENDATIONS

1. The Department of Natural Resources should develop a common negotiating strategy for addressing all levels of conflict regarding the establishment of protected flow levels and for the development of reservoir operation plans. Procedural guidelines which yield the most reliable results with the least amount of litigation should be developed.

2. The Department of Natural Resources should establish an instream flow work group to include personnel from the Division of Fish and Wildlife and the Division of Waters. This group would serve to address specific instream flow issues, continue research and development of species habitat criteria for Minnesota stream fishes, and continue the evaluation of instream flow assessment techniques.

3. Additional research into the habitat requirements of important game fish species should be conducted. Specific research needs include:

   A) Population dynamics, movement and habitat- use data for channel catfish in the Mississippi, Minnesota, and Red rivers. Very little is known about this important game species in Minnesota waters.

   B) Seasonal movement and winter habitat use of smallmouth bass. Over-winter survival may be a factor limiting smallmouth populations in some Minnesota streams.

   C) Habitat use of spawning and young-of-the-year lake sturgeon _Acipenser fluvescens_ in the Rainy, St. Louis, and St. Croix rivers and their tributaries. The lake sturgeon was once a valuable commercial species in Minnesota. Habitat degradation, dams and over-exploitation have greatly reduced populations of this species. Information regarding its reproductive requirements would expedite the recovery of the species by facilitating egg take operations and habitat improvements.

4. The Department of Natural Resources should fully evaluate available habitat improvement techniques for use in warm water streams. Through rehabilitation, stream flow regulation, and habitat improvement, the potential exists to expand recreational opportunities on many of our streams and rivers. Habitat improvement

projects should be based on the specific habitat requirements of targeted species and be a component of a comprehensive watershed management plan.

5. The Department of Natural Resources should evaluate all existing protected flows and hydropower operating plans as to their effectiveness in protecting aquatic resources. Where necessary, protected flows should be revised to reflect improvements which have been made in assessment techniques and our improved understanding of the habitat requirements of stream fishes.

6. Where practical, the Department of Natural Resources should recommend the use of the Instream Flow Incremental Methodology (IFIM) in the establishment of protected flows. In terms of intra-agency coordination, an appropriate Section of Fisheries biologist should be involved in:

   A) Species selection. The selected species should include representatives of prevalent habitat-use guilds in the stream, but may also include game fish and species of special concern.

   B) Selection of channel index variables input into the Physical Habitat Simulation (PHABSIM) model. This should be done for each species life stage.

   C) Selection of habitat suitability curves. Category III curves developed in Minnesota are preferred, but under certain circumstances category III curves developed in other states, category II curves, and, in rare instances, category I curves may be appropriate.

   D) Placement of stream transects from which hydraulic data is collected for use in PHABSIM. This will assure that important habitat types are represented.

   E) Interpretation of the IFIM estimates of weighted useable area versus discharge, and determination of protected flows and/or hydropower operational plans.

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APPENDIX I:

Fish species identified from the Zumbro,
Snake, and Yellow Medicine rivers in Minnesota:
family, species abbreviation, common and scientific names.

PETROMYZONTIDAE/LAMPREYS
CHL - Chestnut lamprey.........*Ichthyomyzon casteneus*

CLUPEIDAE/HERRINGS
GIS - Gizzard Shad............*Dorosoma cepedianum*

UMBRIDAE/MUDMINNOW
CNM - Central Mudminmnow.......*Umbra limi*

ESOCIDAE/PIKES
NOP - Northern Pike...........*Esox lucius*

CYPRINIDAE/CARPS and MINNOWS
CSR - Central Stoneroller......*Campostoma anomalum*
LSR - Largescale Stoneroller...*Campostoma oligolipis*
CAP - Carp....................*Cyprinus carpio*
HHC - Horneyhead Chub.........*Nocomis biguttatus*
GOS - Golden Shiner...........*Notemigonus crysoleucas*
EMS - Emerald Shiner..........*Notropis atherinoides*
RVS - River Shiner............*Notropis blennius*
CSH - Common Shiner...........*Notropis cornutus*
BCS - Blackchin Shiner........*Notropis heterodon*
BNS - Blacknose Shiner........*Notropis heterolepis*
SPO - Spottail Shiner.........*Notropis hudsonius*
SFS - Spotfin Shiner..........*Notropis spilopterus*
SDS - Sand Shiner.............*Notropis stramineus*
MMS - Mimic Shiner............*Notropis volucellus*
SKM - Suckermouth Minnow.......*Phenacobius mirabilis*
BNM - Bluntnose Minnow.........*Pimephales notatus*
FHM - Fathead Minnow..........*Pimephales promelas*
BND - Blacknose Dace..........*Rhinichthys atratulus*
LND - Longnose Dace...........*Rhinichthys cataractae*
RSD - Redside Dace............*Clinostomus elongatus*
CRC - Creek Chub..............*Semotilus atromaculatus*

