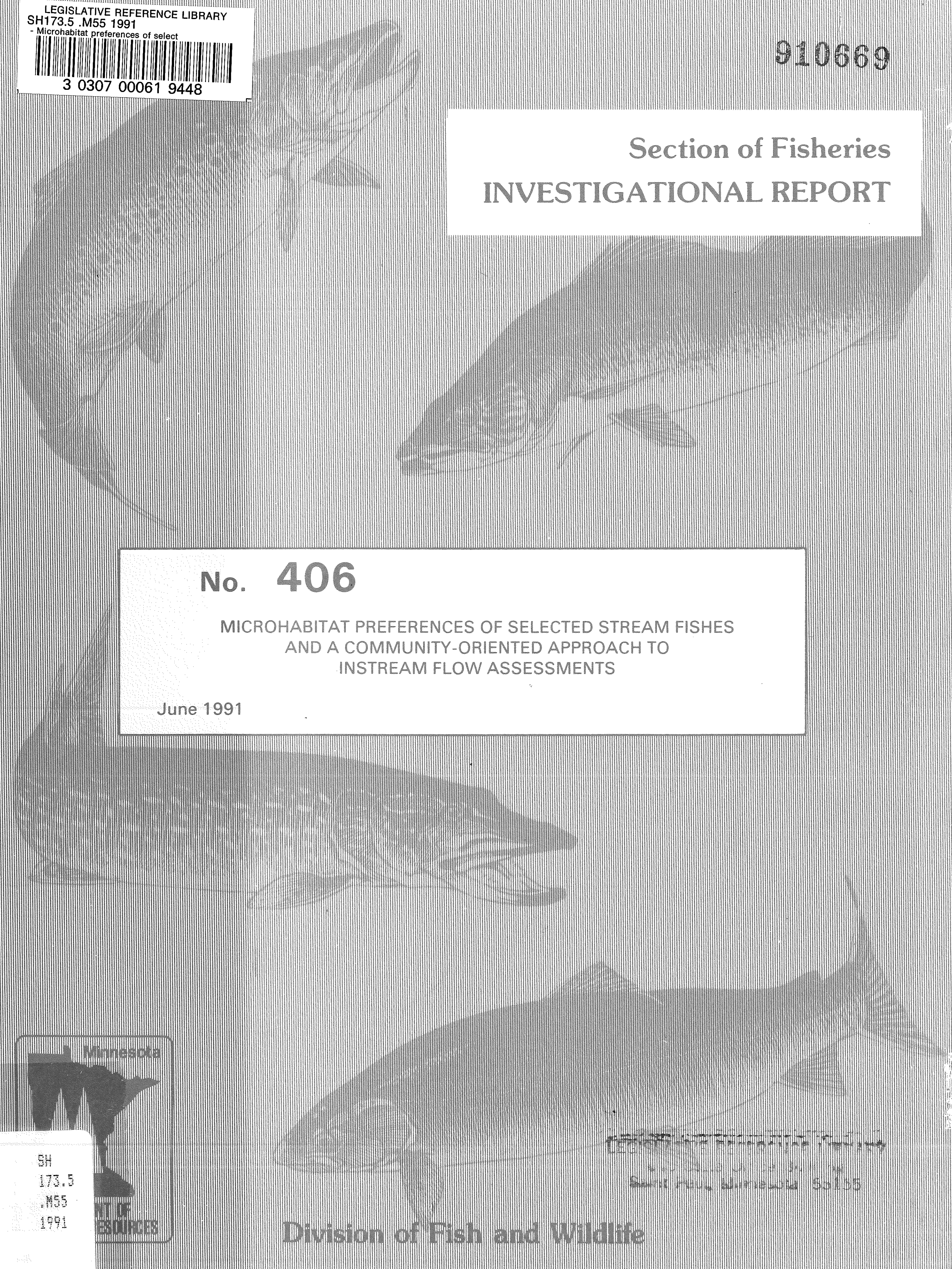

Section of Fisheries

INVESTIGATIONAL REPORT

No. 406

MICROHABITAT PREFERENCES OF SELECTED STREAM FISHES AND A COMMUNITY-ORIENTED APPROACH TO INSTREAM FLOW ASSESSMENTS

June 1991

Minnesota Department of Natural Resources

Division of Fish and Wildlife

ERRATA

Dear Colleague,

Please correct the following printing errors in Minnesota Department of Natural Resources, Investigational Report 406, June 1991: "Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessments," by Aadland et al.

On page 44 Notropis stramineus was incorrectly labeled Notropis volucellus. On pages 75-83 four figures were duplicated and the correct figures were omitted.

Enclosed are corrected replacements for pages 43-44 and 75-84.

TABLE 8. Microhabitat means and ranges (in parentheses) and number of samples in slow riffles (<60 cm depth, 30-59 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	43 (30-59)	32 (10-59)	gravel	vegetation (32%) boulder (23%)	91 (1269 m^2)
Snake	40 (30-59)	31 (8-58)	rubble	boulder (91%) vegetation (39%)	23 (321 m^2)
Yellow Medicine (low flow)	37 (33-43)	12 (10-15)	cobble	boulder (67%) wood (50%)	6 (84 m^2)
Yellow Medicine (high flow)	42 (30-57)	31 (14-58)	cobble	boulder (72%) vegetation (33%)	18 (251 m^2)

TABLE 9. Microhabitat means and ranges (in parentheses) and number of samples in fast riffles (<60 cm depth, >=60 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	83 (60-131)	38 (8-59)	cobble	vegetation (21%) boulder (13%)	87 (1213 m^2)
Snake	83 (75-88)	25 (23-28)	rubble	boulder (100%) vegetation (25%)	4 (56 m^2)
Yellow Medicine (low flow)		NO FAST RIFFLE HABITAT			
Yellow Medicine (high flow)	72 (62-86)	33 (21-49)	cobble	boulder (67%) vegetation (44%)	9 (125 m^2)

TABLE 10. Species-life stages which preferred shallow pools (<60 cm deep, <30 cm/s velocity) in the Zumbro (Z), Yellow Medicine (Y), or Snake (S) rivers. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life stage	N	River
Clupeidae				
Gizzard shad	Dorosoma cepedianum	A	18	Y
Gizzard shad	Dorosoma cepedianum	Y	36	Y
Cyprinidae				
Bluntnose minnow	Pimephales notatus	Y	435	S,Y,Z
Carp	Cyprinus carpio	Y	13	Z
Creek chub	Semotilus atromaculatus	A	82	Y,Z
Creek chub	Semotilus atromaculatus	J	76	Y,Z
Common shiner	Notropis cornutus	J	24	Z
Emerald shiner	Notropis atherinoides	Y	842	Y,Z
Golden shiner	Notemigonus crysoleucas	A	5	S
Golden shiner	Notemigonus crysoleucas	Y	12	S
Longnose dace	Rhinichthys cataractae	Y	272	S
River shiner	Notropis blennius	Y	27	Z
Sand shiner	Notropis stramineus	A	946	Y
Sand shiner	Notropis stramineus	Y	796	Y,Z
Spotfin shiner	Notropis spilopterus	A	1209	Z
Spotfin shiner	Notropis spilopterus	Y	128	Z
Spottail shiner	Notropis hudsonius	A	115	Z,S
Spottail shiner	Notropis hudsonius	Y	274	Y,Z
Catastomidae				
Golden redhorse	Moxostoma erythrurum	Y	258	Y,Z
Northern hogsucker	Hypentellium nigricans	Y	47	Z
River carpsucker	Carpoides carpio	Y	81	Y,Z
Centrarchidae				
Bluegill	Lepomis macrochirus	Y	88	S,Z
Green sunfish	Lepomis cyanellus	A	63	Z
Green sunfish	Lepomis cyanellus	Y	64	Y,Z
Orangespotted sunfish	Lepomis humilis	A	15	Y
Smallmouth bass	Micropterus dolomieui	FR	82	S,Z
Rock bass	Ambloplites rupestris	A	79	S
Percidae				
Johnny darter	Etheostoma nigrum	A	57	Z

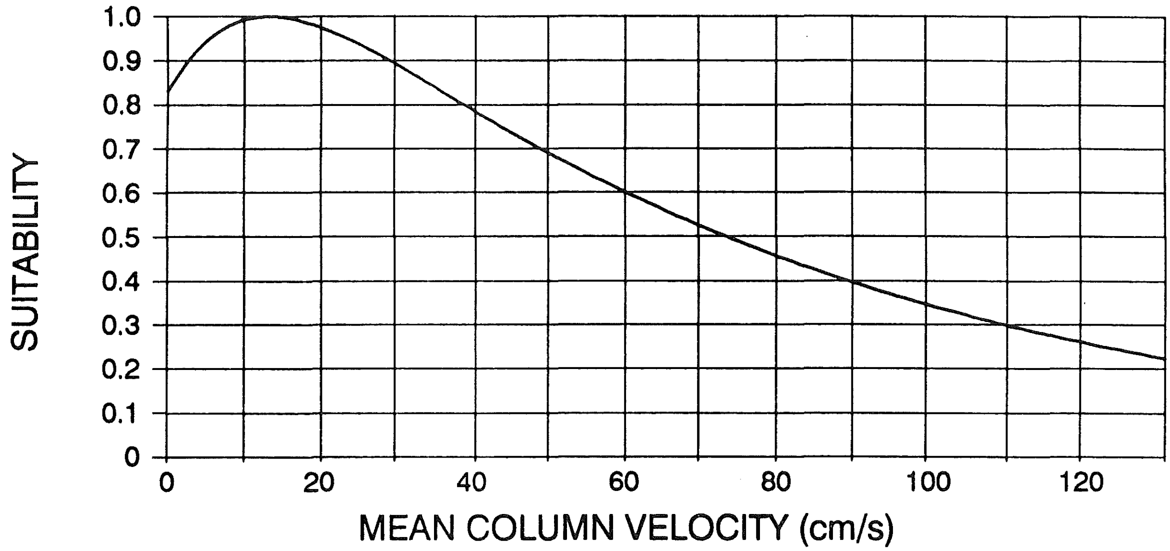

FIGURE 79. Velocity preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

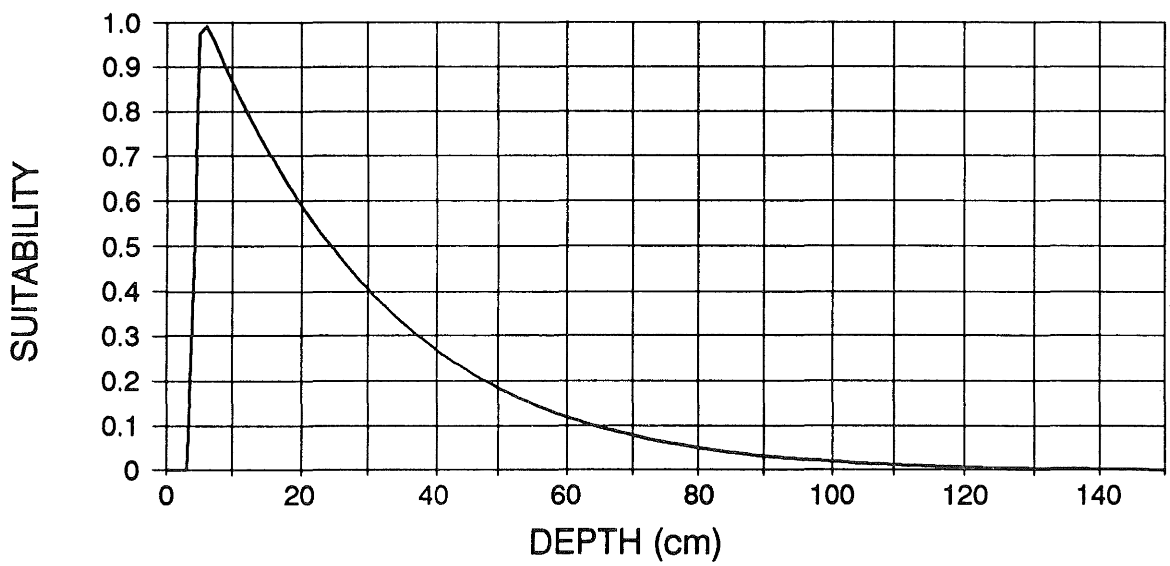

FIGURE 80. Depth preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

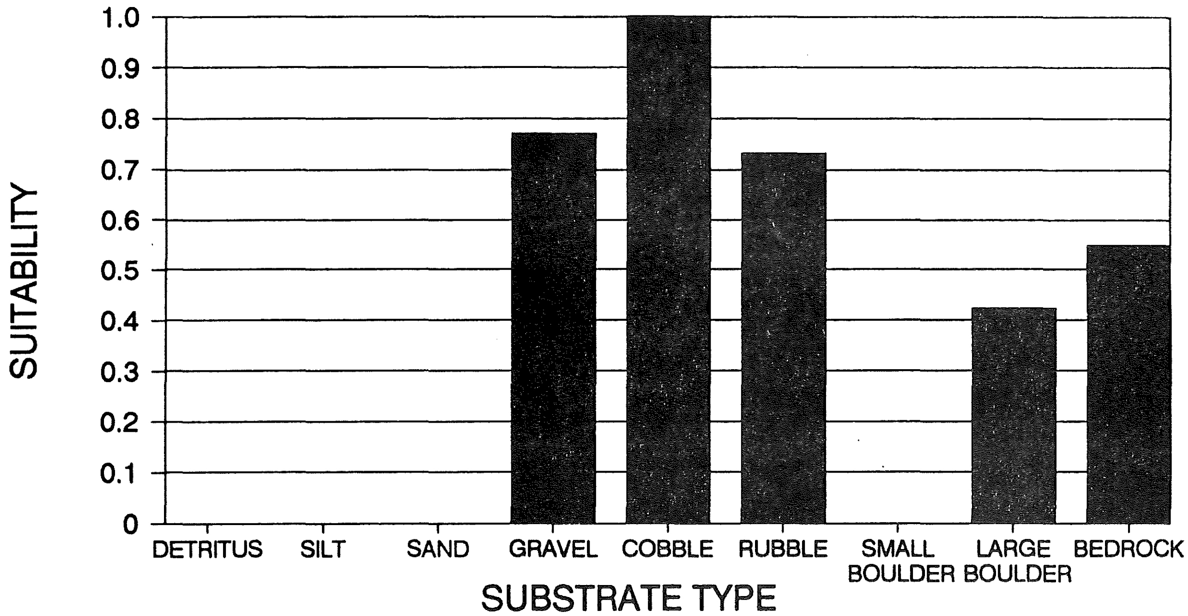

FIGURE 81. Dominant substrate preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

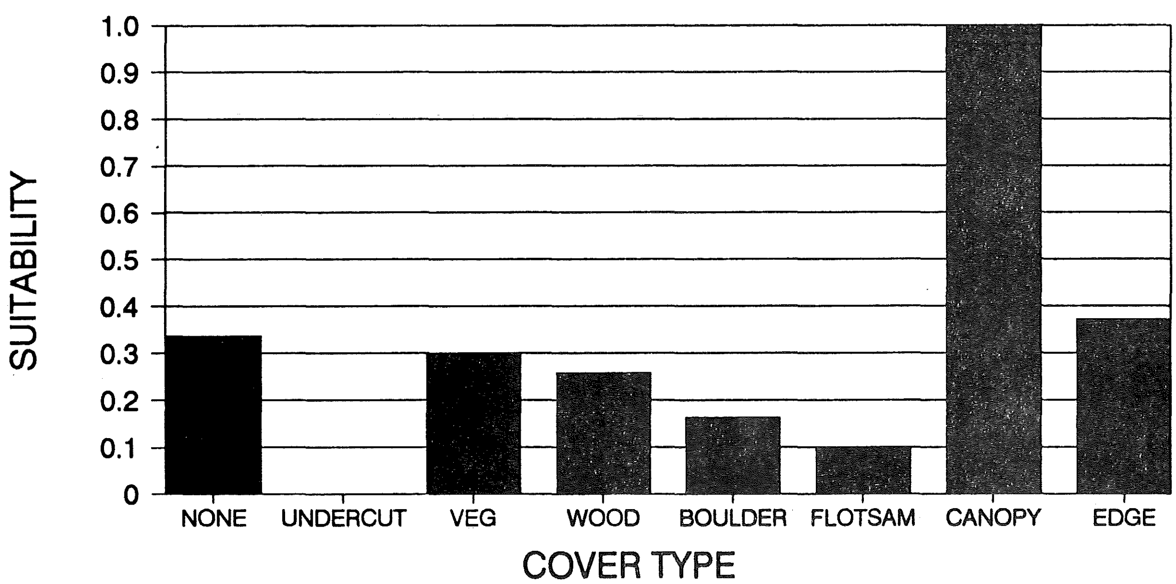

FIGURE 82. Cover preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

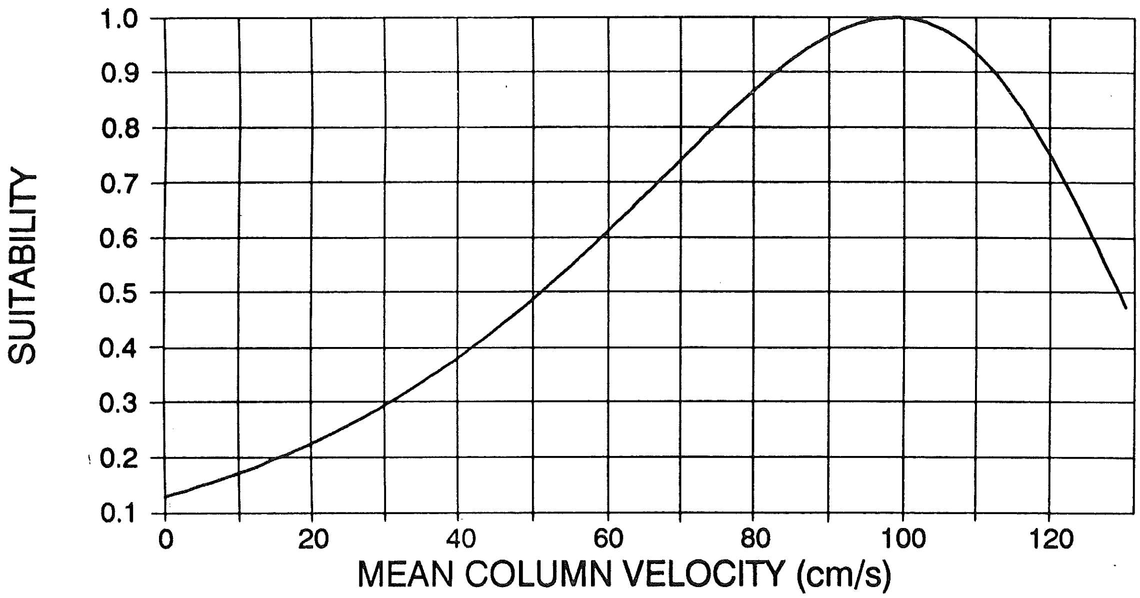

FIGURE 83. Velocity preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

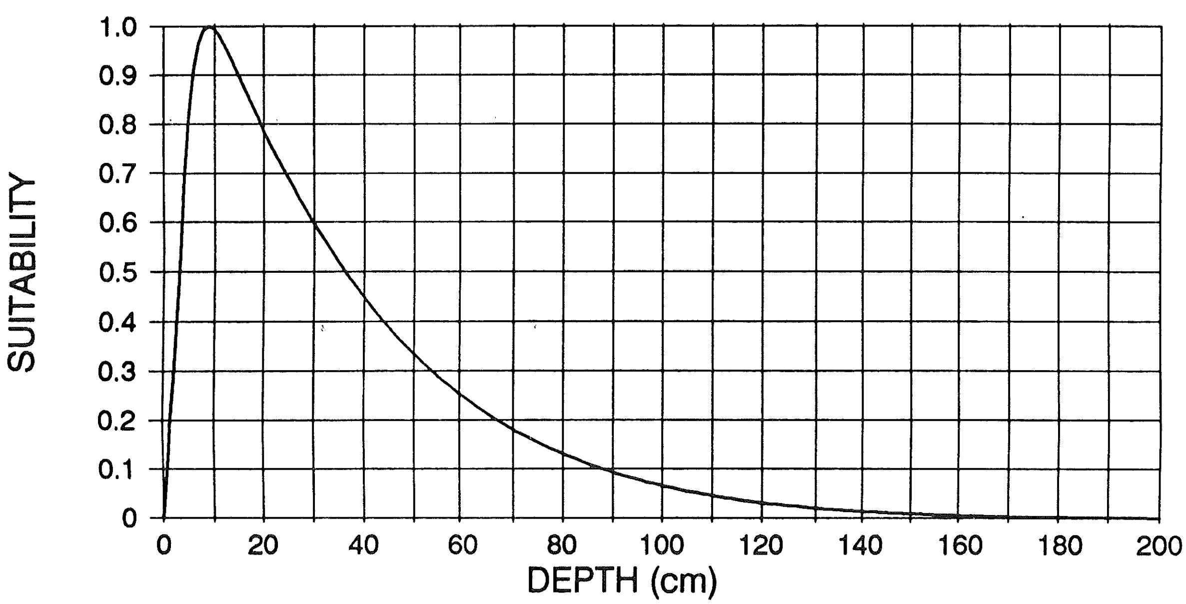

FIGURE 84. Depth preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

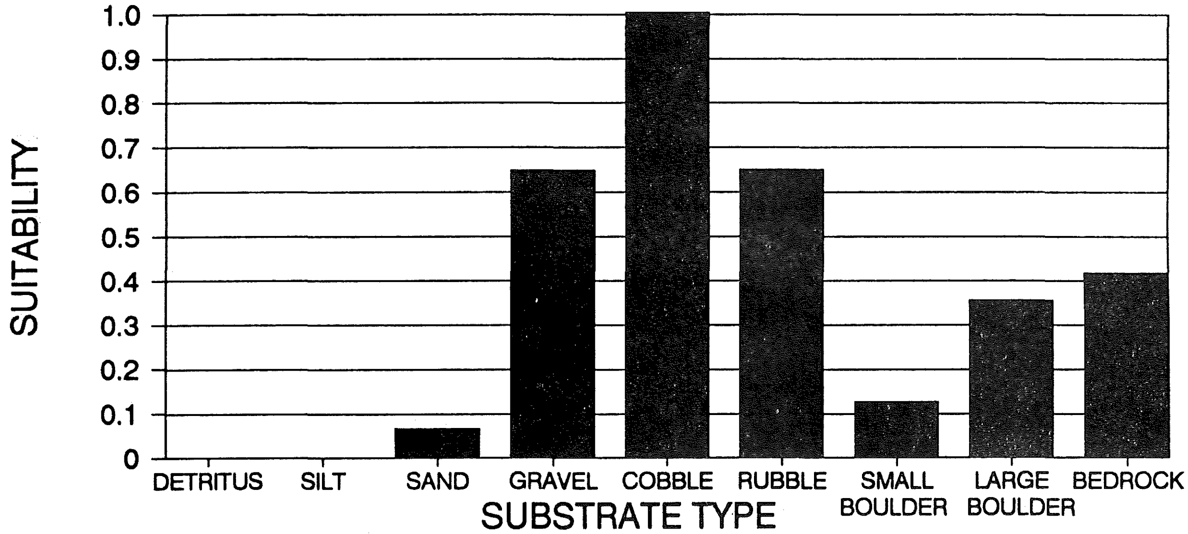

FIGURE 85. Dominant substrate preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

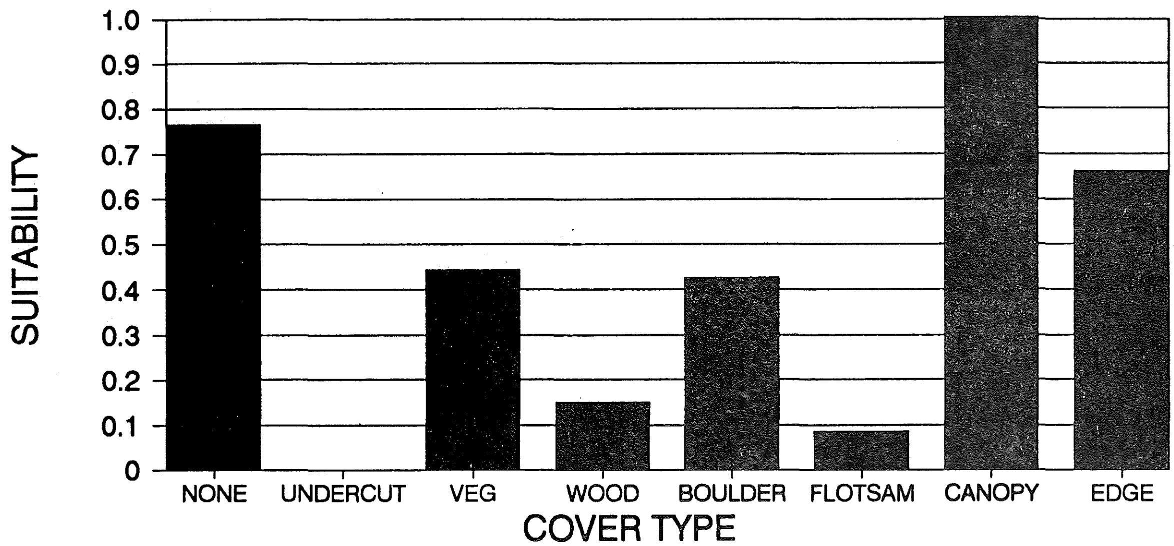

FIGURE 86. Cover preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

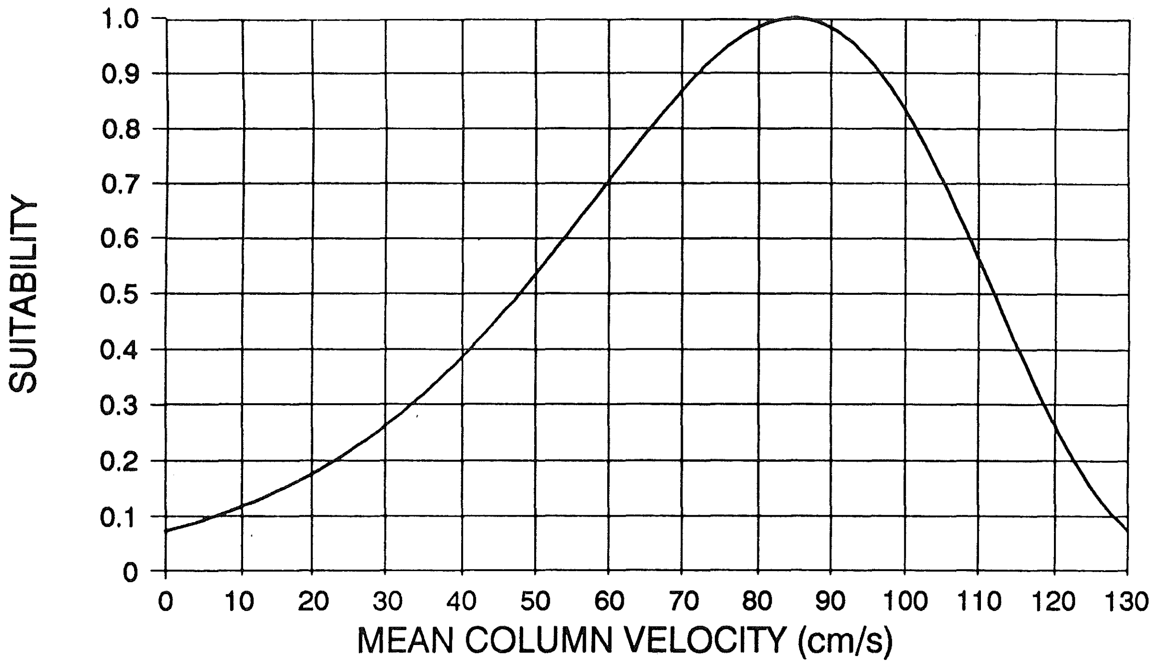

FIGURE 87. Velocity preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

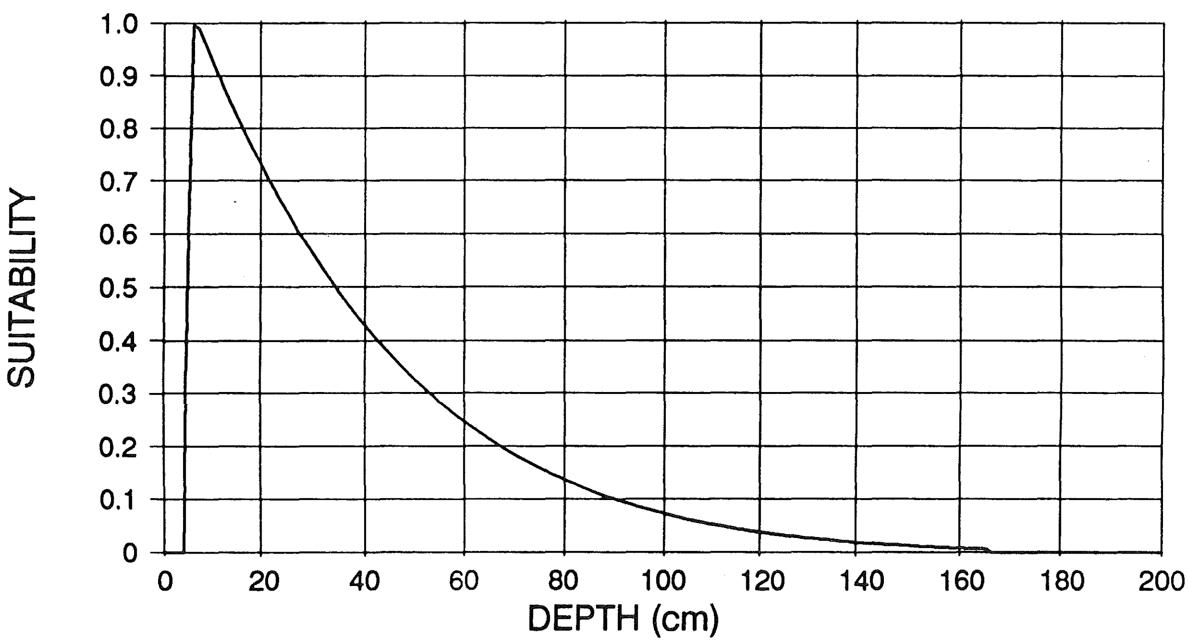

FIGURE 88. Depth preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

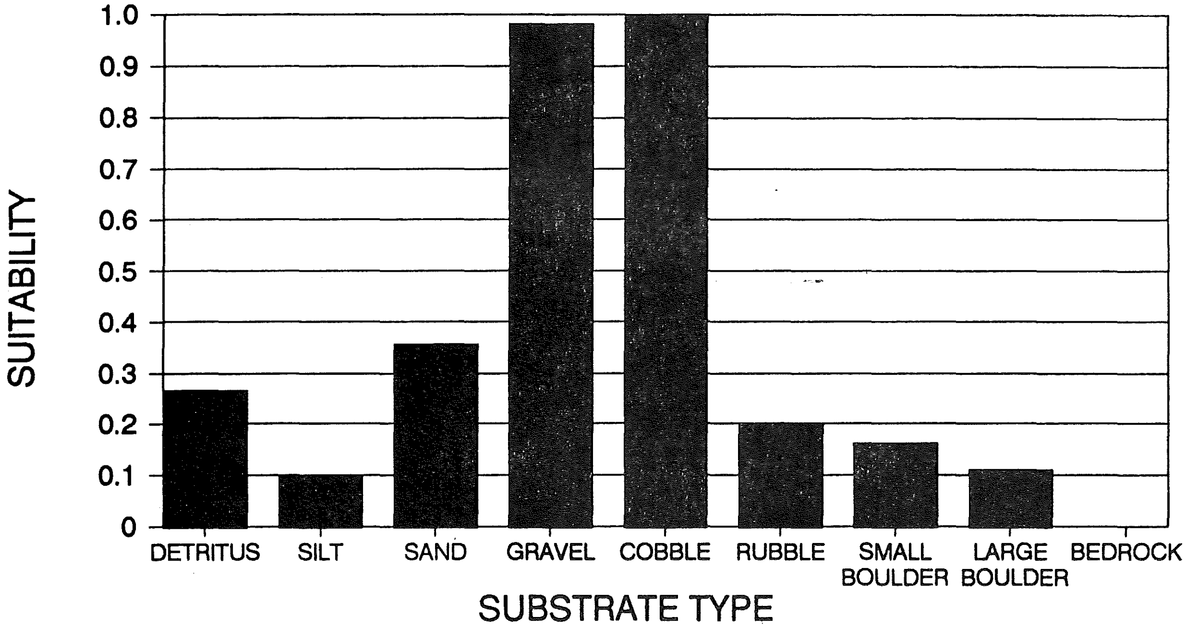

FIGURE 89. Dominant substrate preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

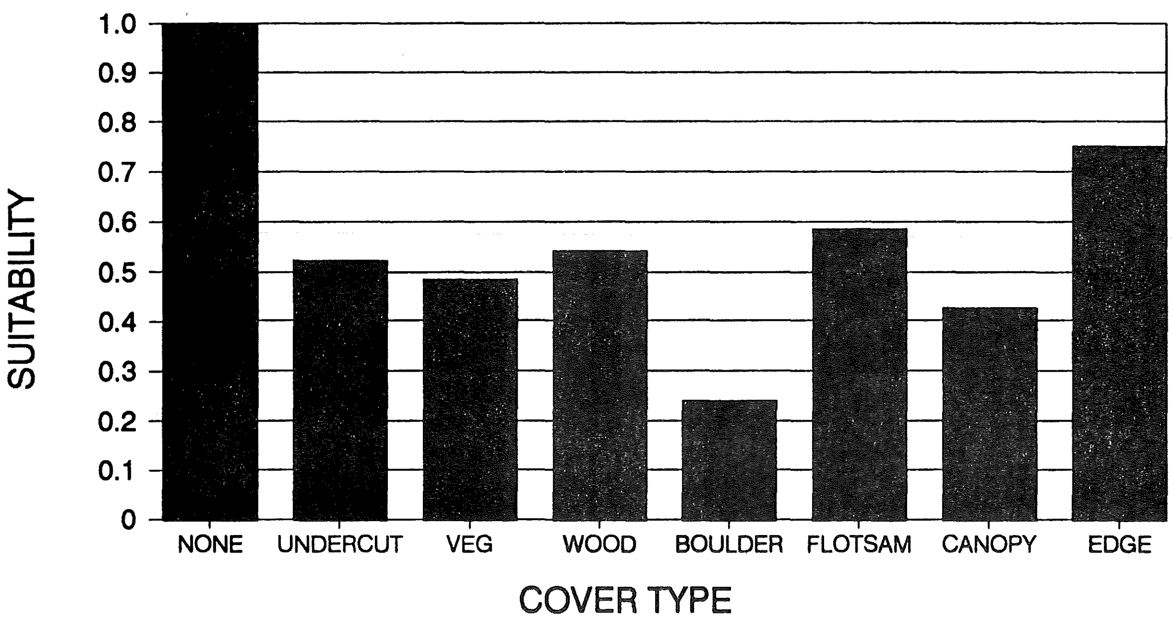

FIGURE 90. Cover preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

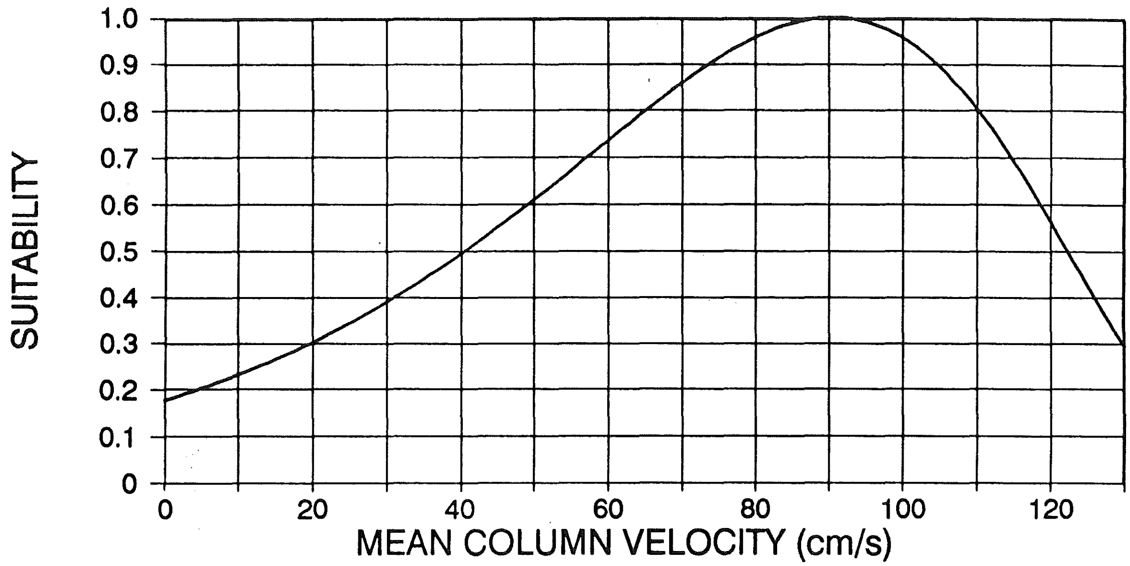

FIGURE 91. Velocity preference of adult northern hog sucker (>150 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=345, number of samples=128).

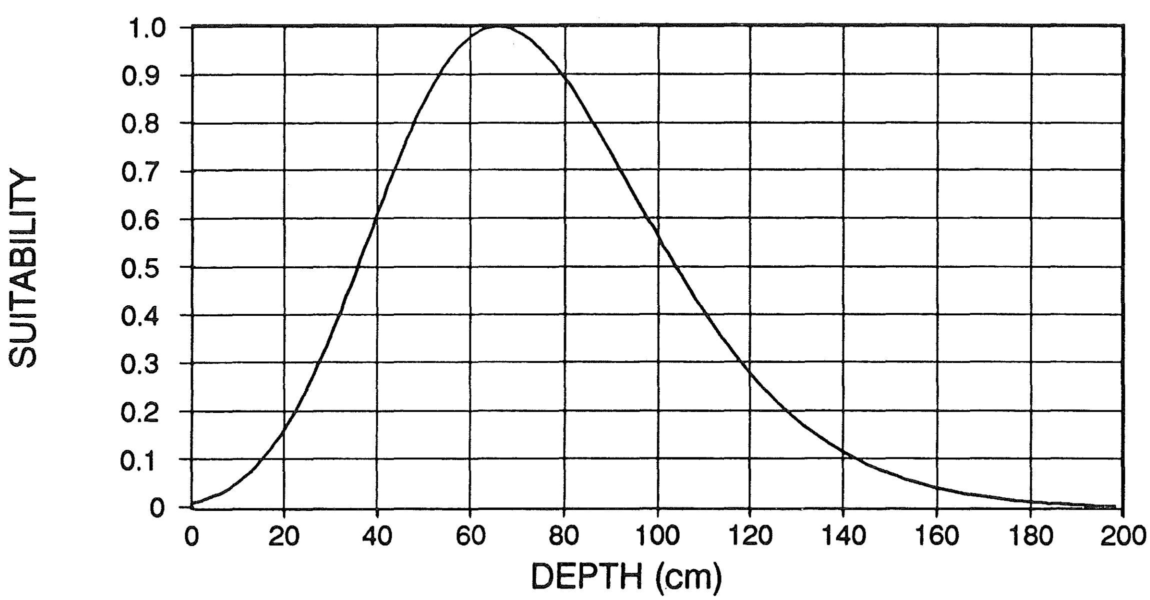

FIGURE 92. Depth preference of adult northern hog sucker (>150 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=345, number of samples=128).

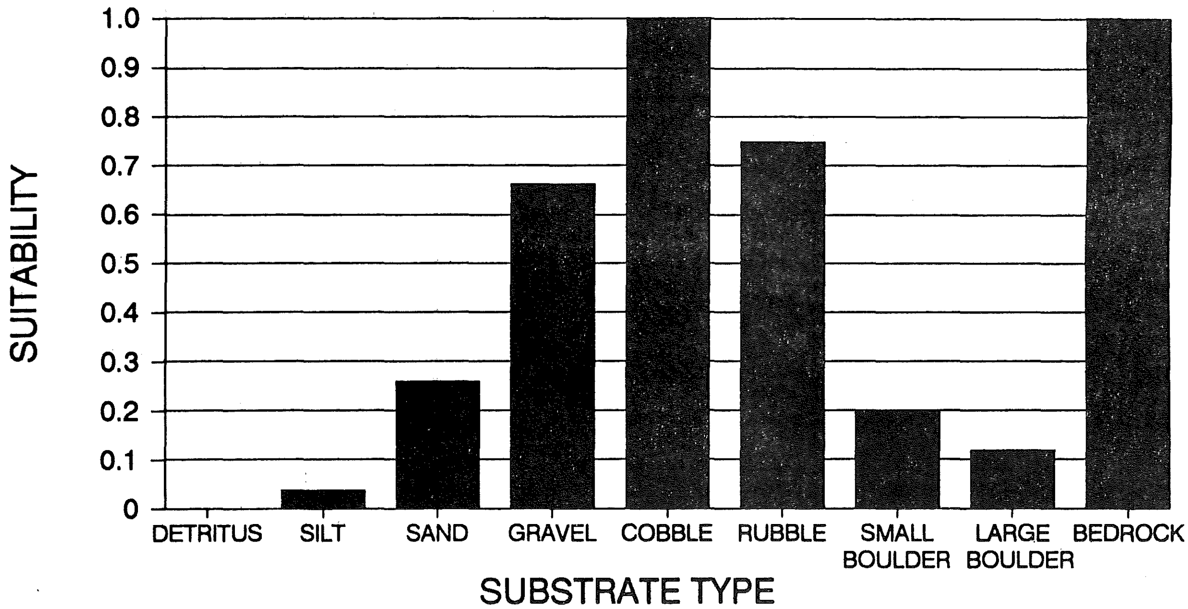

FIGURE 93. Dominant substrate preference of adult northern hog sucker (>150 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=345, number of samples=128).

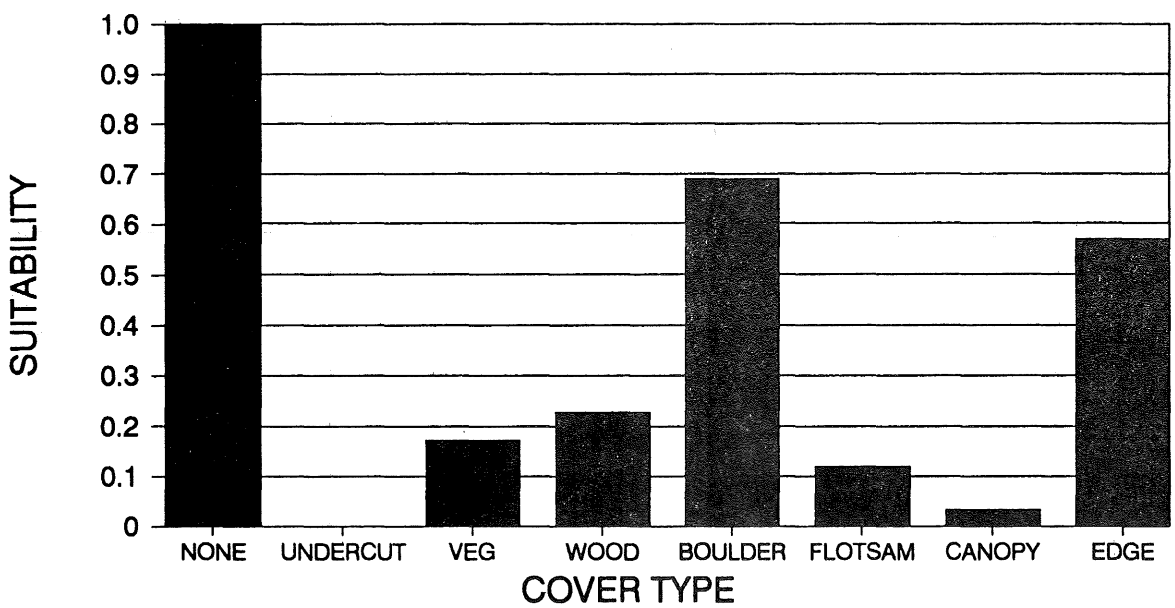

FIGURE 94. Cover preference of adult northern hog sucker (>150 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=345, number of samples=128).

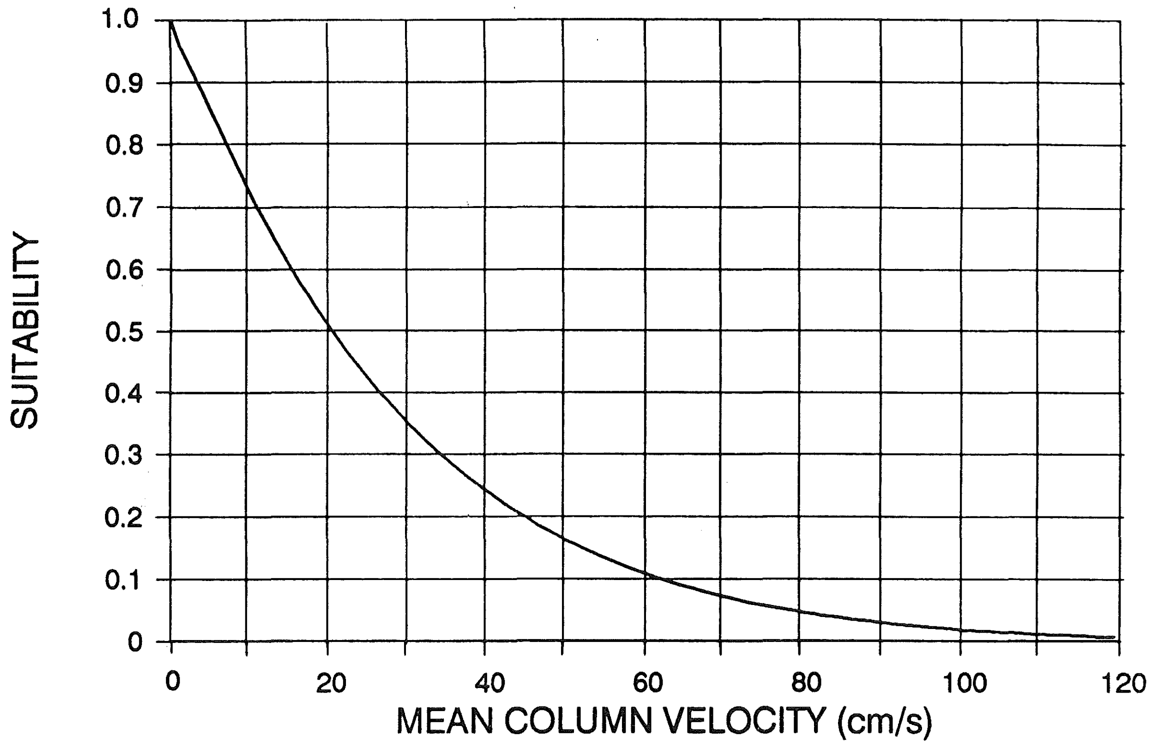

FIGURE 95. Velocity preference of young-of-the-year sand shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=796, number of samples=47).

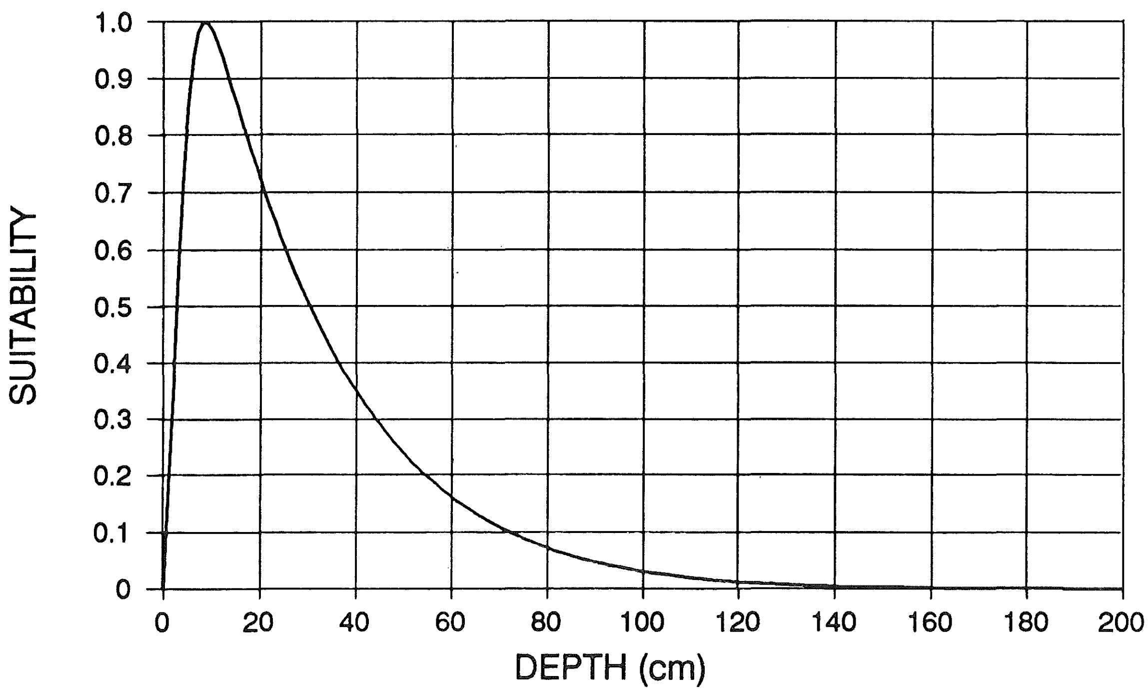

FIGURE 96. Depth preference of young-of-the-year sand shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=796, number of samples=47).

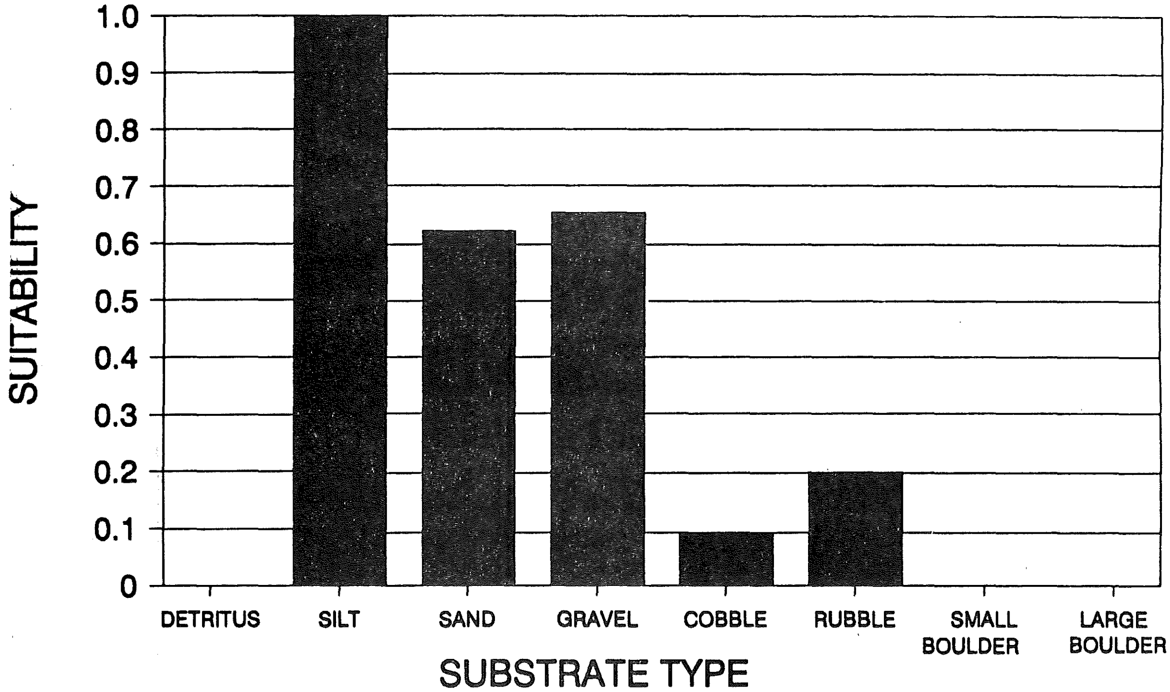

FIGURE 97. Dominant substrate preference of young-of-the-year sand shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=796, number of samples=47).

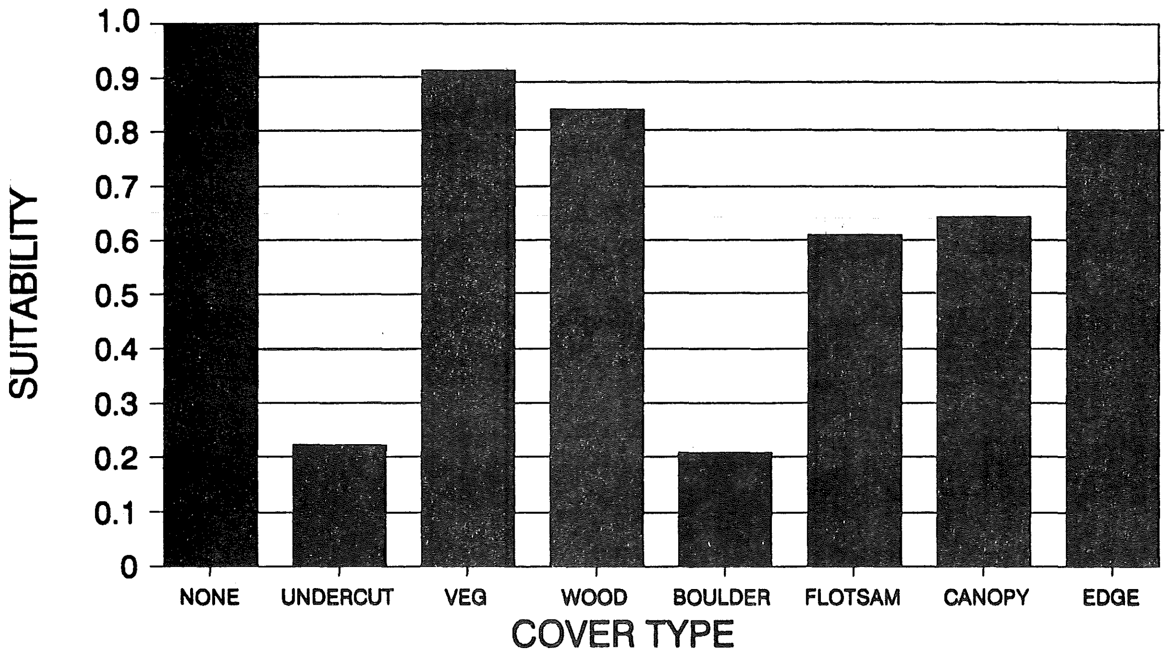

FIGURE 98. Cover preference of young-of-the-year sand shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=796, number of samples=47).