CATOSTOMIDAE/SUCKERS
RCS - River Carpsucker........*Carpiodes carpio*
QBS - Quillback Carpsucker.....*Carpoides cyprinus*
WTS - White Sucker............*Catostomus commersoni*
SPS - Spotted Sucker..........*Minytrema melanops*
NHS - Northern Hog Sucker......*Hypentelium nigricans*
SAB - Smallmouth Buffalo.......*Ictiobus bubalus*
SLR - Silver Redhorse.........*Moxostoma anisurum*
RRH - River Redhorse..........*Moxostoma carinatum*
GLR - Golden Redhorse.........*Moxostoma erythrurum*

SHR - Shorthead Redhorse.......Moxostoma macrolepidotum
GRR - Greater Redhorse.........Moxostoma valenciennesi

ICTALURIDAE/CATFISHES
BLB - Black Bullhead...........Ictalurus melas
YEB - Yellow Bullhead..........Ictalurus natalis
CCF - Channel Catfish..........Ictalurus punctatus
STC - Stonecat.................Noturus flavus

GADIDAE/CODFISHES
BUB - Burbot...................Lota lota

ATHERINIDAE/SILVERSIDES
BKS - Brook Silverside.........Labidesthes sicculus

PERCICHTHYIDAE/TEMPERATE BASSES
WHB - White Bass...............Morone chrysops

CENTRARCHIDAE/SUNFISHES
RKB - Rock Bass................Ambloplites rupestris
GSF - Green Sunfish............Lepomis cyanellus
OSS - Orangespotted Sunfish....Lepomis humilis
BLG - Bluegill Sunfish.........Lepomis machrochirus
SMB - Smallmouth Bass..........Micropterus dolomieui
LMB - Largemouth Bass..........Micropterus salmoides
WHC - White Crappie............Pomoxis annularis
BLC - Black Crappie............Pomoxis nigromaculatus

PERCIDAE/PERCHES
RBD - Rainbow Darter...........Etheostoma caeruleum
FTD - Fantail Darter...........Etheostoma flaballare
JND - Johnny Darter............Etheostoma nigrum
BDD - Banded Darter............Etheostoma zonale
YEP - Yellow Perch.............Perca flavescens
LGP - Log Perch................Percina caprodes
GLD - Gilt Darter..............Percina evides
BSD - Blackside Darter.........Percina maculata
SHD - Slenderhead Darter.......Percina phoxocephala
SAR - Sauger...................Stizostedion canadense
WAE - Walleye..................Stizostedion vitreum

SCIAENIDAE/DRUMS
FRD - Freshwater Drum..........Aplodinotus grunniens

APPENDIX II

Length breaks (mm total length) for species life stages collected from the Zumbro, Snake, and Yellow Medicine rivers in Minnesota, 1987-1988.

ABBREVIATION AND COMMON NAME		YOY	JUV	ADT
CYPRINIDAE/CARPS AND MINNOWS				
CAP	Carp		200	300
CSR	Central Stoneroller		65	79
LSR	Largescale Stoneroller		65	80
BCS	Blackchin Shiner			40
BNS	Blacknose Shiner		40	80
BNM	Bluntnose Minnow			50
CSH	Common Shiner		50	81
CRC	Creek Chub		65	81
EMS	Emerald Shiner			41
FHM	Fathead Minnow			40
GOS	Golden Shiner			64
HHC	Horneyhead Chub		50	100
MMS	Mimic Shiner			40
RCS	River Shiner			60
SDS	Sand Shiner			40
SFS	Spotfin Shiner			41
SPO	Spottail Shiner			67
SKM	Suckermouth Minnow		40	80
BND	Blacknose Dace			40
LND	Longnose Dace		40	80
RSD	Redside Dace		40	60
CATOSTOMIDAE/SUCKERS				
QBS	Quillback Carpsucker		150	350
RCS	River Carpsucker		170	370
NHS	Northern Hogsucker		70	151
SAB	Smallmouth Buffalo		250	350
SPS	Spotted Sucker		60	250
WTS	White Sucker		75	301
GLR	Golden Redhorse		100	251
GRR	Greater Redhorse		50	430
RRH	River Redhorse		50	350
SHR	Shorthead Redhorse		100	250
SLR	Silver Redhorse		100	250