MICROHABITAT PREFERENCES OF SELECTED STREAM FISHES AND A COMMUNITY-ORIENTED APPROACH TO INSTREAM FLOW ASSESSMENTS

by

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ABSTRACT

Microhabitat use information was collected for 63 fish species, 155 species-life stages, and over 36,000 individuals in four Minnesota streams. Depth, velocity, substrate, and cover preference criteria were developed for 32 species-life stages. Each of the species-life stages were placed into one of six habitat preference guilds based on cluster analyses and subsequent determination of their density in six corresponding habitat types; shallow pool, medium pool, deep pool, raceway, slow riffle, and fast riffle. Common representatives of the shallow pool guild included young-of-the-year (y-o-y) sand shiner *Notropis stramineus*, y-o-y golden redhorse *Moxostoma erytrurum*, and smallmouth bass fry *Micropterus dolomieui*. The medium pool guild included; adult bluntnose minnow *Pimephales notatus*, adult silver redhorse *Moxostoma anisurum* and juvenile smallmouth bass. The deep pool guild was represented by adult smallmouth bass, juvenile bluegill *Lepomis macrochirus*, adult channel catfish *Ictalurus punctatus*, and juvenile black crappie *Pomoxis nigromaculatus*. Raceways were preferred by adult northern hog sucker *Hypentellium nigricans*, and by adult and juvenile shorthead redhorse *Moxostoma macrolepidotum*. The slow riffle guild was the most diverse and was represented by adult and juvenile central stoneroller *Campostoma anomalum*, adult river shiner *Notropis blennius*, y-o-y white sucker *Catastomus commersoni*, and y-o-y blackside darter *Percina maculata*. Fast riffles were preferred by adult longnose dace *Rhinichthys cataractae*, juvenile northern hog sucker *Hypentellium nigricans*, and most of the adult and spawning darters. We recommend a community-oriented approach in which representative species-life stages are chosen from each of these guilds for instream flow assessments. Riffles and raceways were the habitat types most sensitive to reductions in flow, and representatives of these guilds require special emphasis in stream flow management.

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INTRODUCTION

Unlike many states in the western and eastern United States, Minnesota has a strong legal framework for protecting instream flow values. 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, Water Appropriations Permit Program Coordinator, DNR Division of Waters, personal communication). The majority of these stream and river permits are issued for agricultural purposes, although the largest users by volume, include hydropower, thermal cooling facilities, and industrial processing.

The DNR Division of Fish and Wildlife is responsible for protecting the interests of anglers and others concerned about fish by maintaining healthy populations of game fish, of forage species which affect game fish, of species with intrinsic non-game value, and of species which need protection from extinction. While the DNR actively manages nearly 2,500 miles of cold water trout streams, little is known about the species and community interactions in the 10,000 miles of warm and cool water streams. Warm water streams are 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 fish species assemblages. Basic information on species habitat needs, stream flow requirements, distribution, and population dynamics is needed to protect the integrity of entire warm water stream communities.

STANDARD SETTING AND INCREMENTAL METHODS

The two general classes of methods used to set protected instream flows differ on whether habitat values are considered directly or indirectly. Standard setting methods based on hydrologic records and hydraulic channel characteristics consider habitat indirectly. Fundamental problems arise in using standard setting methods, as accurate stream flow gages are in place in only 19 of Minnesota's 39 watersheds, and most have collected data only during the last 30 or fewer years. When used for 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 fish habitat.

The second class of instream flow assessment techniques are incremental methods. These approaches require extensive data collection and allow for 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 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. 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. 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 III curves) have been determined and channel hydraulic characteristics have been measured, variables are input into the Physical Habitat Simulation System (PHABSIM). PHABSIM is a computer-run component of IFIM which calculates and simulates changes in the amount of "usable" fish habitat or Weighted Useable Area (WUA) across 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 determination of a stream-flow which maximizes WUA for a single species or group of species.

GOALS

Minnesota streams provide benefits through a variety of instream uses, but many streams, which once supported angling and other recreational uses have been degraded by poor water and land management practices. To balance competing water uses with protection of instream values, the DNR has been given authority to establish protected flow levels (a specific flow volume below which all appropriations are suspended, Minnesota Statute 105.41). Protected flows will be more effective if they recognize specific habitats and fish preferences in warm and cool water streams. Therefore, detailed habitat suitability and preference data must be obtained to examine effects of flow on fishes.

Our goals were to assess techniques for choosing target species and to develop suitability criteria for Minnesota stream fishes. First, detailed information on habitat use by stream fishes was obtained, so a greater understanding of the stream community could be developed. Second, habitat suitability criteria for all fish species collected were developed. Lastly, these habitat suitability criteria were compared to those in the literature to evaluate transferability of suitability curves because curves from other sources may be needed for use in Minnesota.

Game fish species are usually the targets of IFIM analyses, since they are the focus of public concerns. Smallmouth bass *Micropterus dolomieui*, channel catfish *Ictalurus punctatus*, and walleye *Stizostedion vitreum vitreum*, were initially chosen for this study since they are important game fish in Minnesota. The exclusive use of top predators is not adequate for IFIM analyses in warmwater streams (Orth and Maughan 1982; Lyons et al. 1988; Leonard and Orth 1989). A more inclusive community-oriented approach is 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; Power and Matthews 1983; Werner and Gilliam 1984), although their importance has been assumed to be negligible in most IFIM studies. A possible reason for this assumption is that most of the IFIM studies have been conducted on coldwater trout streams in which the fish biomass is dominated by a few species. Warmwater streams are usually species-rich and instream flow assessments should reflect that diversity (Lyons et al. 1988). By sampling all fishes in the study streams, comparisons of the habitat preferences of these fishes in different streams with different fish communities could be made.

STUDY SITES

Three study streams, the Zumbro, Snake, and Yellow Medicine rivers (Fig. 1), were chosen because each represented a different ecoregion within the state (Omerick and Gallant 1988) and contained populations of walleye, channel catfish, and smallmouth bass. Within each stream, two study sites, 400 m long (along the thalweg), 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 (Omerick and Gallant 1988). 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 also flows through a transitional area of east central 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 (Omerick and Gallant 1988). 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 (Omerick and Gallant 1988). The study sites were located approximately 4 and 5 km (2.5 and 3 miles) upstream from the confluence with the Minnesota River. Yellow Medicine River sites were narrower than Zumbro and Snake river sites, with a mean width of 22 m (72 ft). Ranges of velocities and depths were similarly narrower, 0-86 cm/s (0-2.8 ft/s), and 6-139 cm (0.2-4.6 ft), respectively (Table 1).

In addition, spawning walleye observations were made at two sites on the Mississippi River, 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 downstream lakes.

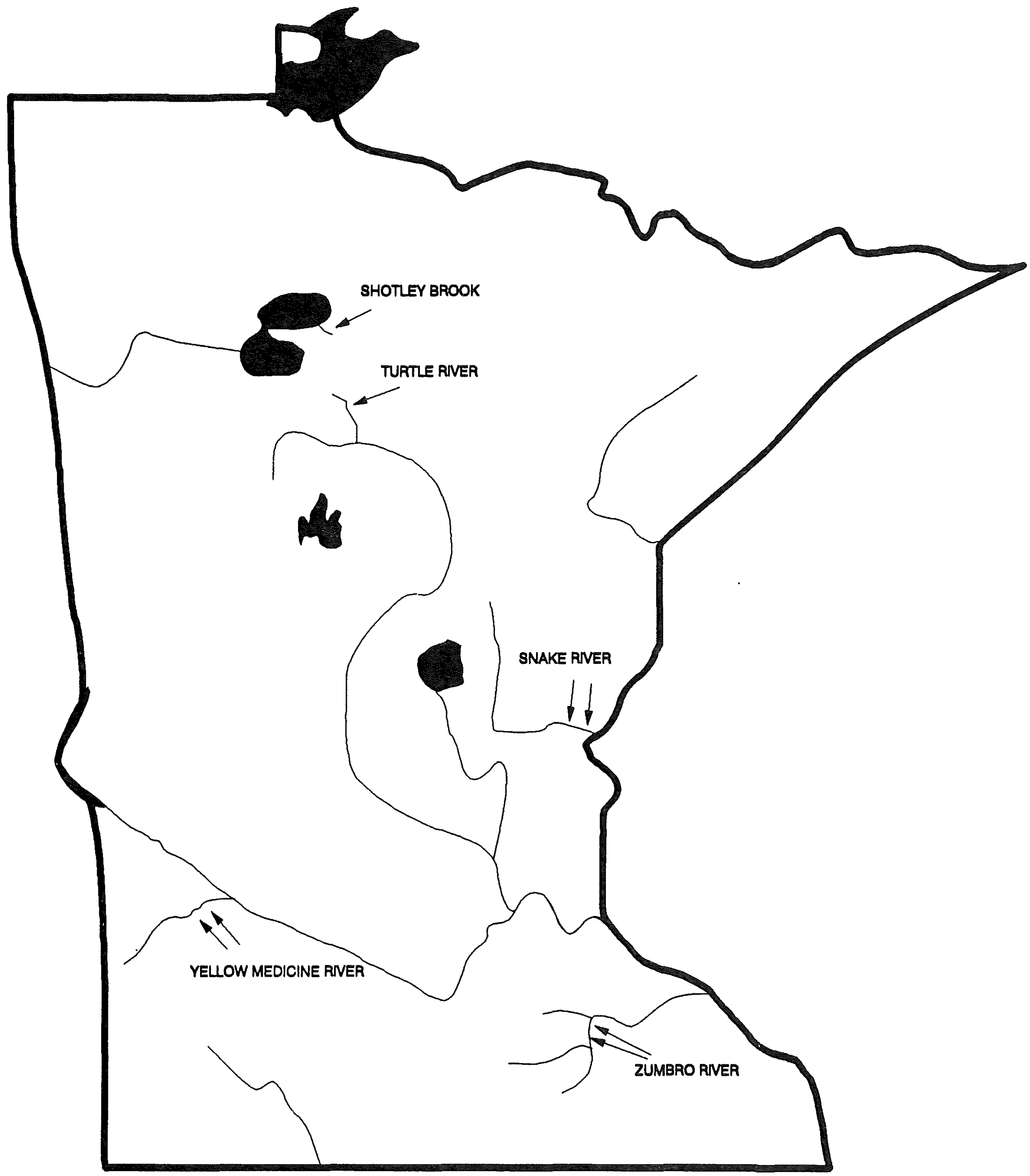


Figure 1. Map of Minnesota showing location of study streams and sites where habitat suitability data were collected. The study sites are indicated by arrows.

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

Characteristic	Zumbro	Yellow Medicine	Snake
USGS gage number	05374900	05313500	05338500
Period of record	1975-present	1931-present	1913-1986
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; available habitat by transect, habitat use by fish, and available habitat by stratified random location.

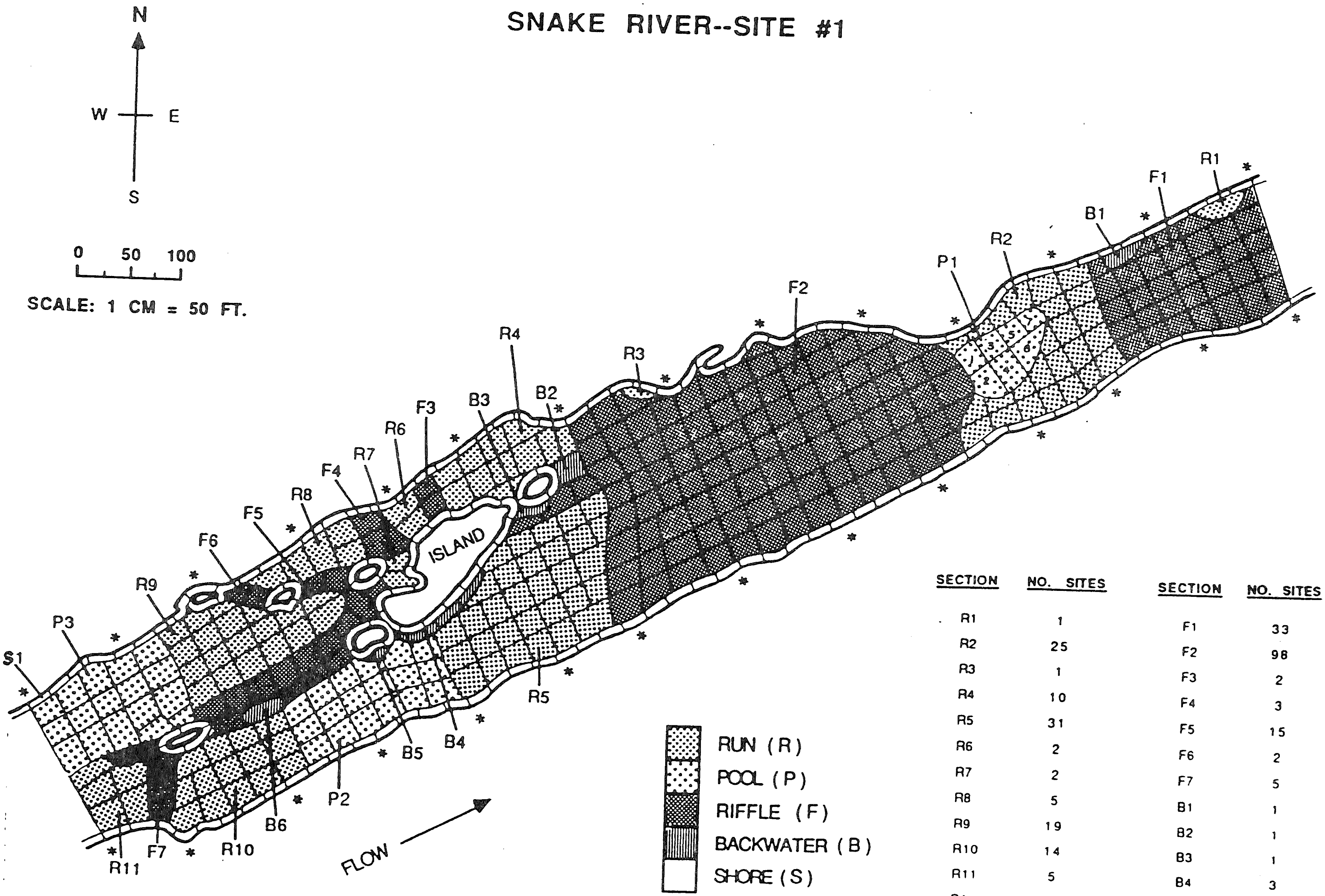
First, habitat availability data were collected by the transect method used by Bovee (1986). These microhabitat data were used to map and describe the sites and included measurements of depth and velocity, determination of substrate composition, and identification of cover types, if present. Fourteen transects were spaced 30 m (100 ft, or approximately one stream width) apart, perpendicular to the thalweg in each study site on each river. Along each transect, 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. Discharge was measured each time habitat availability data was collected.

Habitat was subjectively classified as pool, riffle, raceway, 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 x 7.6 m (25 x 25 ft) on the Zumbro River, and 3 x 7.6 m (9.8 x 25 ft) on the Snake and Yellow Medicine Rivers (Fig. 2). All gear types effectively sampled an area smaller than the cells (14 m^2, 150 ft^2). This allowed placement of the gear so that variation of depth and velocity was minimized within the sampled area. A random numbers table was used to determine the order by which the five 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 cell was sampled only once during a sampling period. Sampling periods at each study site 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 fish were measured. 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),

SNAKE RIVER--SITE #1



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 showing sampling locations and strata.

TABLE 2. Fish habitat use and availability 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

river stage, weather conditions, sample location, gear type, three water depth measurements, three mean column velocity measurements, percentage of each substrate type, percent embeddedness, cover types, presence or absence of shade, species of fish captured, individual fish lengths, 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) and at 0.2 and 0.8 of the depth in water deeper than 0.76 m (Leopold et al. 1964). 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 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 comprising the largest area of 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 (none of the following cover types excluding edge), undercut bank, vegetation, woody cover, boulder, flotsam, canopy, or edge (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 1987. The prepositioned area sampler was determined to be the most versatile and quantitative gear. Pools, and other areas too deep to effectively sample with the prepositioned sampler, 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 sampler were used in the 1988 field season.

<u>Prepositioned Area Sampler</u>

The prepositioned area sampler used in this study was a modification of one described by Bain et al. (1985). The first one used was modeled directly after Bain's prototype with insulation on sections of electrodes. When schools of shiners were observed passing through the unit unaffected, the electrodes were modified and made of bare 6 gauge copper wire. Modifications noticeably increased the effectiveness and durability of the device under the conditions encountered in this study (Fig. 3). Our modified units apparently had a more uniform electrical field; thus, fish were never observed to pass through the grid unaffected. Heavier uninsulated wire also made the unit less cumbersome to set. The prepositioned area sampler 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 (Fig. 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 3,000 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 sampler 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 sampler was 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.

<u>Purse Seine</u>

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 (Fig. 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.

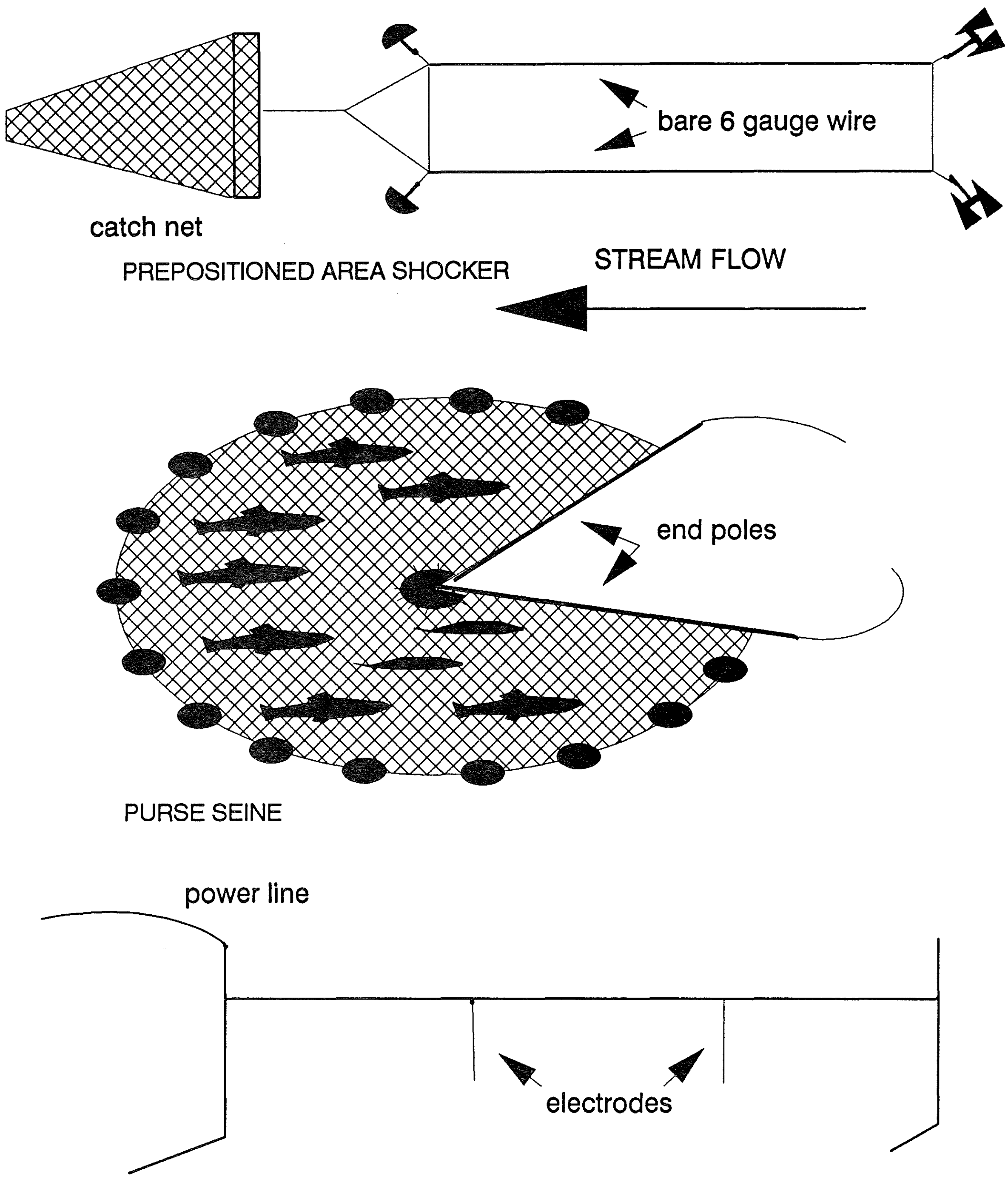


FIGURE 3. Devices used for sampling fish in the Zumbro, Snake, and Yellow Medicine rivers in Minnesota for development of habitat suitability criteria.

Electric Seine

A 3.6 m (12 ft) electric seine was also constructed and used for sampling in some situations in 1987 (Fig. 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. Mobile probes involved movement of researchers through the sampled area and may have resulted in field avoidance by fishes. They were not used in 1988; the prepositioned area shocker proved more effective for these areas since it shocked the entire sampled area simultaneously. 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; the purse seine allowed more effective enclosure of the sampled area.

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 most effective for collection of habitat-use information for single species. Water turbidity, and difficulty of fish identification and counts limited applications of snorkeling.

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.

Visual Observation

Spawning walleye 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. Spawning walleye were also observed in the Turtle River and Shotley Brook in north central Minnesota (Fig. 1) April 26-29, 1989. 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, mean column velocity, substrate, and cover were recorded later at these locations. Nose velocity was also measured in the Turtle River and Shotley Brook.

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 nests and recorded microhabitat data at each. Many of the spawning areas were located by Fisheries personnel from Lake City during boat electrofishing and tagging operations. Since these boat electrofishing operations effectively sampled the majority of the river we drifted through, it is likely that most of the important spawning areas were identified.

Stomach Content Analysis

To determine the importance of different prey types in the diet of smallmouth bass and channel catfish, stomach contents were examined. Stomach samples were collected for fry and fingerling smallmouth bass 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 (Van denavyle and Roussel 1980). Stomachs were then flushed out with water.

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 consistently concentrated in localized areas. Assumptions associated with this decision are covered in the discussion section. 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, a depth interval 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, the number of samples which contained the species life stage of interest, and the number of individuals of the species life stage were calculated.

3) The proportion of samples that were taken in each available habitat interval was calculated as the number of samples taken within the interval divided by the total number of samples.

4a) When calculating an unweighted preference with presence/absence data, habitat use was calculated as the number of samples containing the species life stage within the interval divided by the total number of samples containing the species-life stage.

4b) When calculating a weighted preference with data on each individual fish, habitat use was calculated as the number of individuals collected within the habitat interval divided by the total number of individuals.

5) A preference index was calculated as habitat use within the interval divided by habitat available within the interval.

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 and velocity. Several techniques were assessed to construct the habitat preference curves from preference values, including histogram analysis, and nonlinear regression. 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 or averaging with adjacent cells.

Nonlinear Regression

Nonlinear regressions were calculated to fit curves to preference values. Several nonlinear regression software packages are available; the NONLIN module of SYSTAT (Wilkinson 1988) was used in this study. Nonlinear regression requires input of appropriate equation to describe the preference function and derives "best fit" coefficients. 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 typical of habitat preference data. Consequently, all velocity preference curves were fit 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 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. If it is reasonable to assume that all depths greater than or equal to a critical value have a preference of one, the logistic function may be most appropriate. This 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 normalize the maximum preference value to one, so all values must be divided by the maximal preference estimate to yield a preference curve.

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. 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 explored.

Once satisfactory coefficients were attained, the equation was transferred to a spreadsheet and the estimates for any value of the habitat variable were calculated.

CURVE VERIFICATION

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

To simplify selection of species life stages for the IFIM analysis, habitat-preference guilds were identified. Aadland et al. (1989) recommended six guilds based on cluster analyses of habitat parameter means for sampled species-life stages. Cluster analyses have several limitations for guild assignments: 1) they are not adjusted for availability and therefore have sampling bias; 2) they are based on variable means and the assumption that mean habitat use and preference are synonymous (which is not correct when the distribution is skewed); and 3) cluster analyses are dependent on the nature of the cases being clustered and this prevents any meaningful comparisons between streams. To create preference guilds which would allow comparisons between streams and would have greater consistency in guild membership, six habitat types were defined which had depth and velocity ranges similar to the guilds identified by cluster analysis. Each species-life stage was then reassigned to the guild corresponding to the habitat type in which it had the highest density. This approach reduced biases due to habitat availability and sampling, and yielded more useful guilds than cluster analyses.

POOLING OF MICROHABITAT DATA ACROSS RIVERS

Microhabitat data from fish species from the three streams were pooled for some species-life stages. Pooling was done by summing the weighted (by number of observations) preference values for each flow of each stream and dividing by the total number of observations. Preference values for deep and fast water were pooled only from stream-discharges at which that depth or velocity was available. If it was apparent that the preferred depth or velocity was not available in a stream at a given flow, preference data from that stream was not pooled. For example, because of very low flows in the Yellow Medicine River in August 1988, the maximum available velocity was only 43 cm/s. Banded darter adults *Etheostoma zonale* preferred velocities around 90 cm/s in the Zumbro river where these velocities were available. Consequently, low flow Yellow Medicine river data for banded darters were not used in development of preference curves for this life stage.

RESULTS

Habitat suitability data for over 36,000 fish (63 species and 155 species life stages) were collected in this study (Appendix I). Fish densities by habitat varied among the three study streams (Fig. 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), when 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, had low preference values for the deepest areas in the study sites. However, deep pool habitats were relatively rare, and this limited observations of species life stages which preferred deep pool habitats.

WALLEYE

Walleye populations were relatively small in the three primary study streams, as in similar medium-sized rivers throughout Minnesota. Observations of young-of-the-year, juvenile, and adult walleye were not of sufficient numbers to enable computation of reliable habitat preference curves (19 young-of-the-year, 19 juveniles, and 1 adult). However, 266 spawning walleye 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 (Figs. 5-7). Spawning behavior, such as close escort of a female by one or more males and side by side vibrations, were observed 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 walleye 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 walleye in the Mississippi River. In the Turtle River, day versus nighttime habitat use was significantly different for mean column velocity, nose velocity, and depth ($\underline{P} < .01$). Shotley Brook walleye used similar depths and mean column velocities but different nose velocities ($\underline{P} < .01$). Walleye in the Turtle River and Shotley Brook did not exhibit spawning behavior during the day and showed greater use of cover during the day.

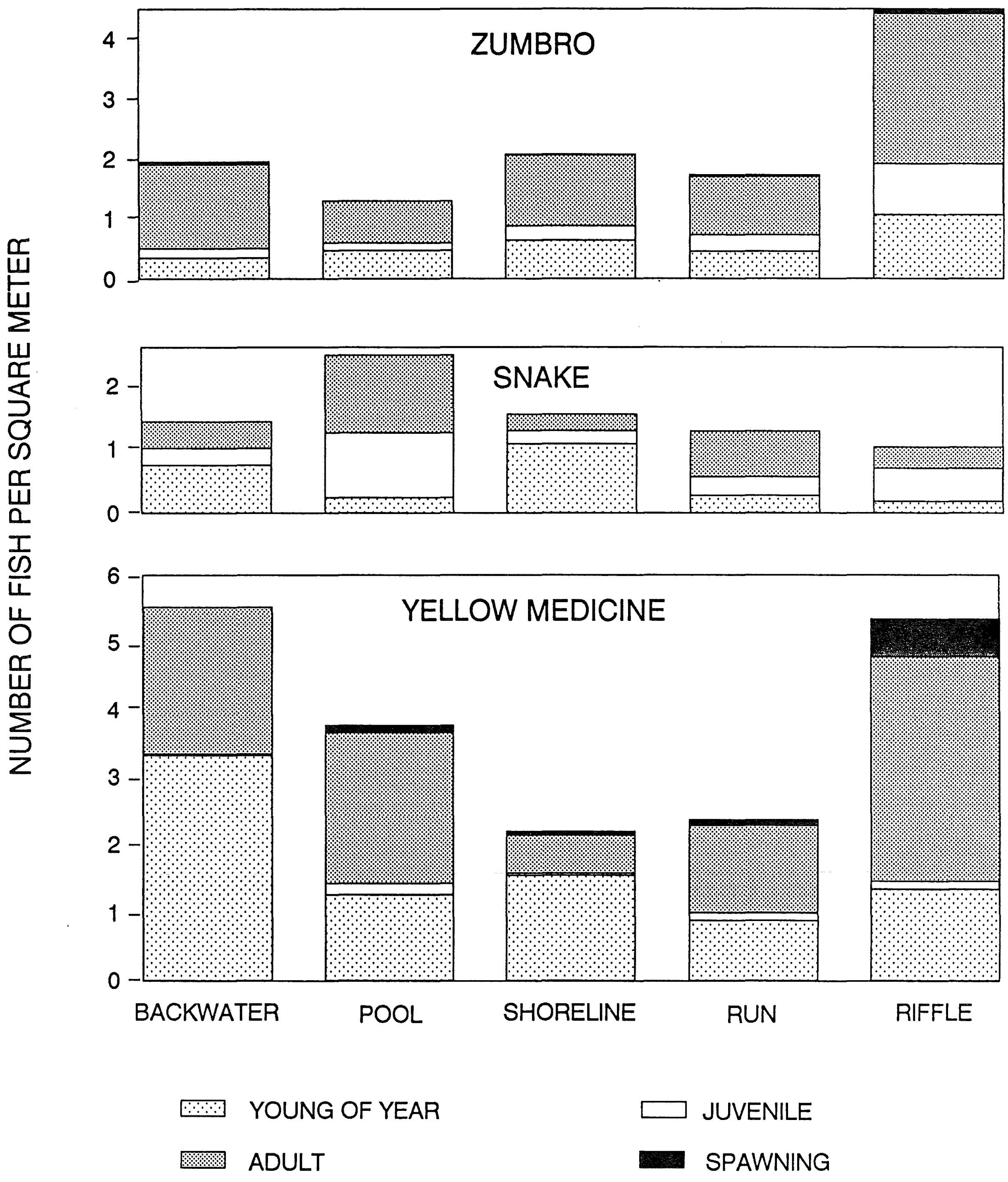


FIGURE 4. Total fish density in subjectively defined strata in the Zumbro, Snake, and Yellow Medicine rivers.

When conducting Physical Habitat Simulation System (PHABSIM) procedures for simulations of walleye spawning habitat, we recommend the use of dominant substrate only 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 and staging activity. Physical habitat simulations could be partitioned to reflect these diurnal differences. This is not practical, however, since variable flows (a potential model-based recommendation of a diurnally partitioned model) seldom favor successful incubation.

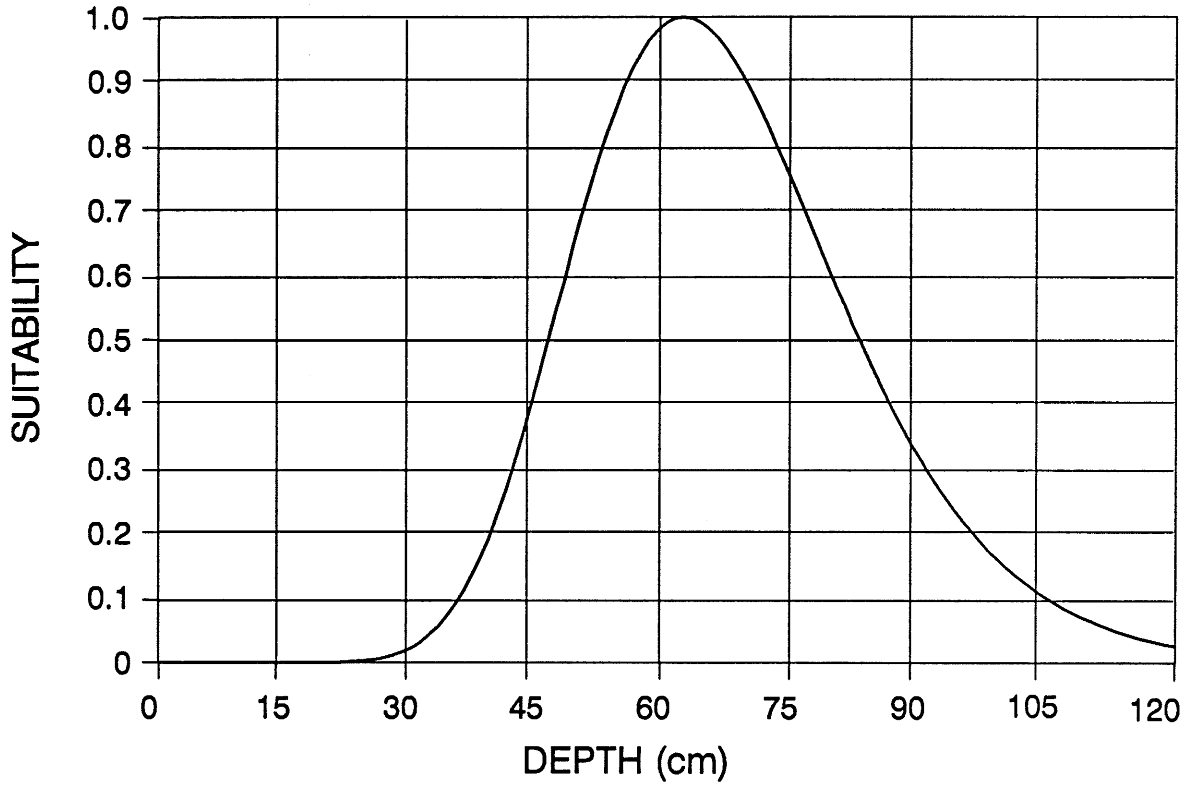


FIGURE 5. Depth use by spawning walleye in the upper Mississippi River (N=266).

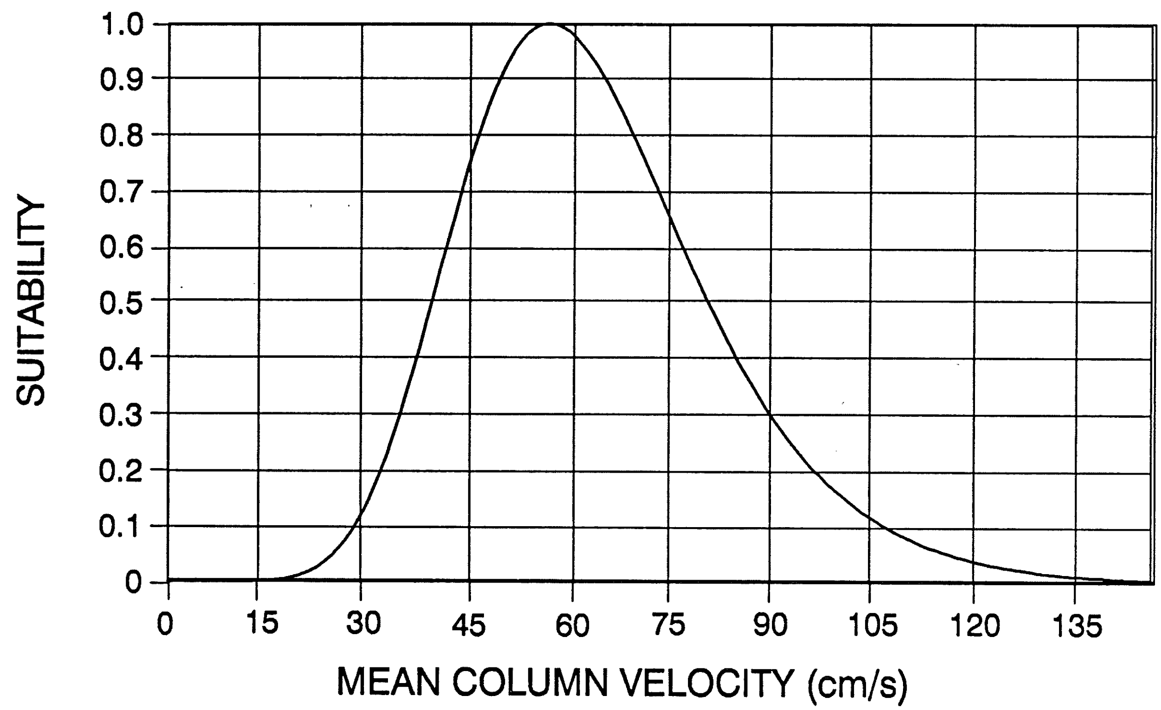


FIGURE 6. Velocity use by spawning walleye in the upper Mississippi River (N=266).

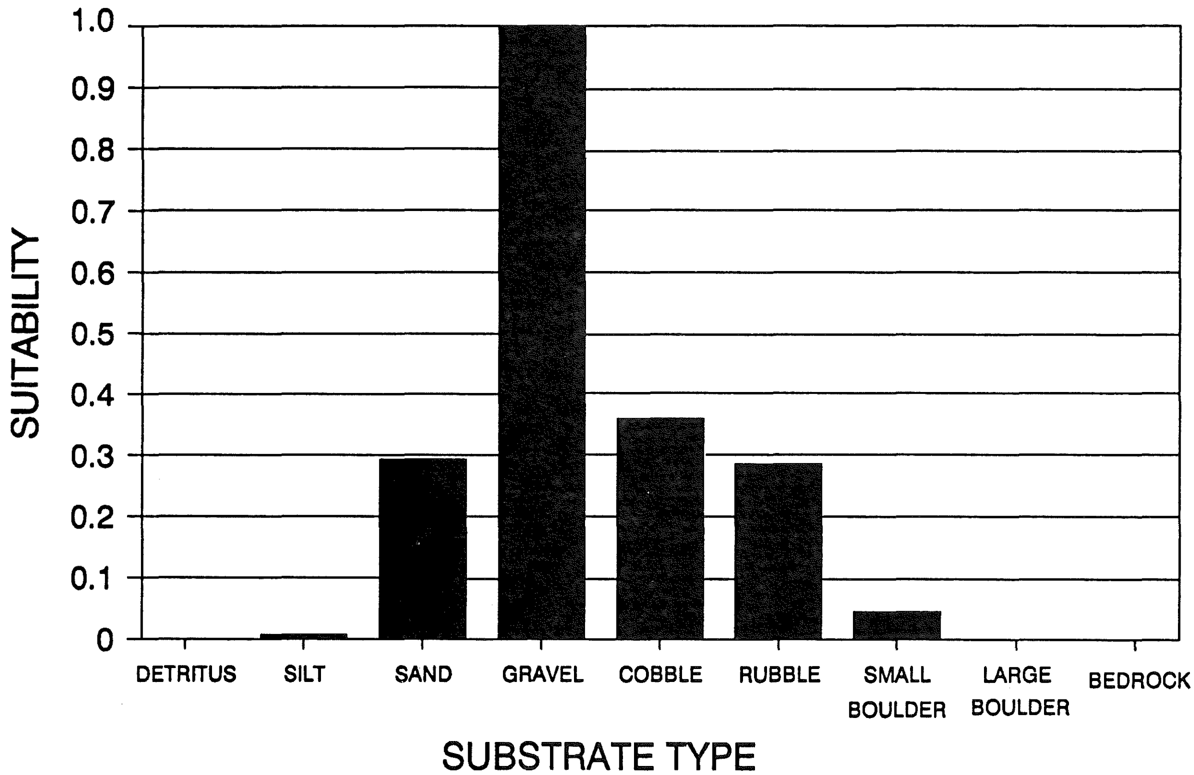


FIGURE 7. Dominant substrate use by spawning walleye in the upper Mississippi River (N=266).

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) (Figs. 8-23). Smallmouth bass fry were not collected from the Yellow Medicine River, so habitat preference curves and histograms (Figs. 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 (Figs. 12-23).

Young-of-the-year smallmouth bass were subdivided into fry and fingerling life stages due to apparent changes in habitat preference at approximately 60 mm (Fig. 24). Nearly 99% of the smallmouth bass fry (<60 mm total length) collected were taken in water flowing at less than 14 cm/s (0.5 ft/s). In contrast, fingerlings (60-99 mm) were collected in water with velocities ranging from 0-90 cm/s (0-3 ft/s). Changes in habitat preference may have been associated with changes in food habits (Fig. 25), tabulated from gut content analysis of 436 smallmouth bass.

Aquatic invertebrates found in stomach samples were classified as either pool or riffle taxa based on descriptions reported by Merritt and Cummins (1984) and Schlosser (1987). 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.

Gut content analysis indicated that 67% (44-86%) of the fishes found in smallmouth bass stomachs were most abundant in riffles (Fig. 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/ft^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/ft^2) in the study sites, paralleling the low piscivory of sampled smallmouth bass (4%). Densities of invertebrates, although not quantified in this study, appeared to be highest in the Snake and lowest in the Yellow Medicine.

Habitat-use curves and histograms were developed for Zumbro River spawning smallmouth bass (Figs. 27-30).

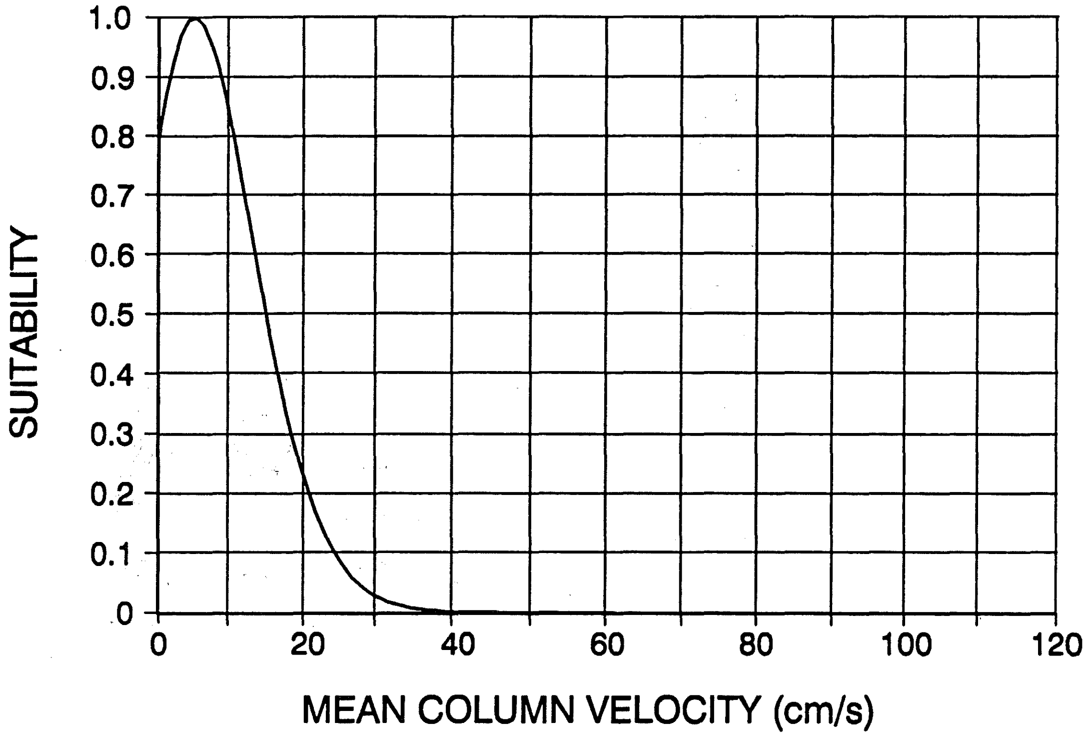


FIGURE 8. Velocity preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers (weighted data; number of individuals=82, number of samples=24).

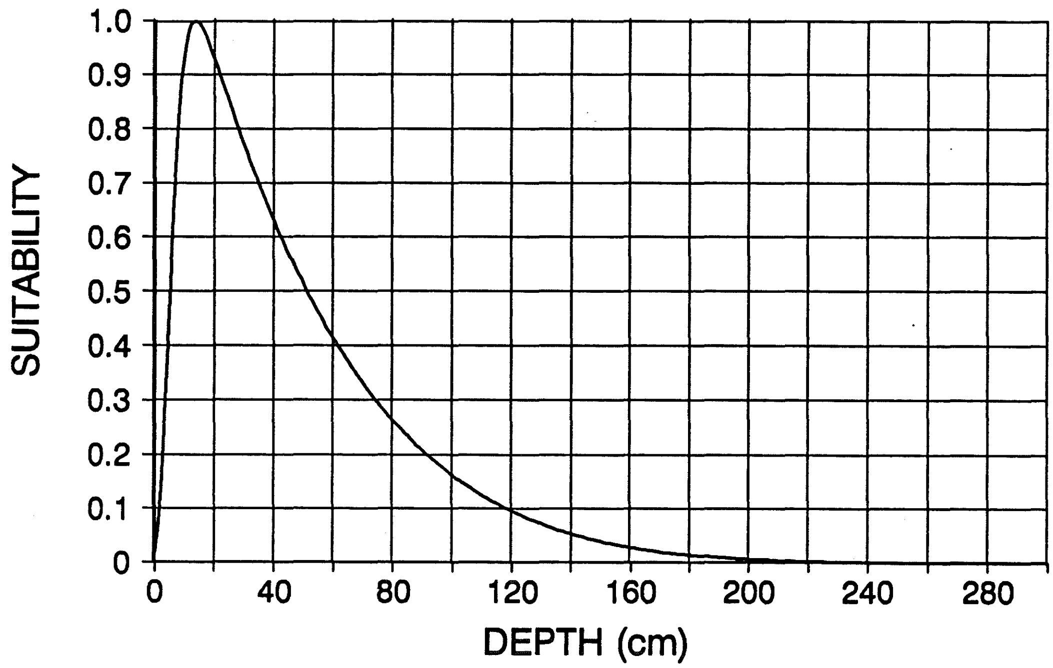


FIGURE 9. Depth preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers (weighted data; number of individuals=82, number of samples=24).

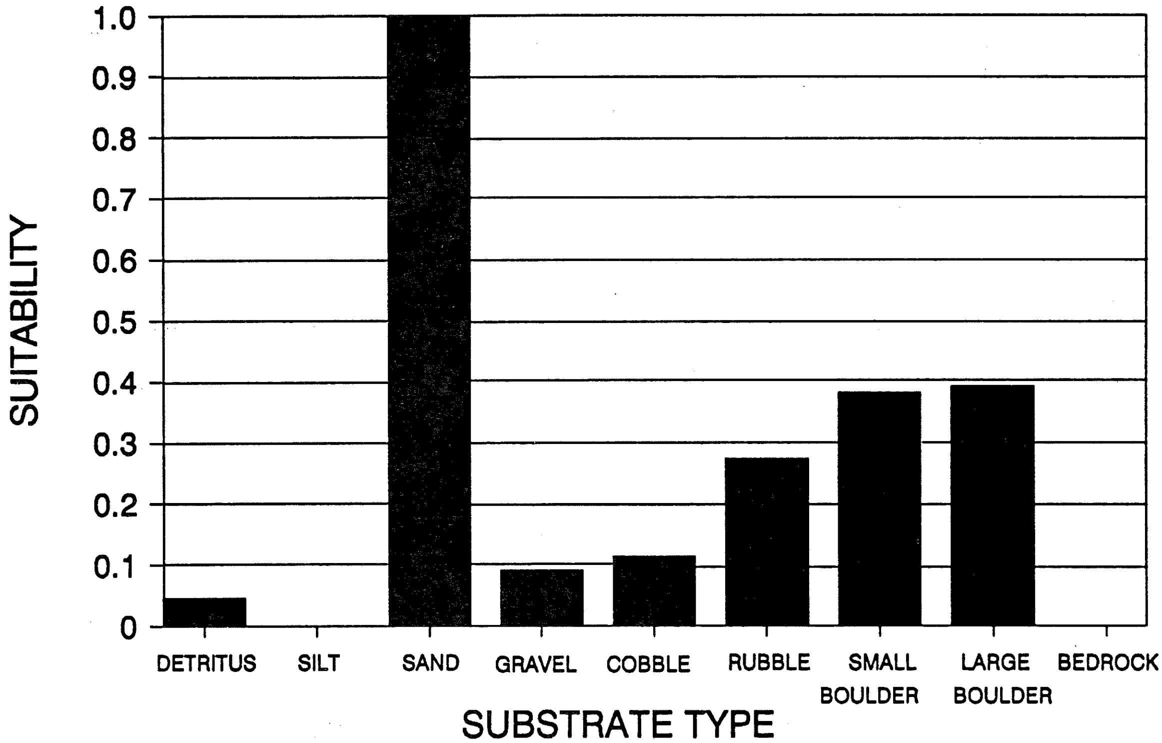


FIGURE 10. Dominant substrate preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers (weighted data; number of individuals=82, number of samples=24).

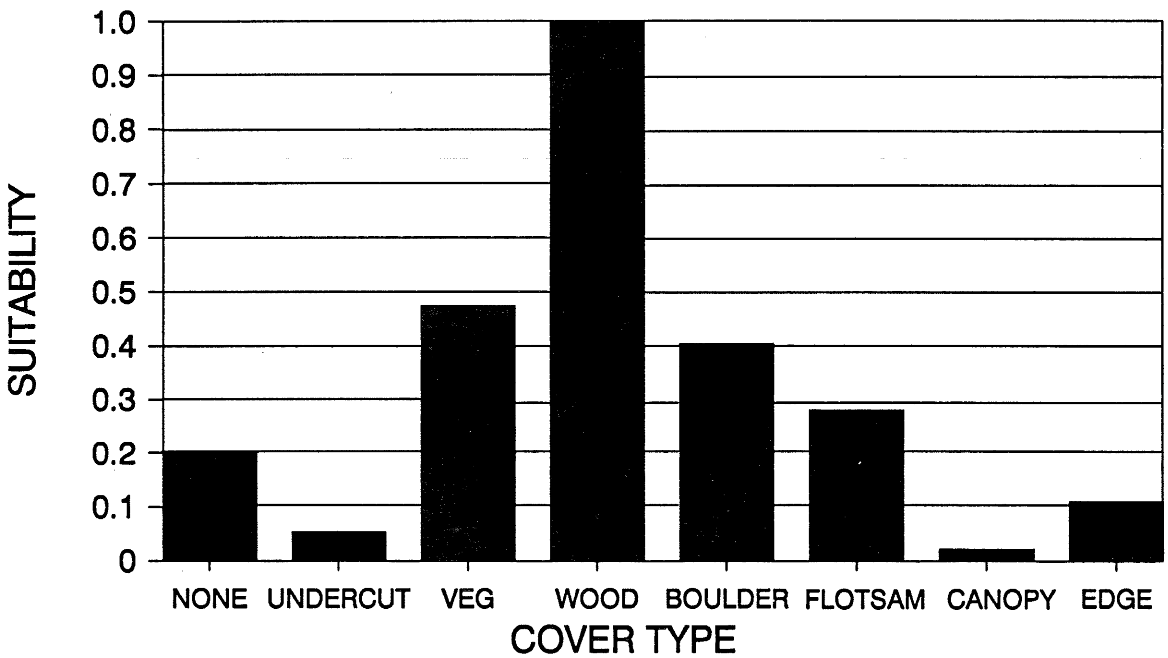


FIGURE 11. Cover preference of smallmouth bass fry (<60 mm) in the Zumbro and Snake rivers (weighted data; number of individuals=82, number of samples=24).

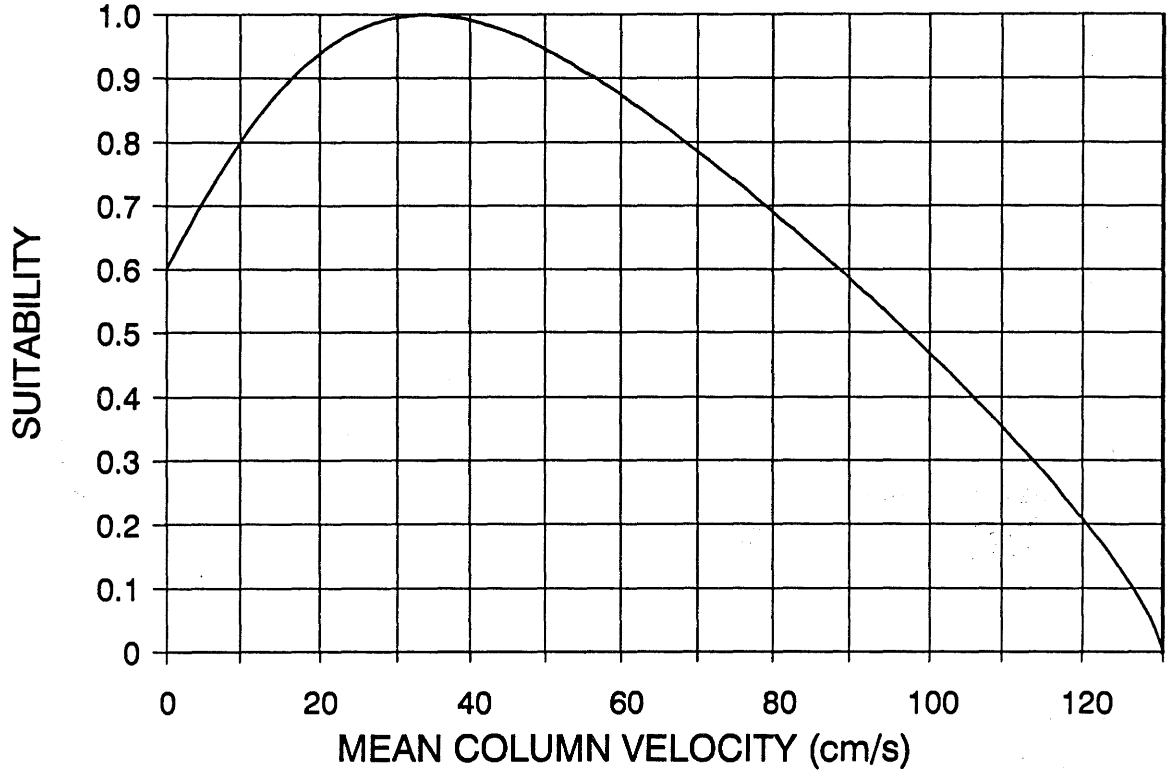


FIGURE 12. Velocity preference of smallmouth bass fingerlings (60-99 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=104, number of samples=60).