ABBREVIATION AND COMMON NAME		YOY	JUV	ADT
ICTALURIDAE/CATFISHES				
BLB	Black Bullhead		70	150
YEB	Yellow Bullhead		70	150
CCF	Channel Catfish		80	310
STC	Stonecat		50	100
GADIDAE/CODFISHES				
BUB	Burbot			250
ATHERINIDAE/SILVERFISHES				
BKS	Brook Silverside			60
PERCICHTHUIDAE/TEMPERATE BASSES				
WHB	White Bass		150	300
CENTRARCHIDAE/SUNFISHES				
BLG	Bluegill Sunfish		35	100
GSF	Green Sunfish			50
OSS	Orangespotted Sunfish		30	50
RKB	Rock Bass		50	70
SMB	Smallmouth Bass	60	100	189
LMB	Largemouth Bass		100	250
BLC	Black Crappie		90	150
WHC	White Crappie		90	150
PETROMYZONTIDAE/LAMPREYS				
CHL	Chestnut Lamprey		70	130
CLUPEIDAE/HERRINGS				
GIS	Gizzard Shad			150
UMBRIDAE/MUDMINNOW				
CNM	Central Mudminnow			50
SCIANIDAE/DRUMS				
FRD	Freshwater Drum		125	300
ESOCIDAE/PIKES				
NOP	Northern Pike			250
PERCIDAE/PERCHES				
BDD	Banded Darter			38
BSD	Blackside Darter			70
FTD	Fantail Darter			40
GLD	Gilt Darter			70
JND	Johnny Darter			56
RBD	Rainbow Darter			40
SHD	Slenderhead Darter			40

ABBREVIATION AND COMMON NAME		YOY	JUV	ADT
LGP	Log Perch			61
YEP	Yellow Perch		70	150
SAR	Sauger		150	250
WAE	Walleye		150	300

APPENDIX III

Coordinates for fish habitat preference curves fit with non-linear regression, using the generalized Poisson equation:

PREFERENCE =(((B-X)/(B-A))^C)* e^((C/D)*(1-((B-X)/(B-A))^D))

where: A= value of X where f(X)=1.0
B= value of X where f(X)=0.0 (X<B)
C= shape parameter for part of curve to right of X=A
D= shape parameter for part of curve to left of X=A
e= base of the natural logarithm
X= habitat variable (Bovee 1986)

SPECIES CURVE	B	A	C	D
Spawning walleye				
velocity	428.747	56.988	24.139	20.375
depth	355.001	61.997	23.057	15.636
Smallmouth bass				
fry velocity	125.000	4.810	26.801	9.583
depth	350.000	13.476	6.340	109.200
fingerling vel	130.000	33.810	0.755	6.706
depth	350.000	29.976	1.968	52.227
juvenile velocity	135.000	23.794	1.593	11.377
depth	502.196	54.812	6.570	30.391
adult velocity	370.002	19.289	9.418	46.222
depth	390.844	123.605	95.873	0.484
spawning velocity	no curve			
depth	26419000	63.000	3202876	3517165
Channel catfish juveniles				
velocity	90.000	13.065	29.856	0.487
depth	288.032	87.842	92.899	0.676
Sand shiner young-of-the-year				
velocity	365.001	0.000	12.504	149.719
depth	387.684	8.356	12.949	170.897
Zumbro shorthead redhorse adult				
velocity	844.637	64.696	25.817	10.240
depth	500.300	92.905	168.030	1.768
Zumbro banded darter adult				
velocity	193.768	88.306	62.345	0.183
depth	355.000	23.634	10.782	41.092

SPECIES CURVE	B	A	C	D
Zumbro longnose dace juveniles				
velocity	215.370	102.268	58.816	0.518
depth	355.005	19.995	11.777	39.914