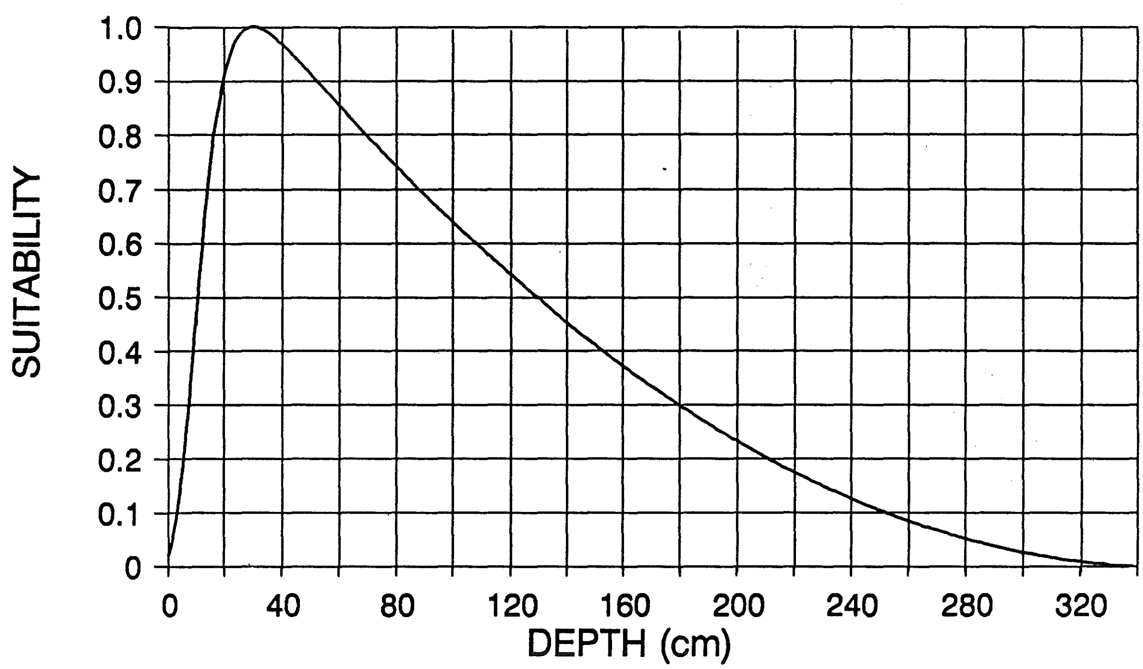


FIGURE 13. Depth preference of smallmouth bass fingerlings (60-99 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=104, number of samples=60).

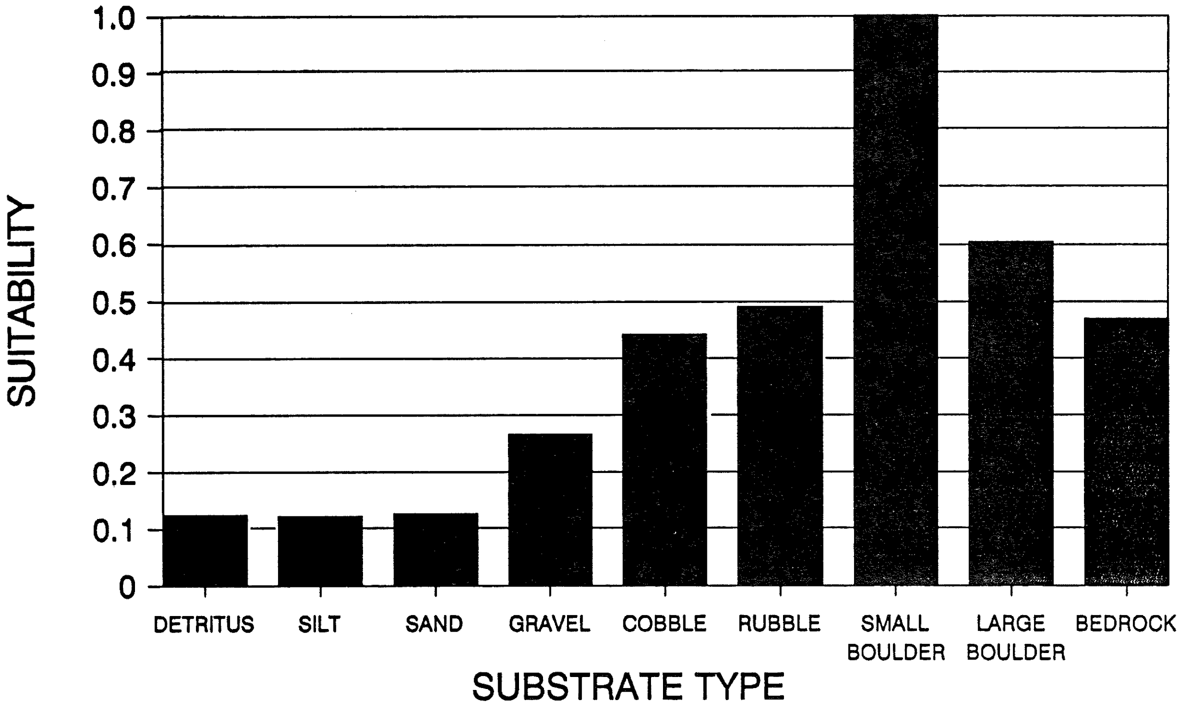


FIGURE 14. Dominant substrate preference of smallmouth bass fingerlings (60-99 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=104, number of samples=60).

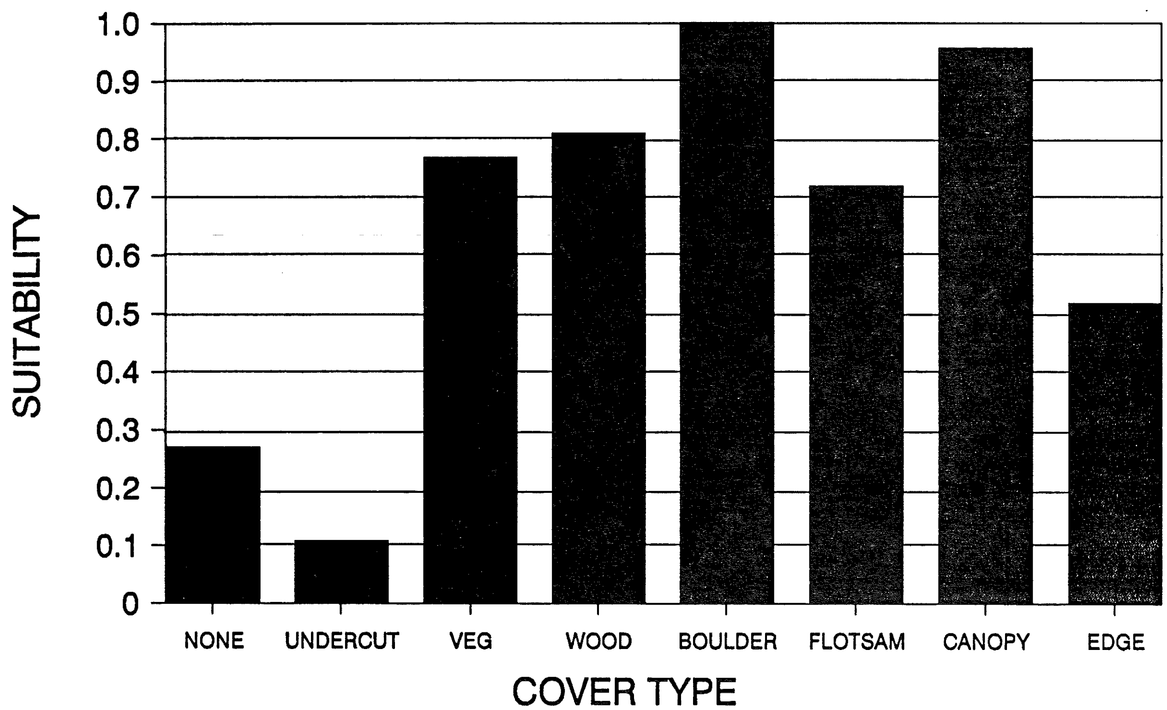


FIGURE 15. Cover preference of smallmouth bass fingerlings (60-99 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=104, number of sambles=60).

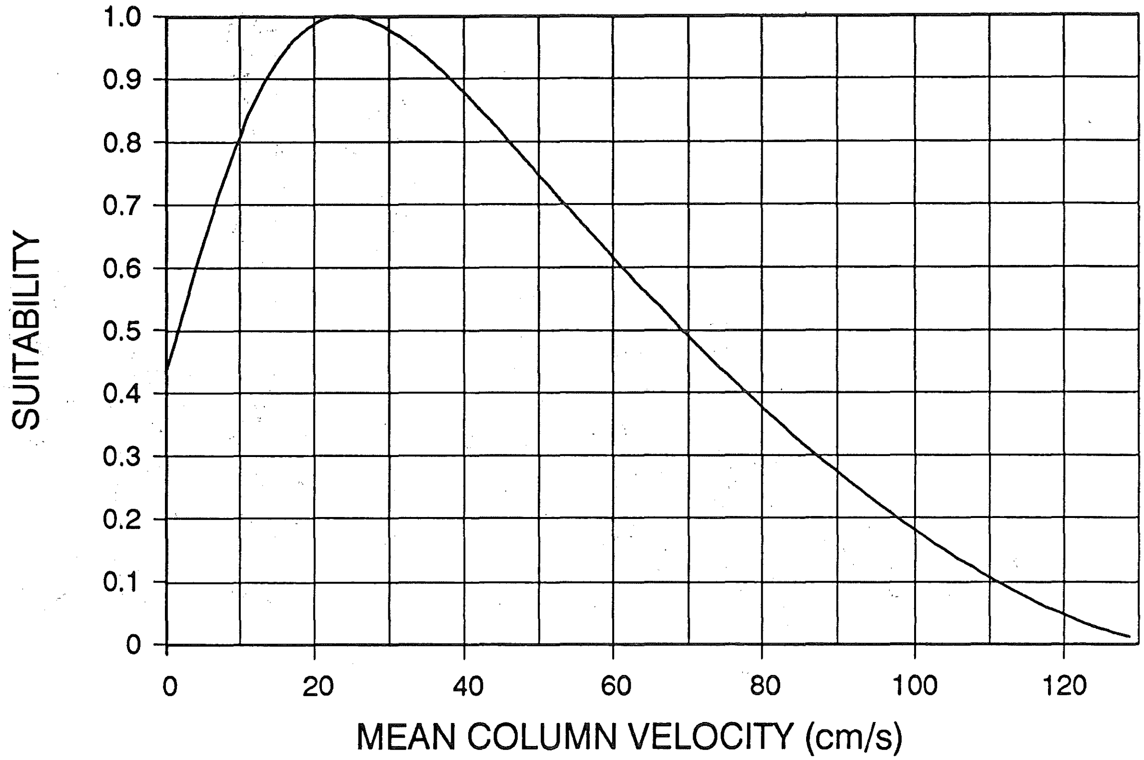


FIGURE 16. Velocity preference of juvenile smallmouth bass (100-189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=335, number of samples=144).

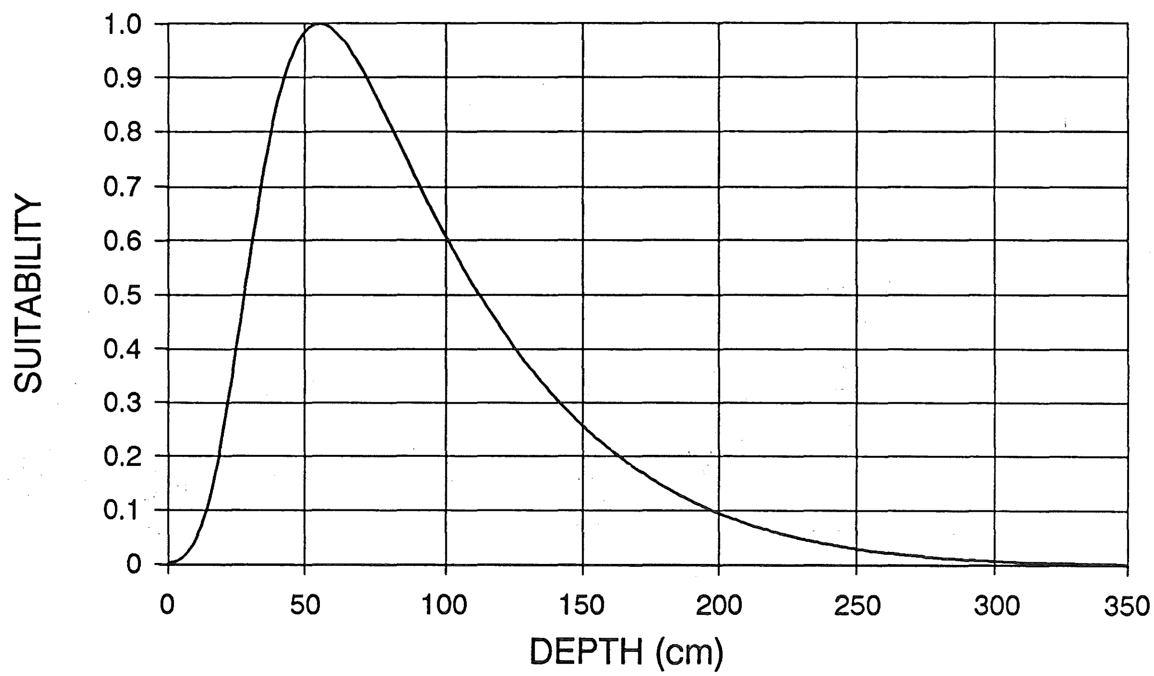


FIGURE 17. Depth preference of juvenile smallmouth bass (100-189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=335, number of samples=144).

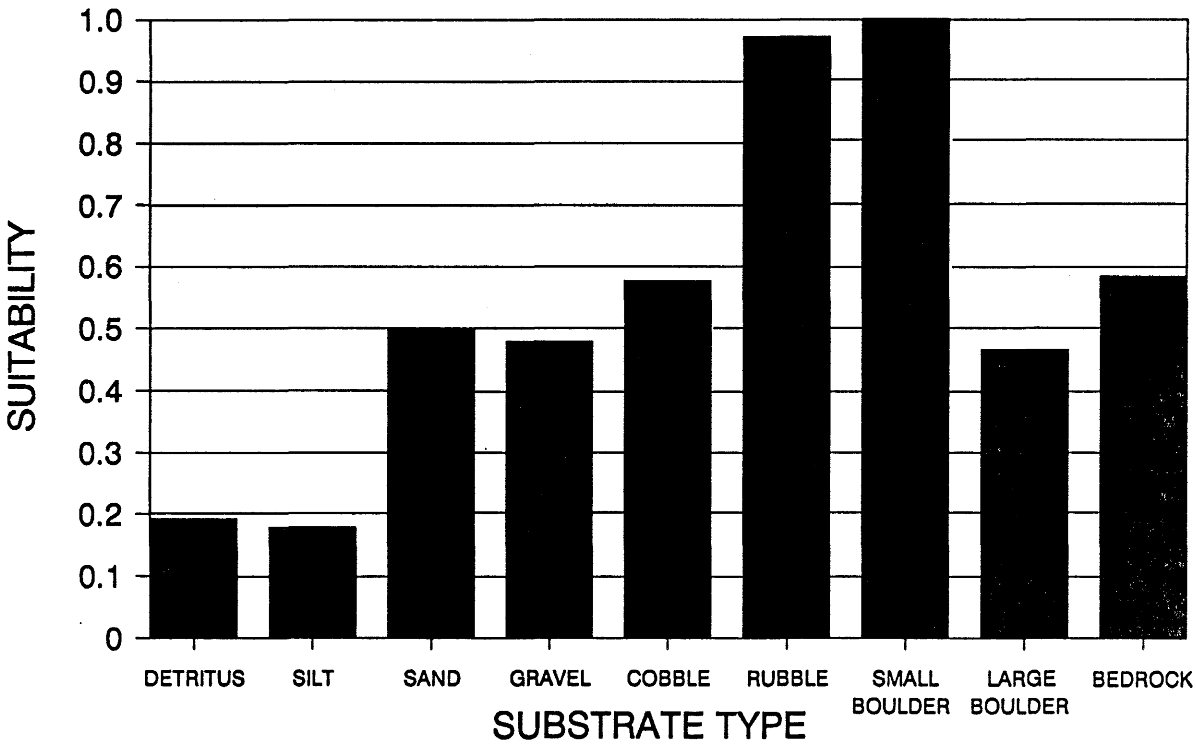


FIGURE 18. Dominant substrate preference of juvenile smallmouth bass (100-189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals= 335, number of samples=144).

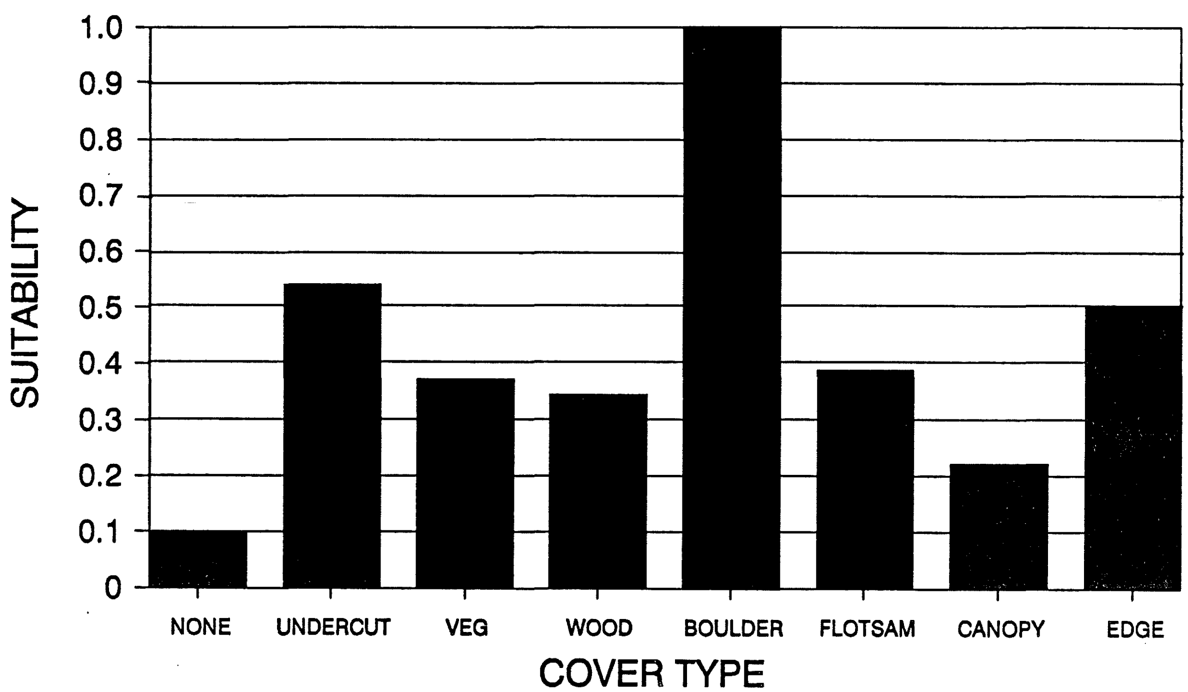


FIGURE 19. Cover preference of juvenile smallmouth bass (100-189 mm in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=335, number of samples=144).

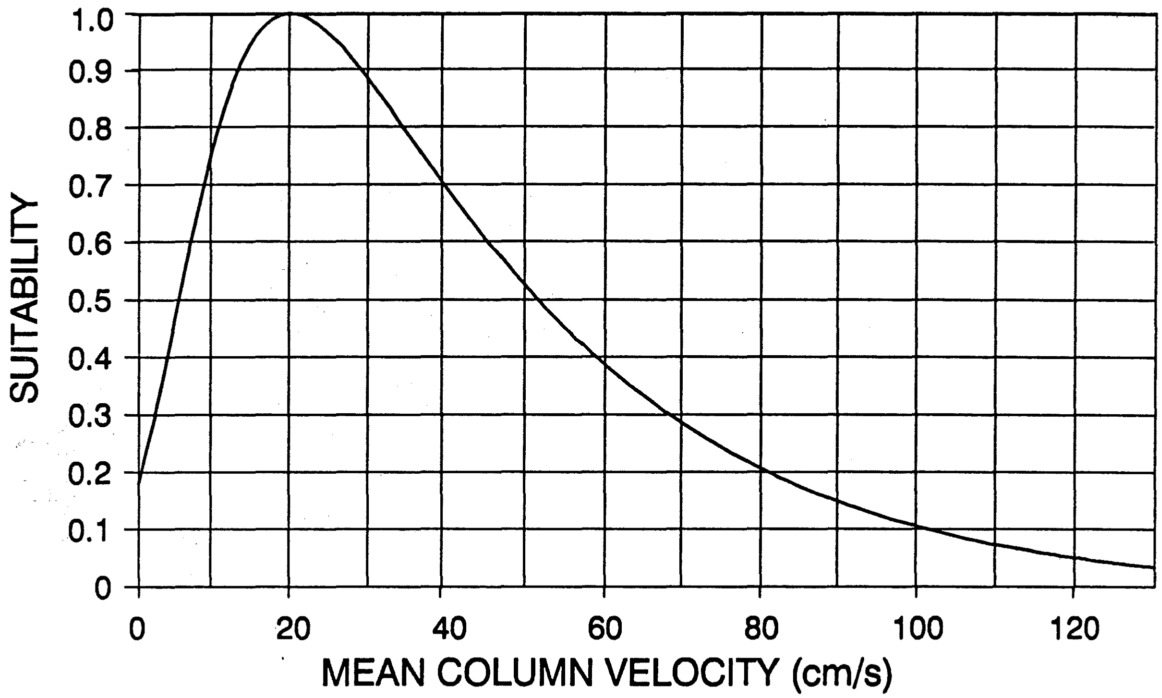


FIGURE 20. Velocity preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=109, number of samples=63).

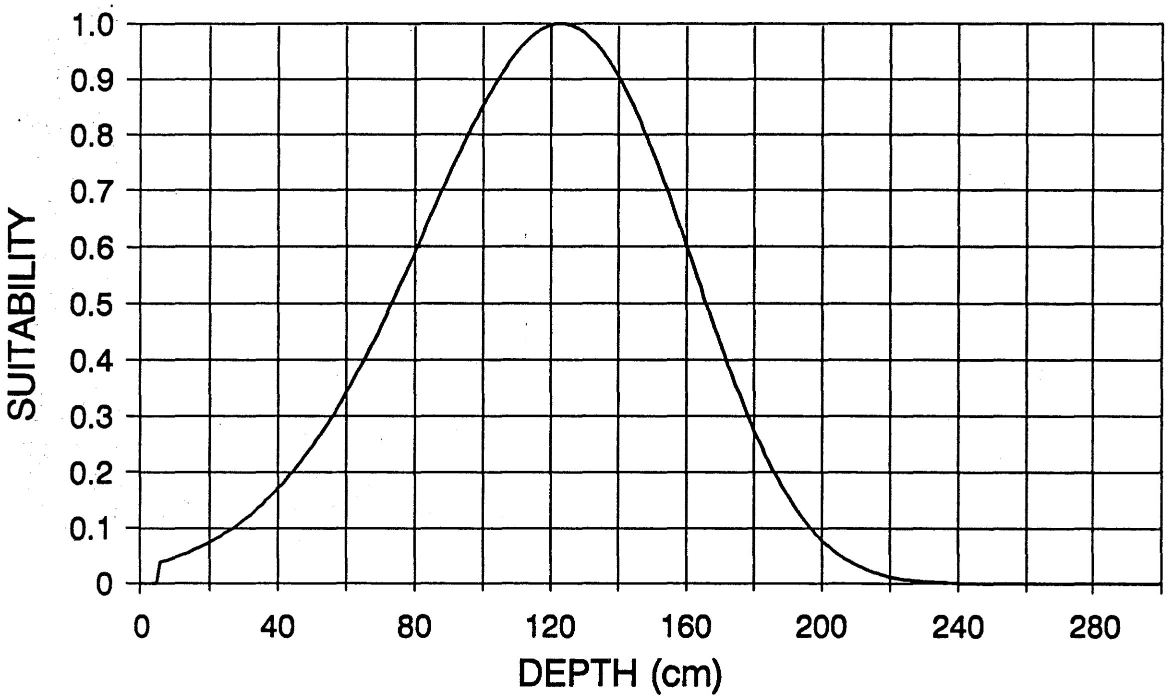


FIGURE 21. Depth preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=109, number of samples=63).

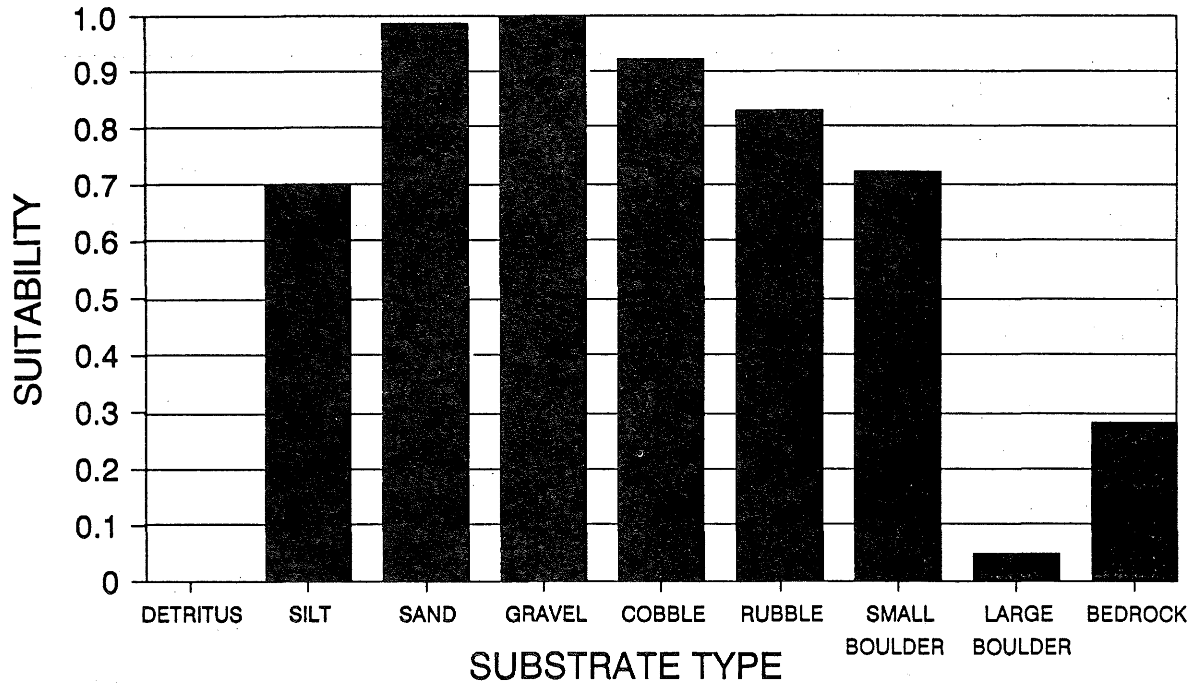


FIGURE 22. Dominant substrate preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=189, number of samples=63).

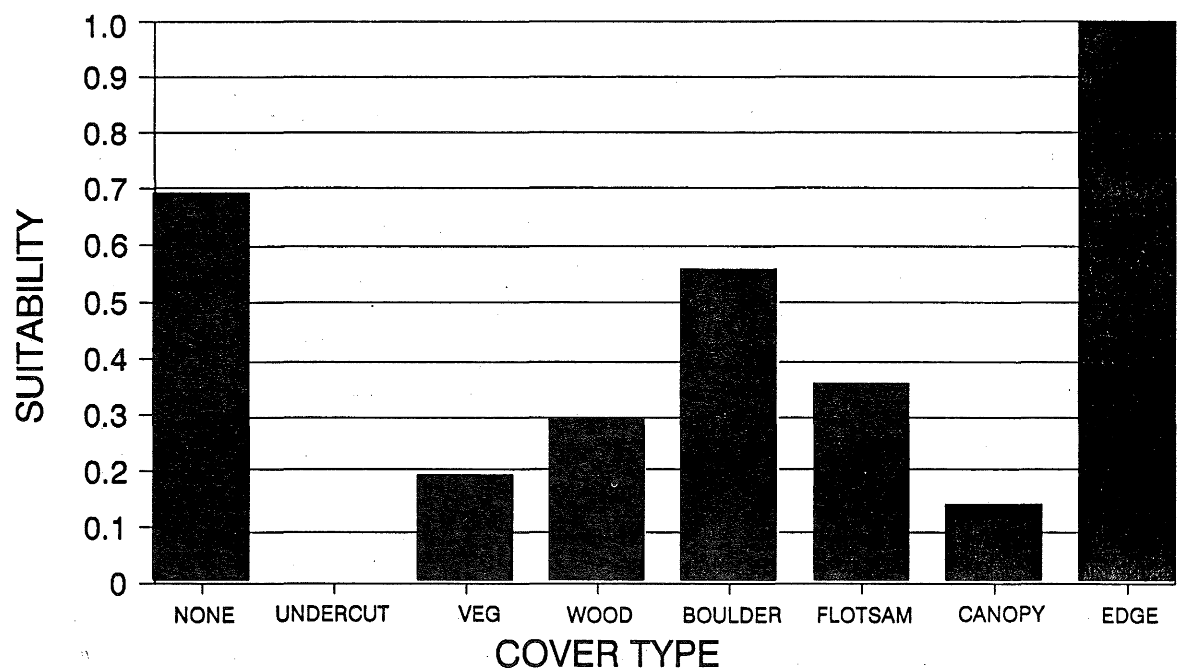


FIGURE 23. Cover preference of adult smallmouth bass (>189 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=109, number of samples=63).

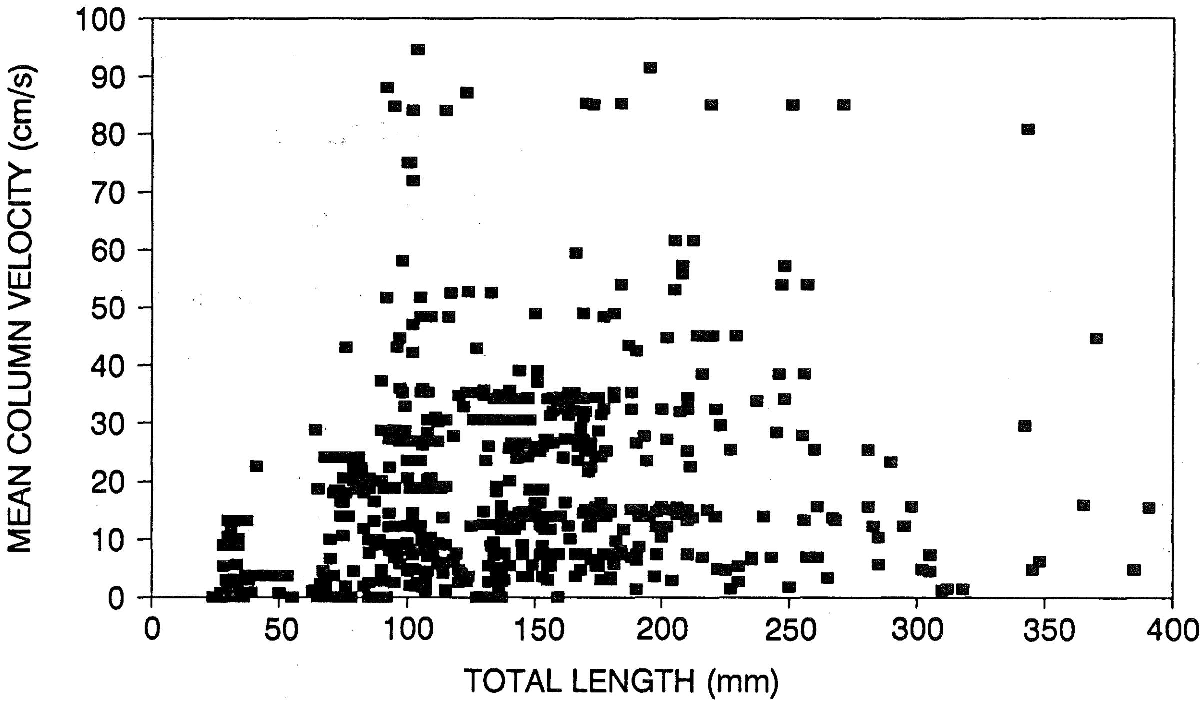


FIGURE 24. Velocity used by Zumbro, Snake, and Yellow Medicine smallmouth bass as a function of total length.

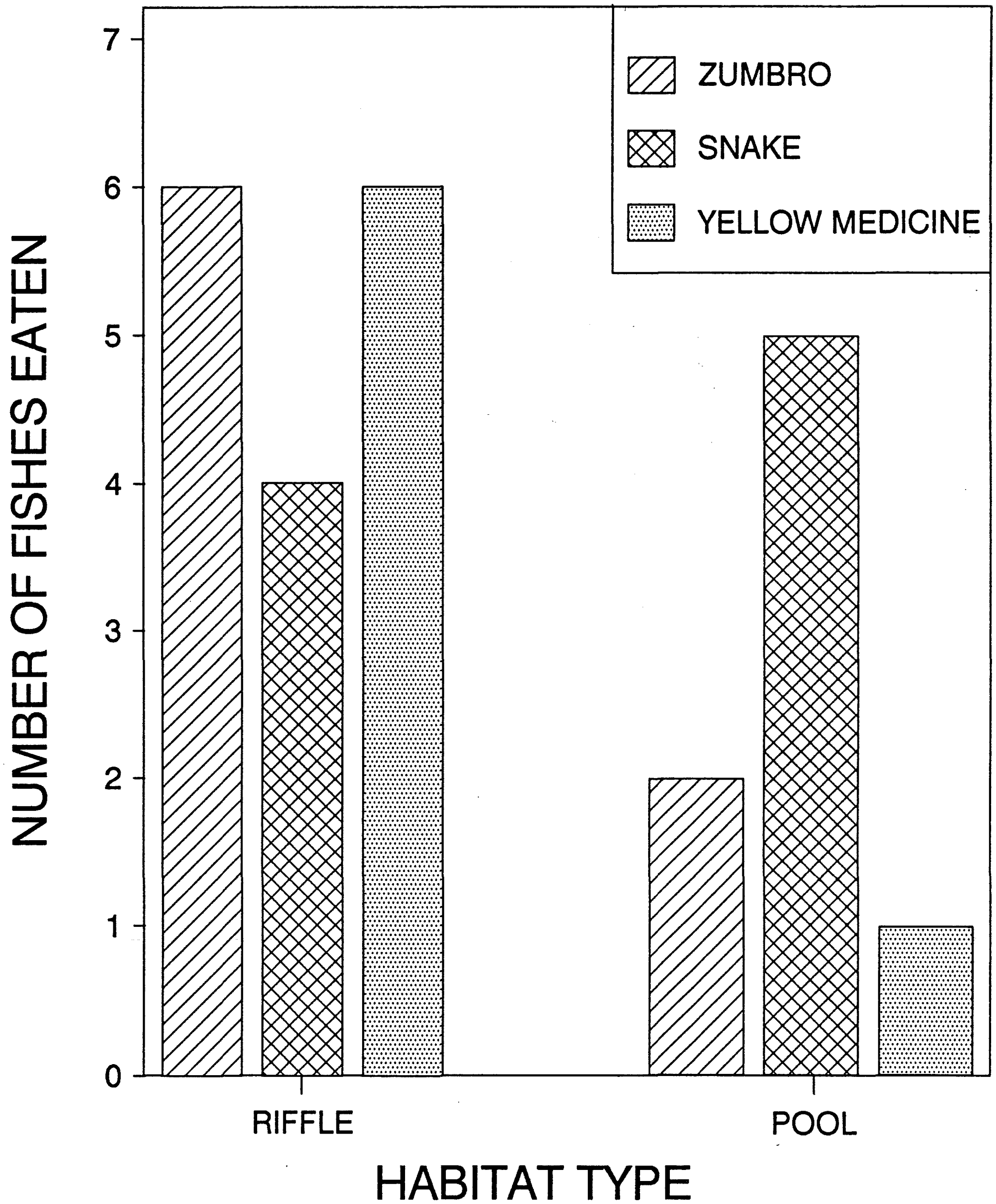


FIGURE 26. Fishes found in smallmouth bass stomachs versus the habitat in which they were most abundant in each stream.

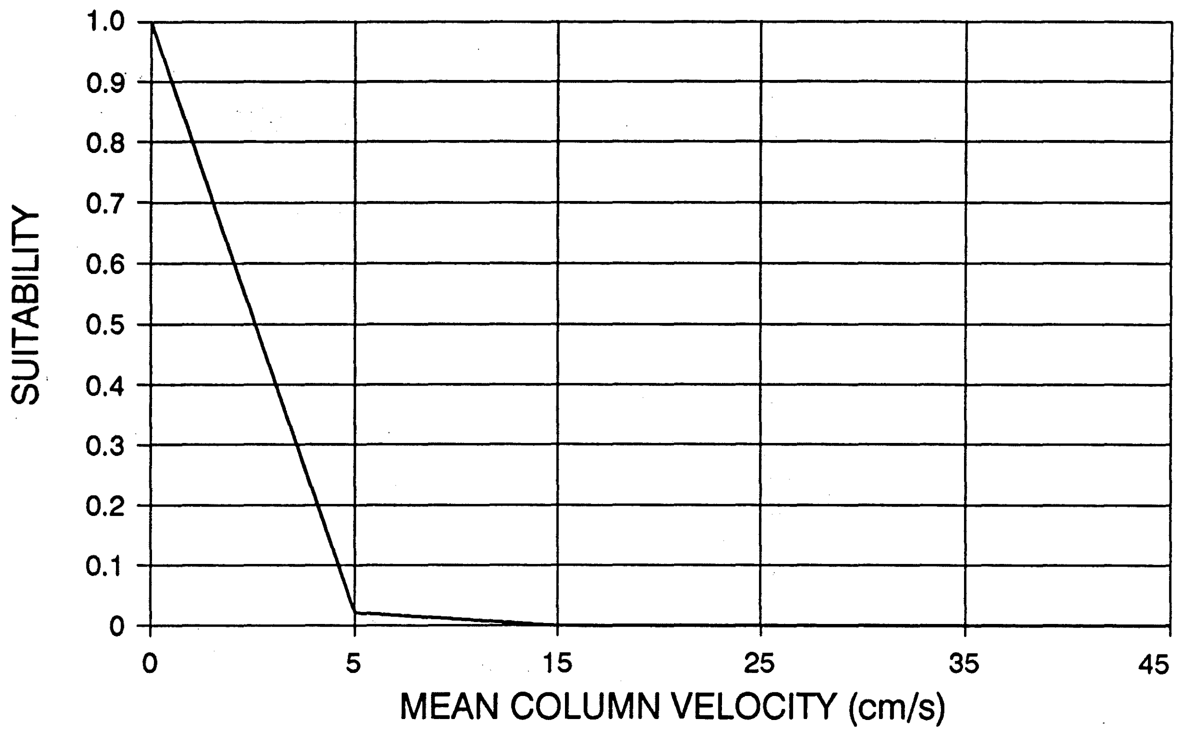


FIGURE 27. Velocity use by spawning smallmouth bass in the Zumbro river (N=94).

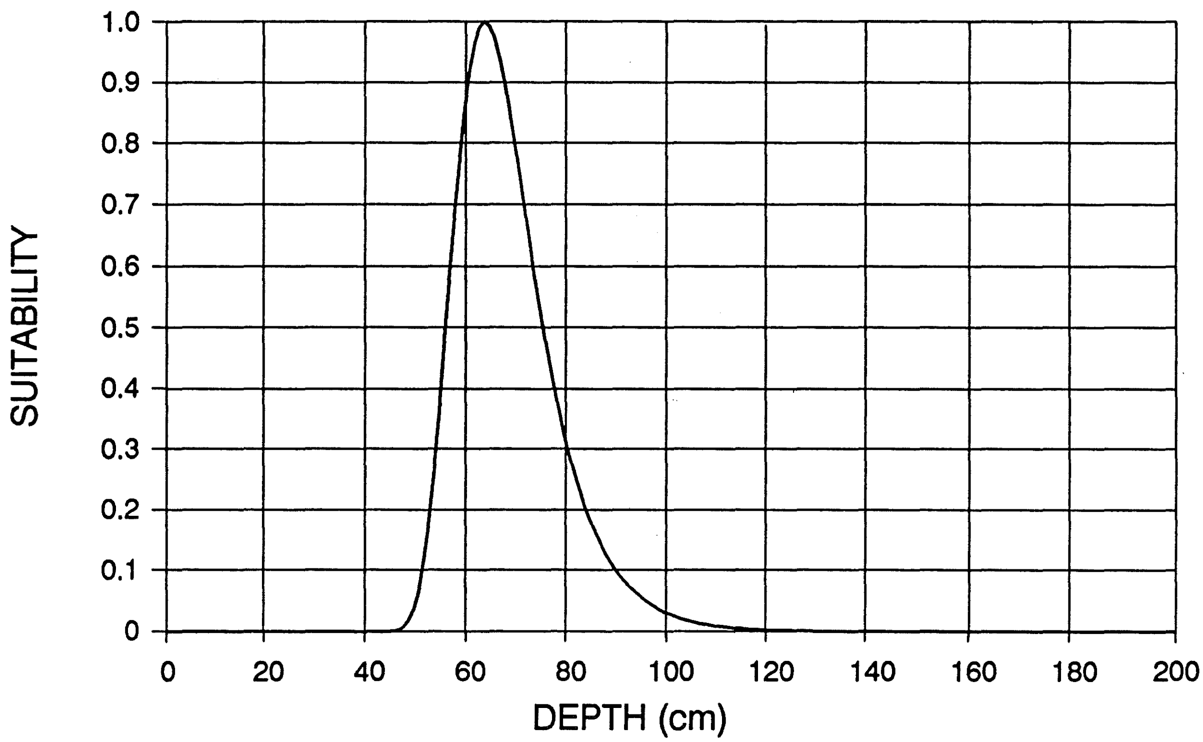


FIGURE 28. Depth use by spawning smallmouth bass in the Zumbro river (N=94).

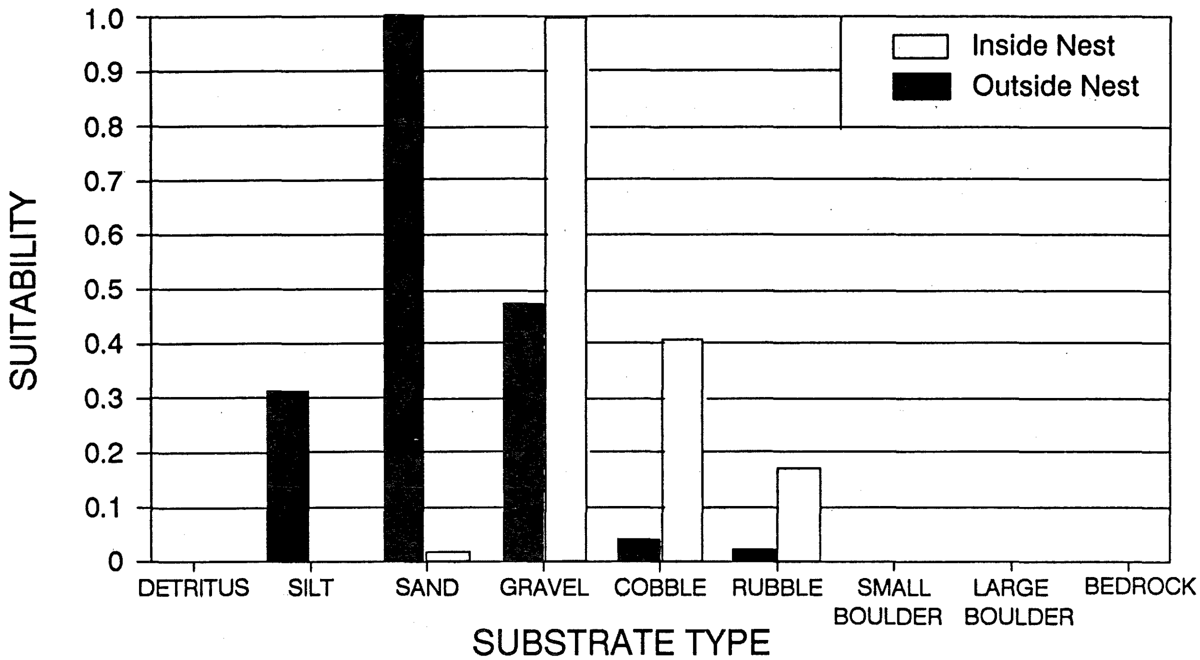


FIGURE 29. Dominant substrate use by spawning smallmouth bass in the Zumbro River (N=94).

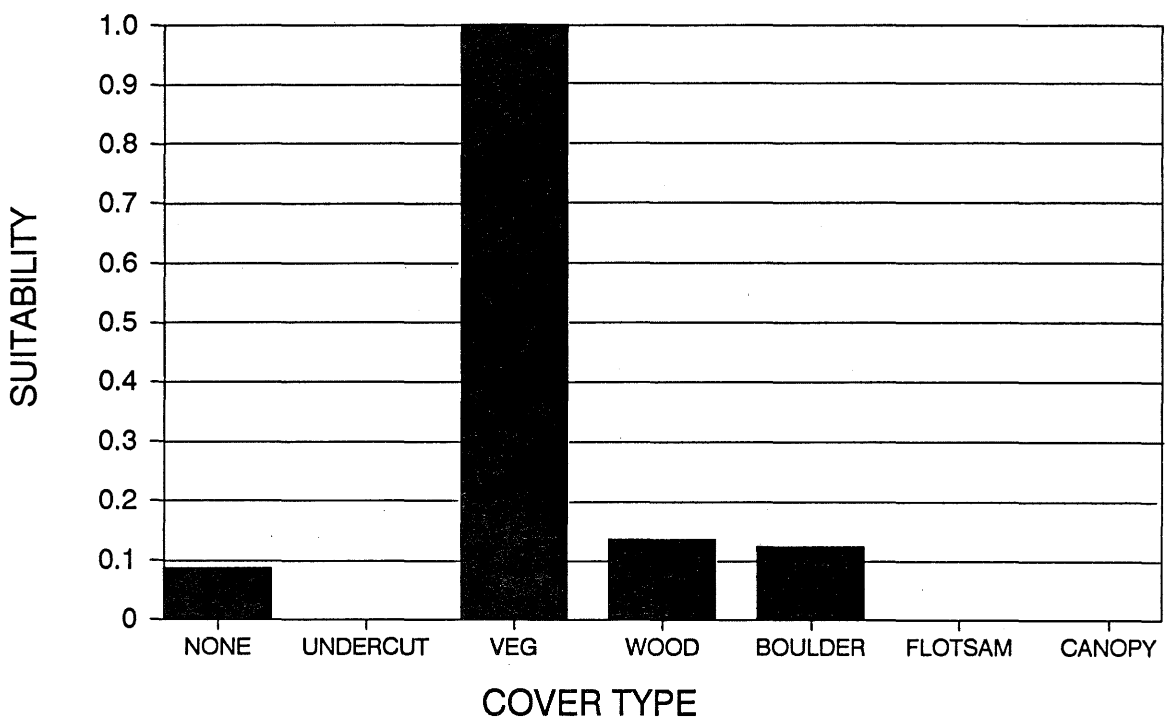


FIGURE 30. Cover use by spawning smallmouth bass in the Zumbro River (N=94).

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 insides of nests had been cleaned of silt and sand, and were composed of clean gravel, cobble, or rubble. All observed nests contained these larger substrates. Since substrate outside the nest is most comparable to substrate observed when recording available habitat for PHABSIM, we recommend its use for spawning habitat simulations instead of within nest substrate suitability. Cover is also important in habitat simulations; 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 viable fisheries for catfish. Only 19 young-of-the-year and 22 adults were collected throughout the study, so reliable preference relationships could not be constructed for these life stages. Habitat preference curves and histograms were developed for juveniles (Figs. 31-34) from the Yellow Medicine River. Weighted data were used to construct the preference relationships because channel catfish were most abundant in a few relatively deep 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. Deep pools without cover apparently held few if any catfish. Due to the scarcity of deep pool habitat in the Yellow Medicine River and selectivity of catfish for deep water, these preference curves are probably not appropriate for large rivers.

Based on our food habits analysis, juvenile and adult channel catfish in the Yellow Medicine River were almost exclusively piscivorous. 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 hog sucker (1).

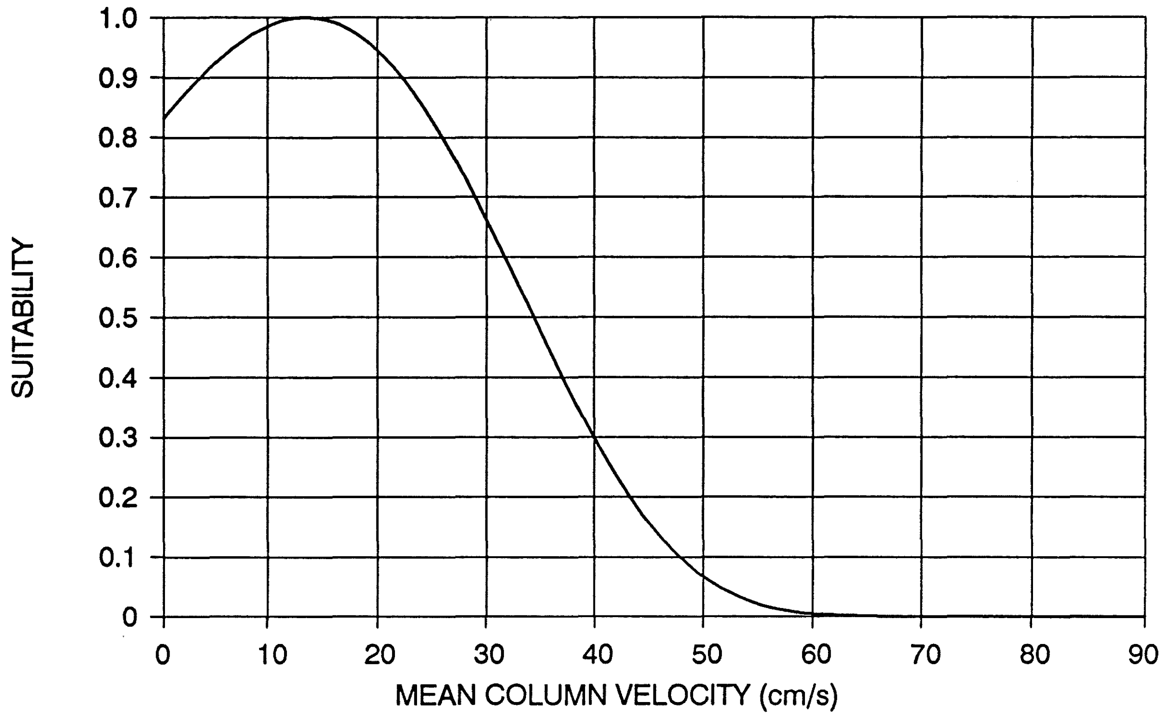


FIGURE 31. Velocity preference of juvenile channel catfish (80-309 mm) from the Yellow Medicine River (weighted data; number of individuals=55, number of samples=13).

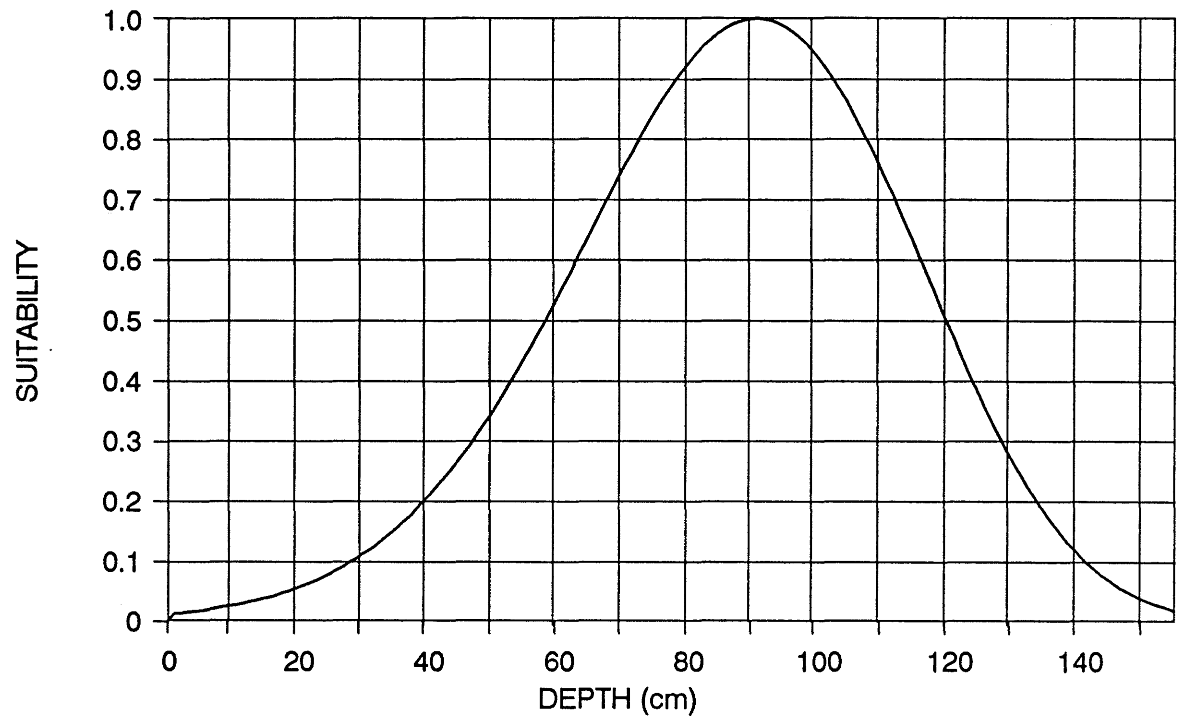


FIGURE 32. Depth preference of juvenile channel catfish (80-309 mm) from the Yellow Medicine River (weighted data; number of individuals=55, number of samples=13).

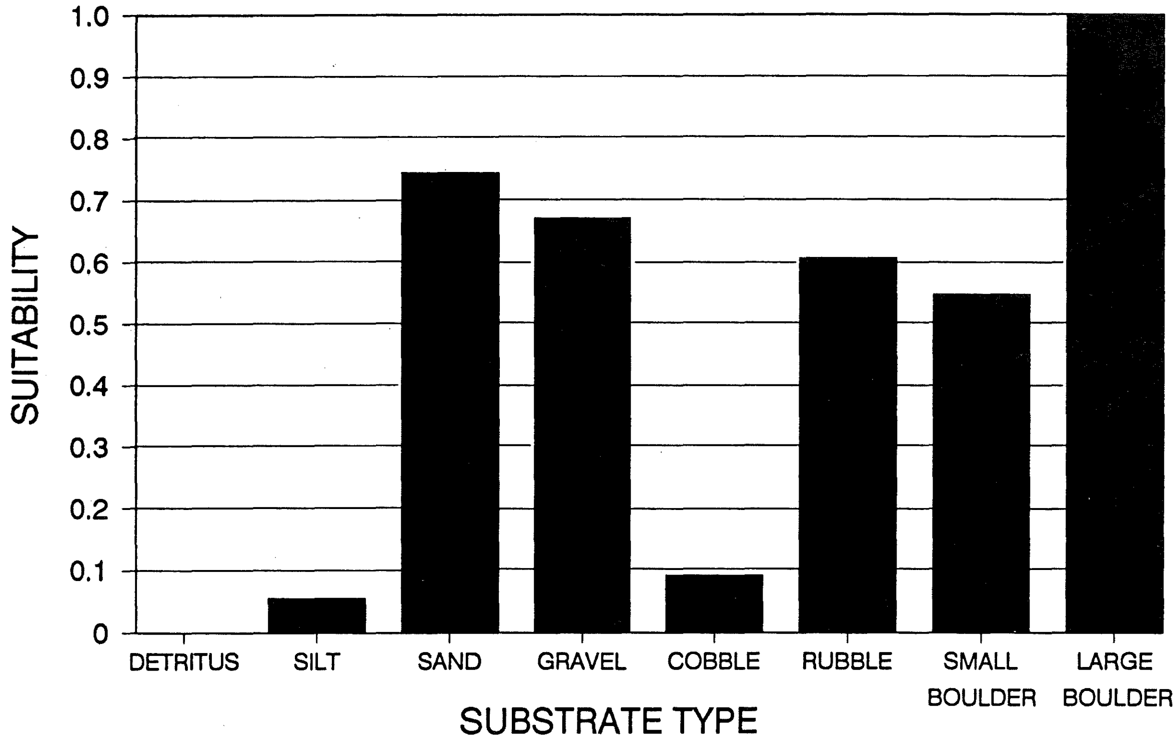


FIGURE 33. Dominant substrate preference of juvenile channel catfish (80-309 mm) in the Yellow Medicine River (weighted data; number of individuals=55, number of samples=13).

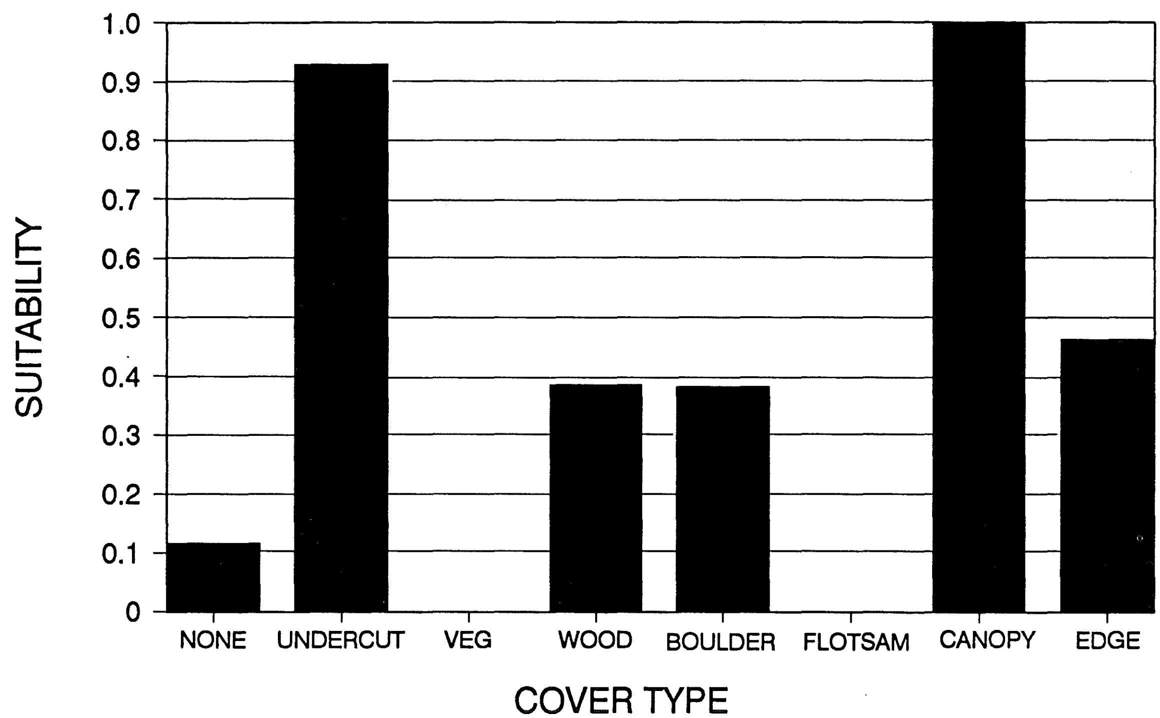


FIGURE 34. Cover preference of juvenile channel catfish (80-309 mm) in the Yellow Medicine River (weighted data; number of individuals=55, number of samples=13).

HABITAT PREFERENCE GUILDS

All species-life stages were assigned to one of six habitat preference guilds based on their densities in corresponding habitat types; shallow pool (less than 60 cm deep, less than 30 cm/s velocity, medium pool (60-149 cm deep, less than 30 cm/s velocity), deep pool (greater than or equal to 150 cm deep), raceway (60-149 cm deep, greater than or equal to 30 cm/s velocity), slow riffle (less than 60 cm deep, 30-59 cm/s velocity), and fast riffle (less than 60 cm deep, greater than or equal to 60 cm/s velocity). Available depth, velocity, substrate, and cover in each of these habitat types are shown in Tables 4-9.

Guild designations were made for each species-life stage based on the habitat type where their densities were highest (Tables 10-15). Since these guilds are based on density (adjusted for availability) rather than use alone, the resulting guilds reflect actual habitat preference.

Guild affiliation was consistent from stream to stream for 57% of the species-life stages common to two or more streams when the associated habitat type was available. Most of the species-life stages which were assigned to different guilds in different streams simply had preferences near the "cutoffs" for depth or velocity which separated habitat types (i.e. 60 cm/s velocity is the cutoff above which riffles are classified as "fast riffles" and below which they are "slow riffles". Some species-life stages did appear to prefer noticeably different habitat types in different streams. Much of this variation can be attributed to differences in habitat availability. For instance, banded darters, _Etheostoma zonale_, preferred fast riffles in the Zumbro River and in the Yellow Medicine River at high flow but were most abundant in slow riffles in the Yellow Medicine River at low flow; fast riffles were not present at low flow. For other species-life stages these variations in habitat preference may be due to biotic interactions (Schlosser 1987).

TABLE 4. Microhabitat means and ranges (in parentheses) and number of samples in shallow pools (<60 cm depth, <30 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	10 (0-29)	31 (3-59)	sand	vegetation (54%) undercut (37%)	279 (3876 m^2)
Snake	11 (0-29)	24 (3-57)	rubble	boulder (93%) vegetation (74%)	128 (1785 m^2)
Yellow Medicine (low flow)	5 (0-29)	26 (7-56)	cobble	boulder (64%) wood (53%)	36 (502 m^2)
Yellow Medicine (high flow)	8 (0-28)	33 (6-59)	sand	wood (38%) boulder (34%)	56 (781 m^2)

TABLE 5. Microhabitat means and ranges (in parentheses) and number of samples in medium pools (60-149 cm depth, <30 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	11 (0-29)	83 (60-148)	sand	wood (45%) vegetation (37%)	147 (2050 m^2)
Snake	6 (0-26)	95 (60-137)	cobble	boulder (83%) vegetation (70%)	30 (418 m^2)
Yellow Medicine (low flow)	0 (0-1)	100 (66-138)	gravel	boulder (70%) wood (40%)	10 (139 m^2)
Yellow Medicine (high flow)	15 (0-29)	81 (60-139)	gravel	wood (69%) boulder (38%)	13 (181 m^2)

TABLE 6. Microhabitat means and ranges (in parentheses) and number of samples in deep pools (>=150 cm depth) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	22 (6-57)	207 (152-354)	gravel	flotsam (21%) boulder (16%)	19 (265 m^2)
Snake	6 (5-10)	193 (170-213)	gravel	boulder (50%) flotsam (17%)	6 (84 m^2)
Yellow Medicine			NO DEEP POOL HABITAT		

TABLE 7. Microhabitat means and ranges (in parentheses) and number of samples in raceways (60-149 cm depth, >=30 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	54 (30-126)	83 (60-130)	cobble	boulder (23%) vegetation (6%)	87 (1213 m^2)
Snake	35 (32-39)	66 (60-72)	rubble	boulder (100%) wood (33%)	3 (42 m^2)
Yellow Medicine (low flow)			NO RACEWAY HABITAT		
Yellow Medicine (high flow)	40 (33-46)	77 (63-101)	cobble	boulder (100%) undercut (20%)	5 (70 m^2)

TABLE 8. Microhabitat means and ranges (in parentheses) and number of samples in slow riffles (<60 cm depth, 30-59 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	43 (30-59)	32 (10-59)	gravel	vegetation (32%) boulder (23%)	91 (1269 m^2)
Snake	40 (30-59)	31 (8-58)	rubble	boulder (91%) vegetation (39%)	23 (321 m^2)
Yellow Medicine (low flow)	37 (33-43)	12 (10-15)	cobble	boulder (67%) wood (50%)	6 (84 m^2)
Yellow Medicine (high flow)	42 (30-57)	31 (14-58)	cobble	boulder (72%) vegetation (33%)	18 (251 m^2)

TABLE 9. Microhabitat means and ranges (in parentheses) and number of samples in fast riffles (<60 cm depth, >=60 cm/s velocity) sampled in the Zumbro, Snake, and Yellow Medicine rivers.

River	Velocity (cm/s)	Depth (cm)	Dominant Substrate	Dominant Cover Types	Number of Samples
Zumbro	83 (60-131)	38 (8-59)	cobble	vegetation (21%) boulder (13%)	87 (1213 m^2)
Snake	83 (75-88)	25 (23-28)	rubble	boulder (100%) vegetation (25%)	4 (56 m^2)
Yellow Medicine (low flow)	NO FAST RIFFLE HABITAT				
Yellow Medicine (high flow)	72 (62-86)	33 (21-49)	cobble	boulder (67%) vegetation (44%)	9 (125 m^2)

TABLE 10. Species-life stages which preferred shallow pools (<60 cm deep, <30 cm/s velocity) in the Zumbro (Z), Yellow Medicine (Y), or Snake (S) rivers. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life stage	N	River
Clupeidae				
Gizzard shad	*Dorosoma cepedianum*	A	18	Y
Gizzard shad	*Dorosoma cepedianum*	Y	36	Y
Cyprinidae				
Bluntnose minnow	*Pimephales notatus*	Y	435	S,Y,Z
Carp	*Cyprinus carpio*	Y	13	Z
Creek chub	*Semotilus atromaculatus*	A	82	Y,Z
Creek chub	*Semotilus atromaculatus*	J	76	Y,Z
Common shiner	*Notropis cornutus*	J	24	Z
Emerald shiner	*Notropis atherinoides*	Y	842	Y,Z
Golden shiner	*Notemigonus crysoleucas*	A	5	S
Golden shiner	*Notemigonus crysoleucas*	Y	12	S
Longnose dace	*Rhinichthys cataractae*	Y	272	S
River shiner	*Notropis blennius*	Y	27	Z
Sand shiner	*Notropis volucellus*	A	946	Y
Sand shiner	*Notropis volucellus*	Y	796	Y,Z
Spotfin shiner	*Notropis spilopterus*	A	1209	Z
Spotfin shiner	*Notropis spilopterus*	Y	128	Z
Spottail shiner	*Notropis hudsonius*	A	115	Z,S
Spottail shiner	*Notropis hudsonius*	Y	274	Y,Z
Catastomidae				
Golden redhorse	*Moxostoma erythrurum*	Y	258	Y,Z
Northern hog sucker	*Hypentellium nigricans*	Y	47	Z
River carpsucker	*Carpoides carpio*	Y	81	Y,Z
Centrarchidae				
Bluegill	*Lepomis macrochirus*	Y	88	S,Z
Green sunfish	*Lepomis cyanellus*	A	63	Z
Green sunfish	*Lepomis cyanellus*	Y	64	Y,Z
Orangespotted sunfish	*Lepomis humilis*	A	15	Y
Smallmouth bass	*Micropterus dolomieui*	FR	82	S,Z
Rock bass	*Ambloplites rupestris*	A	79	S
Percidae				
Johnny darter	*Etheostoma nigrum*	A	57	Z

TABLE 11. Species-life stages which preferred medium pools (60-149 cm deep, <30 cm/s velocity) in the Zumbro (Z), Snake (S), or Yellow Medicine (Y, YL=summer low flow) river. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life stage	N	River
Clupeidae				
Gizzard shad	*Dorosoma cepedianum*	A	92	Z
Gizzard shad	*Dorosoma cepedianum*	Y	111	Z
Cyprinidae				
Bluntnose minnow	*Pimephales promelas*	A	115	Z
Carp	*Cyprinus carpio*	A	30	YL,Z
Carp	*Cyprinus carpio*	J	20	S
Common shiner	*Notropis cornutus*	A	269	S
Common shiner	*Notropis cornutus*	J	396	S
Emerald shiners	*Notropis atherinoides*	A	49	Y
Hornyhead chub	*Nocomis biguttatus*	J	91	S
Hornyhead chub	*Nocomis biguttatus*	Y	103	S
Sand shiner	*Notropis stramineus*	A	24	S
Spotfin shiner	*Notropis spilopterus*	S	56	YL
Catastomidae				
Greater redhorse	*Moxostoma valenciennesi*	A	15	S,Z
Silver redhorse	*Moxostoma anisurum*	A	27	YL,Z,S
Silver redhorse	*Moxostoma anisurum*	J	6	YL
White sucker	*Catastomus commersoni*	A	16	Z
Ictaluridae				
Black bullhead	*Ictalurus melas*	A	9	Y,S
Black bullhead	*Ictalurus melas*	Y	33	S
Channel catfish	*Ictalurus punctatus*	A	15	Y
Channel catfish	*Ictalurus punctatus*	J	55	Y
Channel catfish	*Ictalurus punctatus*	Y	18	Y
Percichthyidae				
White bass	*Morone chrysops*	J	29	Z
White bass	*Morone chrysops*	Y	63	Z
Centrarchidae				
Black crappie	*Pomoxis nigromaculatus*	A	6	S
Black crappie	*Pomoxis nigromaculatus*	J	6	S
Largemouth bass	*Micropterus salmoides*	J	59	Z
Smallmouth bass	*Micropterus dolomieui*	J	116	Z
Smallmouth bass	*Micropterus dolomieui*	S*	94	Z
Smallmouth bass	*Micropterus dolomieui*	FI	43	Z
Rock bass	*Ambloplites rupestris*	A	9	Y,Z
Rock bass	*Ambloplites rupestris*	J	21	S
Rock bass	*Ambloplites rupestris*	Y	98	S
White crappie	*Pomoxis annularis*	A	32	S
Percidae				
Blackside darter	*Percina maculata*	Y	33	S
Walleye	*Stizostedion vitreum*	J	19	S,Z
Walleye	*Stizostedion vitreum*	Y	19	S
Yellow perch	*Perca flavescens*	A	5	S
Yellow perch	*Perca flavescens*	J	79	S,Z

TABLE 12. Species-life stages which preferred deep pools (>=150 cm deep) in the Zumbro (Z) or Snake (S) river. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life stage	N	River
Cyprinidae				
Common shiner	*Notropis cornutus*	Y	31	S
Spotfin shiner	*Notropis spilopterus*	A	323	S
Catastomidae				
Golden redhorse	*Moxostoma erythrurum*	A	26	S,Z
Silver redhorse	*Moxostoma anisurum*	J	16	S
White sucker	*Catastomus commersoni*	A	6	S
Ictaluridae				
Channel catfish	*Ictalurus punctatus*	A	7	S,Z
Centrarchidae				
Black crappie	*Pomoxis nigromaculatus*	A	21	Z
Black crappie	*Pomoxis nigromaculatus*	J	87	Z
Bluegill	*Lepomis macrochirus*	J	169	Z
Largemouth bass	*Micropterus salmoides*	Y	133	Z
Smallmouth bass	*Micropterus dolomieui*	A	74	Z
Percidae				
Johnny darter	*Etheostoma nigrum*	Y	12	S
Yellow perch	*Perca flavescens*	A	14	Z

TABLE 13. Species-life stages which preferred raceways (60-149 cm deep, >=30 cm/s velocity) in the Zumbro (Z), Snake (S), or Yellow Medicine (YH=spring high flow) river. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life stage	N	River
Cyprinidae				
Carp	*Cyprinus carpio*	A	23	YH
Catastomidae				
Northern hog sucker	*Hypentellium nigricans*	A	295	Z
Shorthead redhorse	*Moxostoma macrolepidotum*	A	562	S,Z
Shorthead redhorse	*Moxostoma macrolepidotum*	J	188	S,Z
Ictaluridae				
Stonecat	*Noturus flavus*	A	12	S
Centrarchidae				
Smallmouth bass	*Micropterus dolomieui*	A	32	S
Smallmouth bass	*Micropterus dolomieui*	J	204	S
Percidae				
Log Perch	*Percina caprodes*	S	8	Z

TABLE 14. Species-life stages which preferred slow riffles (<60 cm deep, 30-59 cm/s velocity) in the Zumbro (Z), Snake (S), or Yellow Medicine (Y, YL=summer low flow, YH=spring high flow) river. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life stage	N	River
Cyprinidae				
Bluntnose minnow	*Pimephales notatus*	A	50	S
Carp	*Cyprinus carpio*	Y	8	S
Creek chub	*Semotilis atromaculatus*	Y	122	Z
Common shiner	*Notropis cornutus*	A	225	Z
Common shiner	*Notropis cornutus*	S	8	Z
Central stoneroller	*Campostoma anomalum*	A	1979	Y,Z
Central stoneroller	*Campostoma anomalum*	J	864	Z
Emerald shiner	*Notropis atherinoides*	A	4016	Z
Hornyhead chub	*Nocomis biguttatus*	A	46	S,Y
Largescale stoneroller	*Campostoma oligolipis*	A	64	YL
Largescale stoneroller	*Campostoma oligolipis*	J	25	YL
Longnose dace	*Rhinichthys cataractae*	A	324	S
Longnose dace	*Rhinichthys cataractae*	S	25	Z
Mimic shiner	*Notropis volucellus*	A	38	Z
River shiner	*Notropis blennius*	A	1899	Z
Sand shiner	*Notropis stramineus*	A	630	Z
Sand shiner	*Notropis stramineus*	S	26	Z
Spotfin shiner	*Notropis spilopterus*	A	2413	YL
Spotfin shiner	*Notropis spilopterus*	Y	1513	YL
Spotfin shiner	*Notropis spilopterus*	S	111	Z
Suckermouth minnow	*Phenacobius mirabilis*	A	8	Z
Catastomidae				
Golden redhorse	*Moxostoma erythrurum*	J	7	Z
Golden redhorse	*Moxostoma erythrurum*	S	9	Z,YH
Greater redhorse	*Moxostoma valenciennesi*	S	16	YH
Northern hog sucker	*Hypentellium nigricans*	A	49	S,YH
Northern hog sucker	*Hypentellium nigricans*	J	17	S,YL
Northern hog sucker	*Hypentellium nigricans*	S	31	Z,YH
River redhorse	*Moxostoma carinatum*	A	35	S
Shorthead redhorse	*Moxostoma macrolepidotum*	Y	443	Z
Silver redhorse	*Moxostoma anisurum*	Y	45	Z
White sucker	*Catastomus commersoni*	J	1254	Z
White sucker	*Catastomus commersoni*	Y	1647	Z
Ictaluridae				
Stonecat	*Noturus flavus*	J	6	YL
Centrarchidae				
Smallmouth bass	*Micropterus dolomieui*	J	15	Y
Percidae				
Banded darter	*Etheostoma zonale*	A	109	YL
Banded darter	*Etheostoma zonale*	Y	6	YL
Blackside darter	*Percina maculata*	Y	48	Z
Blackside darter	*Percina maculata*	A	6	S,YL

Table 14 (continued)

Common name	Scientific name	Life stage	N	River
Fantail darter	*Etheostoma flaballare*	A	24	YL
Fantail darter	*Etheostoma flaballare*	Y	5	YL
Johnny darter	*Etheostoma nigrum*	Y	465	Z
Log Perch	*Percina caprodes*	Y	29	Z
Rainbow darter	*Etheostoma caeruleum*	A	29	YL
Rainbow darter	*Etheostoma caeruleum*	Y	9	YL
Slenderhead darter	*Percina phoxocephala*	A	169	YL,Z

TABLE 15. Species-life stages which preferred fast riffles (<60 cm deep, >=60 cm/s velocity) in the Zumbro (Z), Snake (S), or Yellow Medicine (Y, YL=summer low flow, YH=spring high flow) river. Number of observations (N) refers to the total number collected in the river or rivers indicated. Life stages listed are adult (A), juvenile (J), young of the year (Y), fingerling 60-99 mm (FI), fry <60 mm (FR), and spawning (S).

Common name	Scientific name	Life Stage	N	River
Cyprinidae				
Central stoneroller	*Campostoma anomalum*	Y	1178	Z
Longnose dace	*Rhinichthys cataractae*	A	409	Z
Longnose dace	*Rhinichthys cataractae*	Y	69	Z
Catastomidae				
Northern hog sucker	*Hypentellium nigricans*	J	176	YH,Z
Shorthead redhorse	*Moxostoma macrolepidotum*	A	48	YH
Shorthead redhorse	*Moxostoma macrolepidotum*	S	159	YH
Ictaluridae				
Stonecat	*Noturus flavus*	J	23	S
Stonecat	*Noturus flavus*	Y	14	S
Centrarchidae				
Smallmouth bass	*Micropterus dolomieui*	FI	60	S
Percidae				
Banded darter	*Etheostoma zonale*	A	1178	Z,YH
Banded darter	*Etheostoma zonale*	S	57	Z,YH
Banded darter	*Etheostoma zonale*	Y	121	Z,YH
Blackside darter	*Percina maculata*	A	16	Z
Gilt darter	*Percina evides*	A	8	S
Gilt darter	*Percina evides*	Y	8	S
Log perch	*Percina caprodes*	A	736	Z,S
Rainbow darter	*Etheostoma caeruleum*	A	82	Z,YH
Rainbow darter	*Etheostoma caeruleum*	S	31	Z,YH
Slenderhead darter	*Percina phoxocephala*	A	88	S,YH
Slenderhead darter	*Percina phoxocephala*	S	42	Z,YH
Fantail darter	*Etheostoma flaballare*	S	12	YH

Shallow pool guild

The shallow pool guild was made up largely of shiners (*Notropis spp.*), young-of-the-year suckers (Catostomidae), and sunfishes (Table 10). Habitat used by these fishes was usually found along the channel margin (Table 4).

Medium pool guild

The medium pool guild consisted of sunfishes, adult cyprinids and many of the predatory fishes (Table 11). Medium pools had a variety of cover and substrate types (Table 5). Many of the members of this guild were relatively ubiquitous, and were found in different habitat types in different rivers.

Deep pool guild

Members of the deep pool guild included several shiners (*Notropis* spp.), sunfishes, suckers and channel catfish (Table 12). These fish used the deepest water available (Table 6). Many of the deep pool guild members are species which do not typically occur in streams without lake influence or are ubiquitous in their habitat use. Channel catfish adults are the exception to this generalization and were consistently found in the deepest available pools in all study streams.

Raceway guild

The raceway guild was comprised of juvenile and adult suckers (northern hog sucker and *Moxostoma* spp.) and, in the Snake river, by juvenile and adult smallmouth bass (Table 13). These fishes used areas which had moderate velocity and depth, large substrates and boulder or no cover (Table 7). Raceways had relatively low species diversity but probably possessed the highest fish biomass of the habitat types since they had high densities of large fishes.

Slow riffle guild

Slow riffles were preferred by more species-life stages than any of the other habitat types. Adult and young of the year darters (*Etheostoma* spp.), adult and juvenile stonerollers (*Campostoma* spp.), adult and spawning shiners, and adult and spawning suckers typified riffle assemblages (Table 14). The habitat used by these fishes was shallow with moderate to high velocities, gravel, cobble, or rubble substrate and vegetation or boulder cover (Table 8).

Fast riffle guild

Fast riffles were preferred by juvenile and adult longnose dace, adult, young of the year and spawning darters, spawning shorthead redhorse and juvenile northern hog sucker (Table 15). These species-life stages were found in the highest velocity areas which were shallow and had cobble or rubble substrates, and boulder or vegetation cover (Table 9).

NONGAME SPECIES

Banded Darter (*Etheostoma zonale*).

Banded darters of all life stages (young of the year, spawning, and adult) preferred fast riffles when available (Figs. 35-46). Banded darters were collected in the Yellow Medicine and Zumbro rivers and are found in many of the Southern Minnesota streams of the Mississippi Drainage. Due to the relative difficulty of collecting this species, it is probably more abundant and more widely distributed than many records indicate.

Miller and Robison (1973) report spawning occurred in riffles on attached algae. This is consistent with our findings as 74% of the spawning banded darters collected in the Yellow Medicine River and 88% of those collected in the Zumbro River used areas with attached algae. Mean velocity and depth use by banded darters in these two rivers were almost identical and were 56 cm/s and 33 cm in the Yellow Medicine River and 57 cm/s and 32 cm in the Zumbro river. The suitability curves presented here (Figs. 43-46) are composites from the Zumbro and Yellow Medicine rivers. Water temperatures ranged from 10 to 23.5°C during spawning. Spawning banded darters were sampled from 21 April to 11 May in the Yellow Medicine River and from 19 May to 7 June in the Zumbro River.

Bluntnose Minnow (*Pimephales notatus*).

Bluntnose minnows were collected in shallow to moderate pools and slow riffles which contained algal masses or macrophytes. Spawning occurs on the underside of logs, rocks and other objects (Hubbs and Cooper 1936). Only 2 spawning condition bluntnose minnows were collected in this study. These were sampled in a shallow backwater at a water temperature of 25°C. Young of the year bluntnose minnows preferred shallow pools and 70% of the individuals were collected in areas which had vegetation cover (Figs. 47-50). Adult bluntnose minnows were most abundant in medium pools (Zumbro River) and slow riffles (Snake River) with edge or vegetation cover (Figs. 51-54).

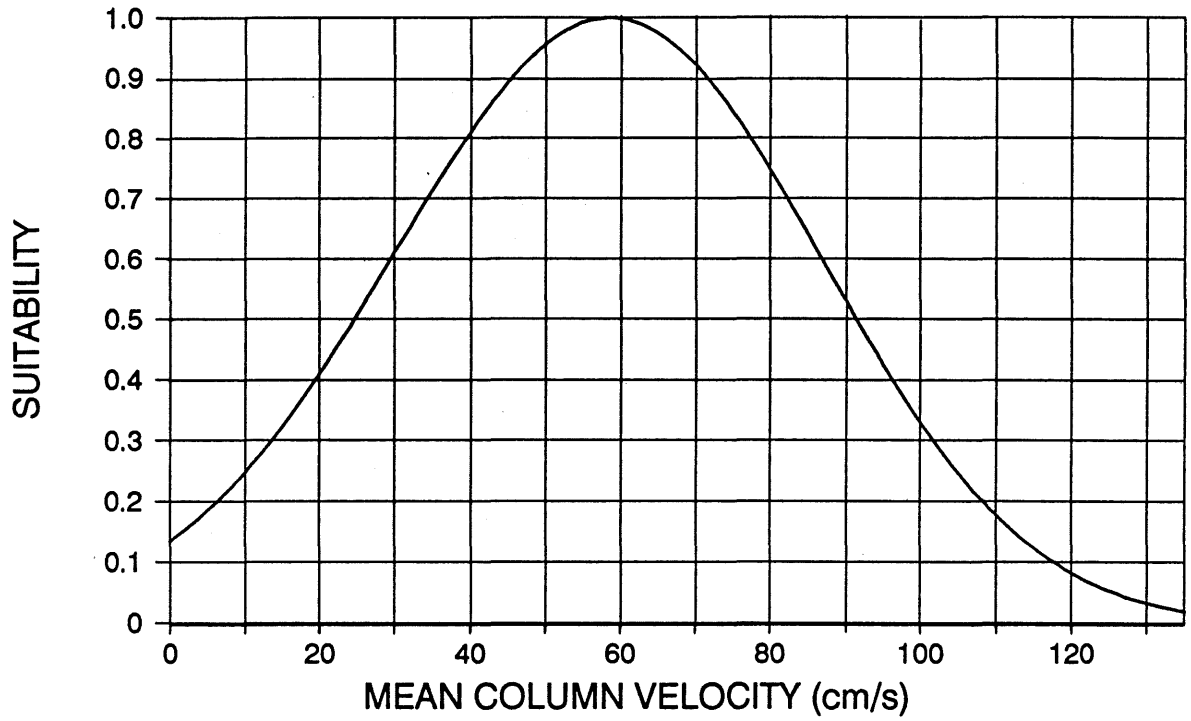


FIGURE 35. Velocity preference of young-of-the-year banded darter (<38 mm) from the Zumbro and Yellow Medicine rivers (number of individuals=155, number of samples=64).

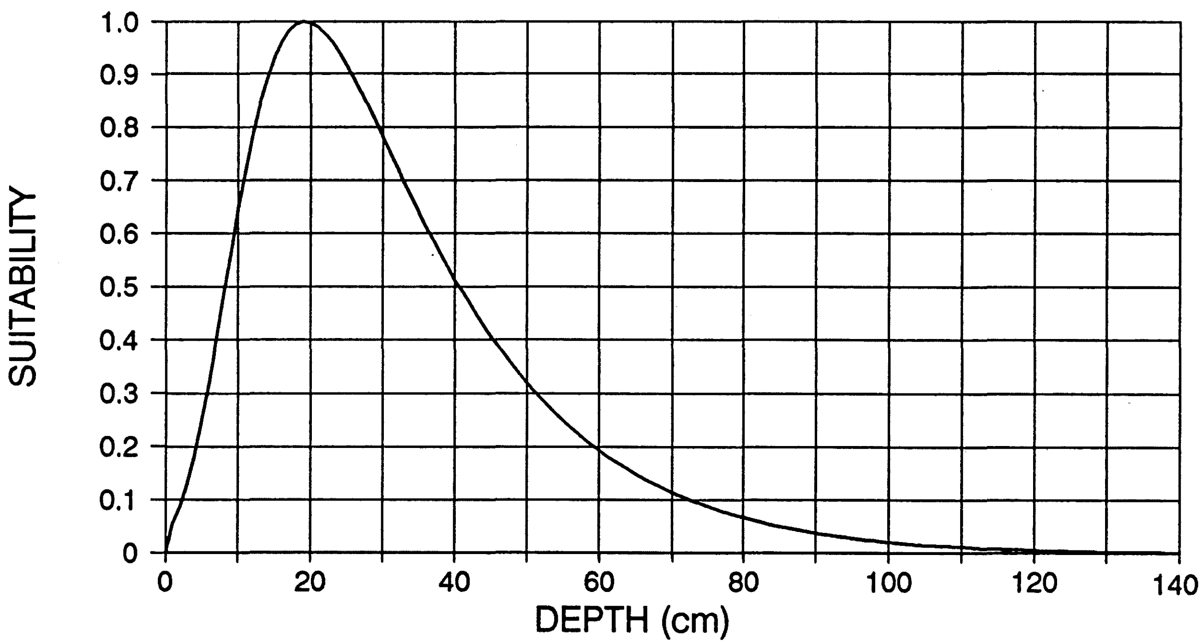


FIGURE 36. Depth preference of young-of-the-year banded darter (<38 mm) from the Zumbro and Yellow Medicine rivers (number of individuals=155, number of samples=64).

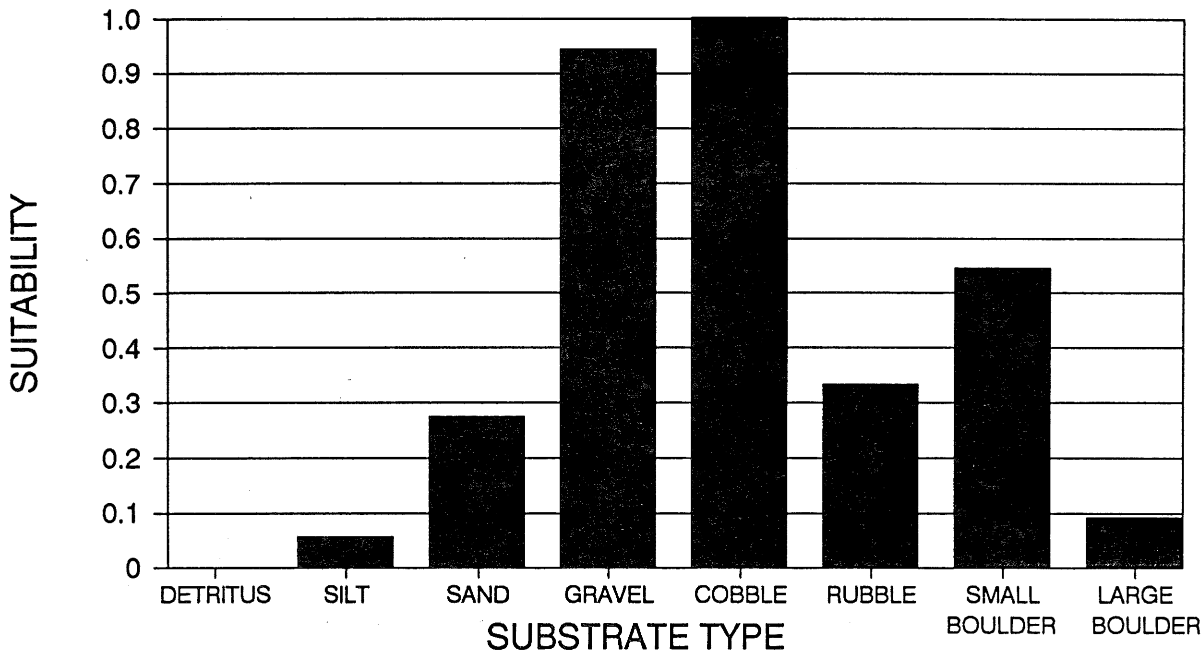


FIGURE 37. Dominant substrate preference of young-of-the-year banded darter (<38 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=155, number of samples=64).

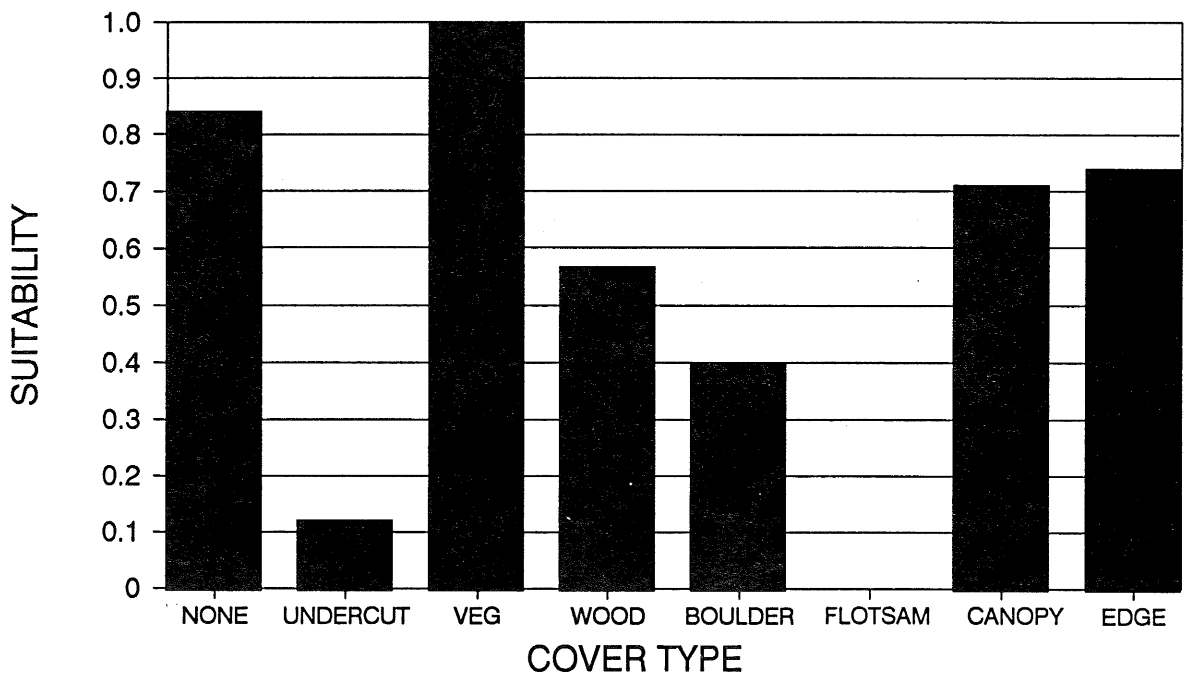


FIGURE 38. Cover preference of young-of-the-year banded darter (<38 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=155, number of samples=64).

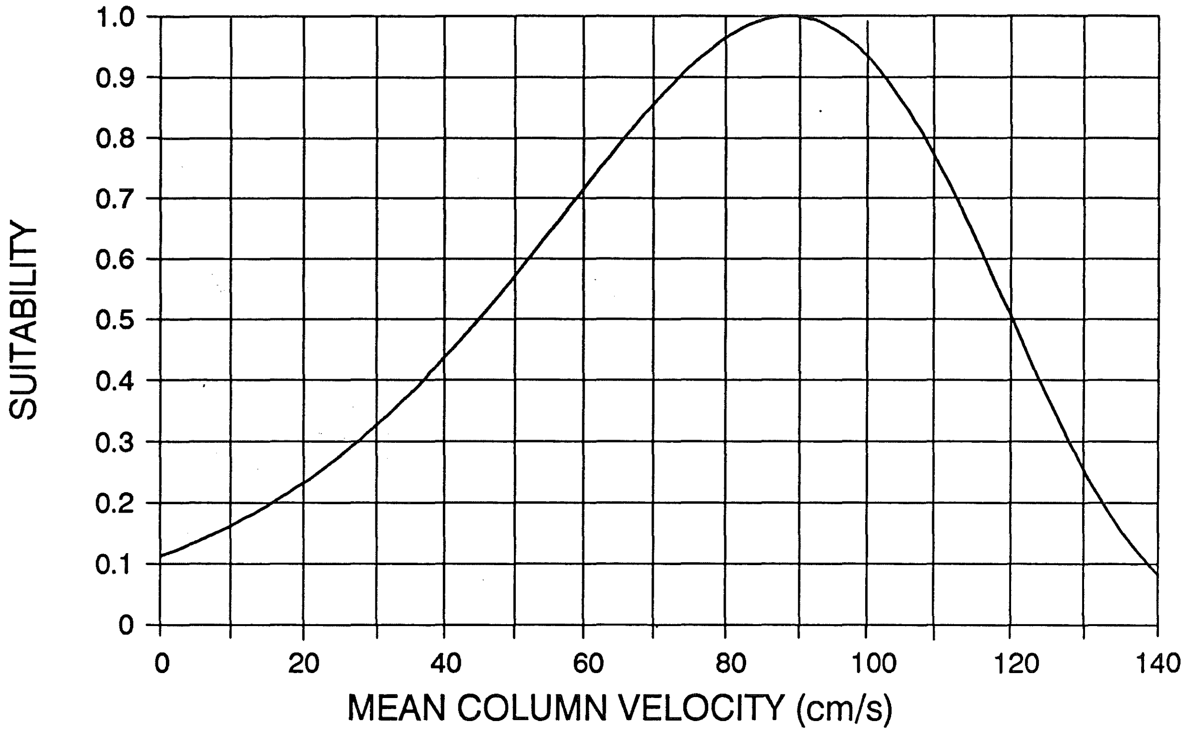


FIGURE 39. Velocity preference of adult banded darter (>or=38 mm) in the Zumbro River (number of individuals=1142, number of samples=134).

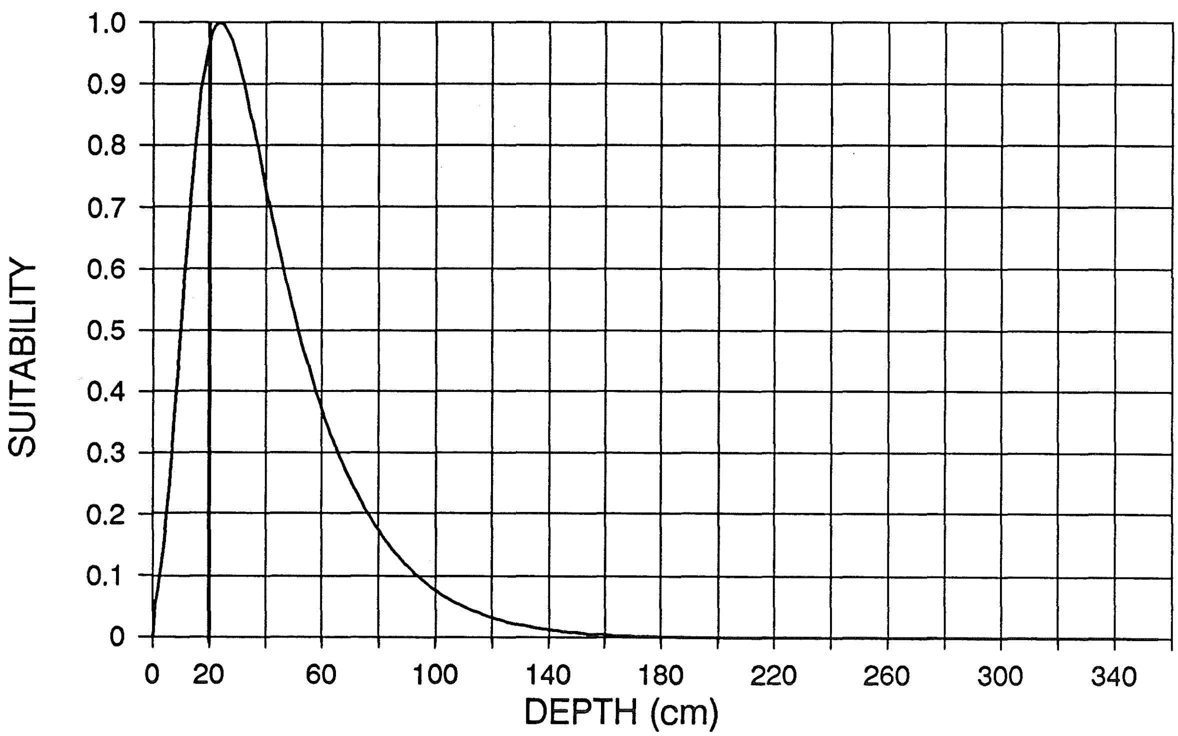


FIGURE 40. Depth preference of adult banded darter (>or=38 mm) in the Zumbro River (number of individuals=1142, number of samples=134).

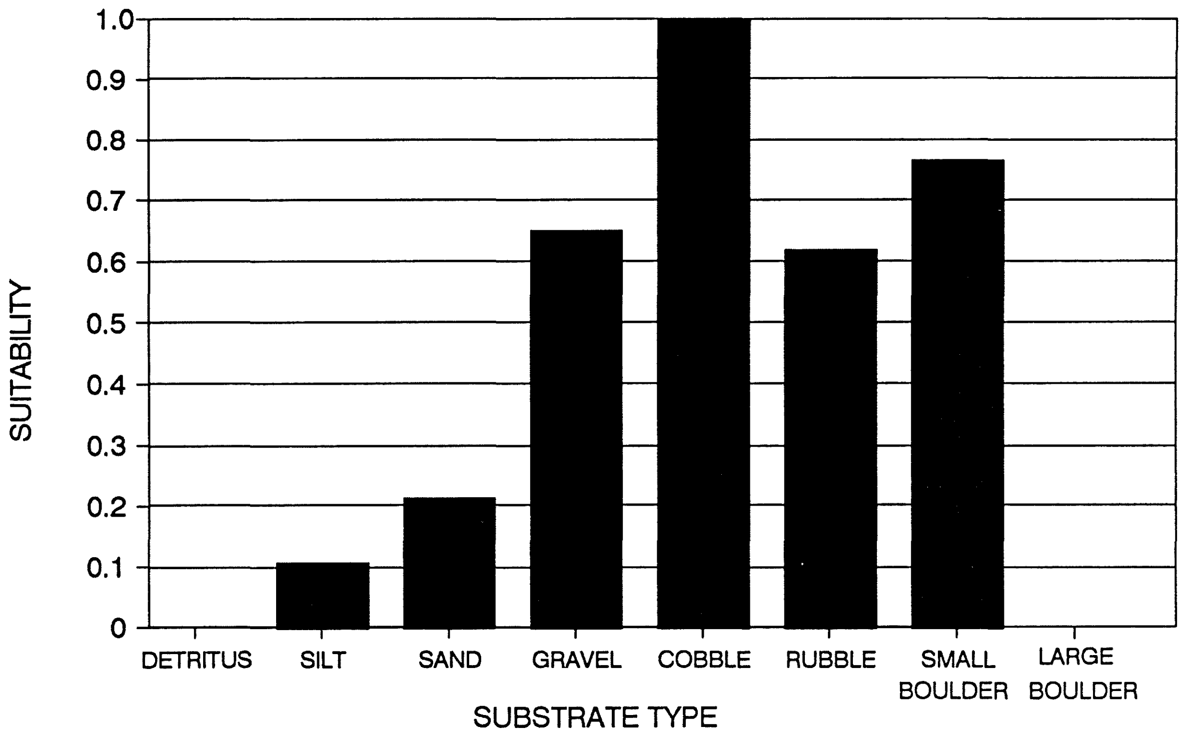


FIGURE 41. Dominant substrate preference of adult banded darter (>or=38 mm) in the Zumbro River (number of individuals=1142, number of samples=134).

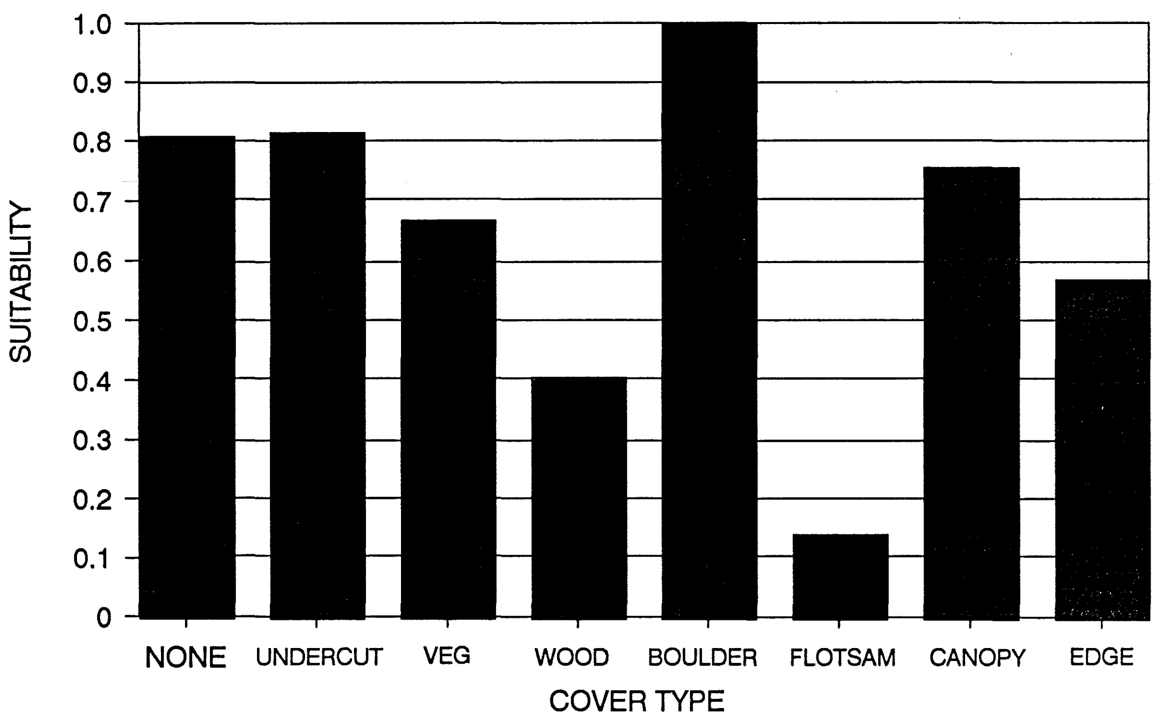


FIGURE 42. Cover preference of adult banded darter (>or=38 mm) in the Zumbro River (number of individuals=1142, number of samples=134).

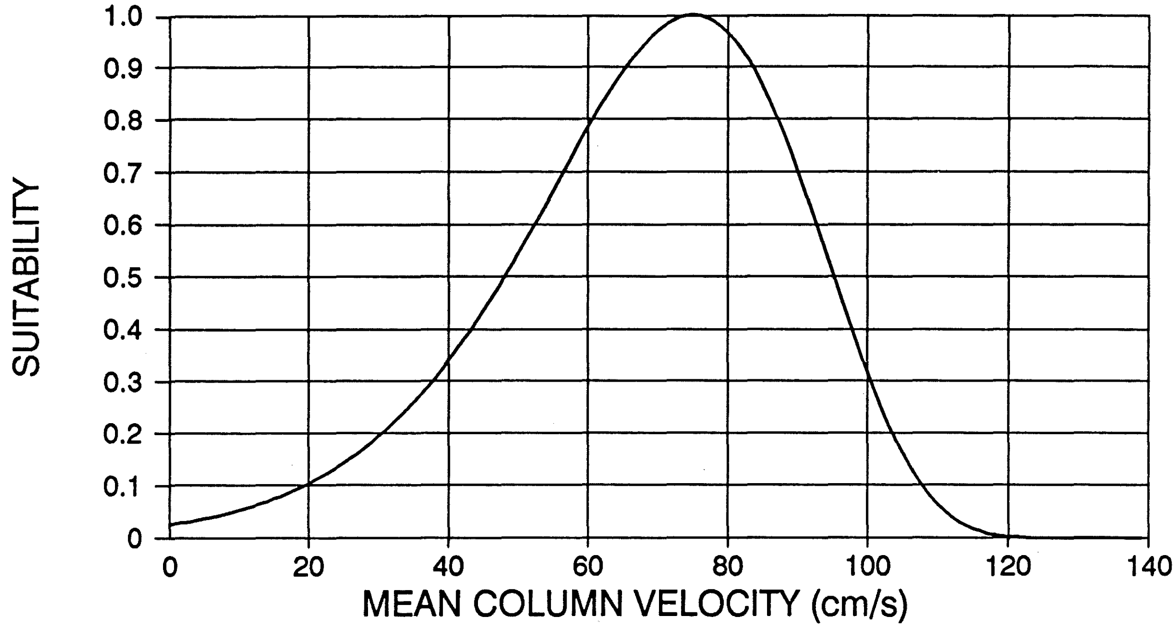


FIGURE 43. Velocity preference of spawning banded darter in the Zumbro and Yellow Medicine rivers (number of individuals=57, number of samples=25).

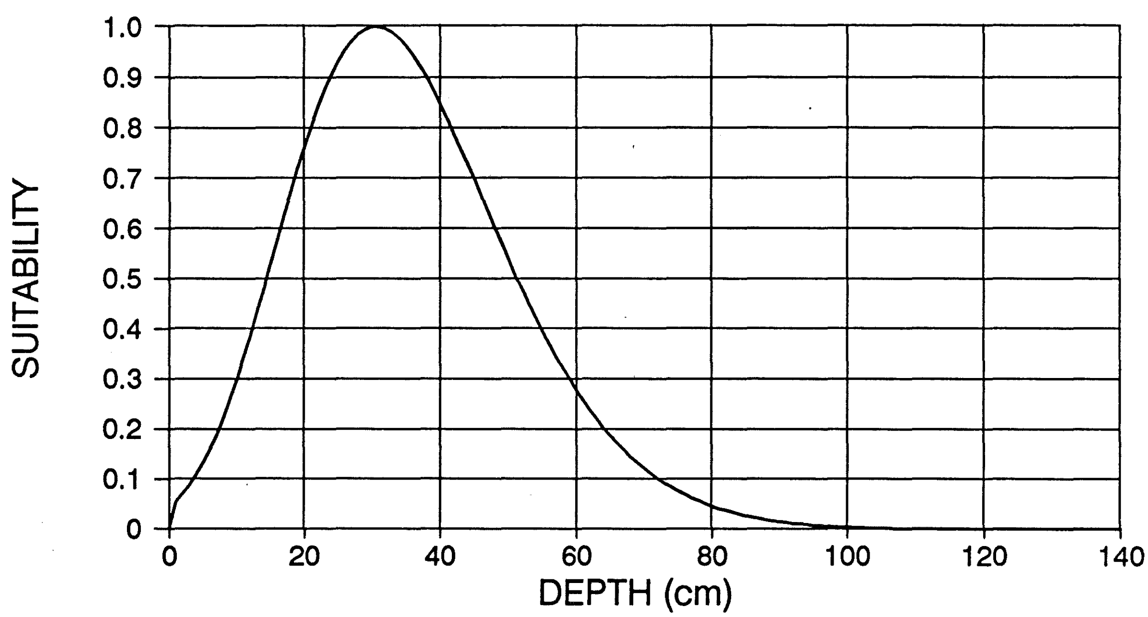


FIGURE 44. Depth preference of spawning banded darter in the Zumbro and Yellow Medicine rivers (number of individuals=57, number of samples=25).

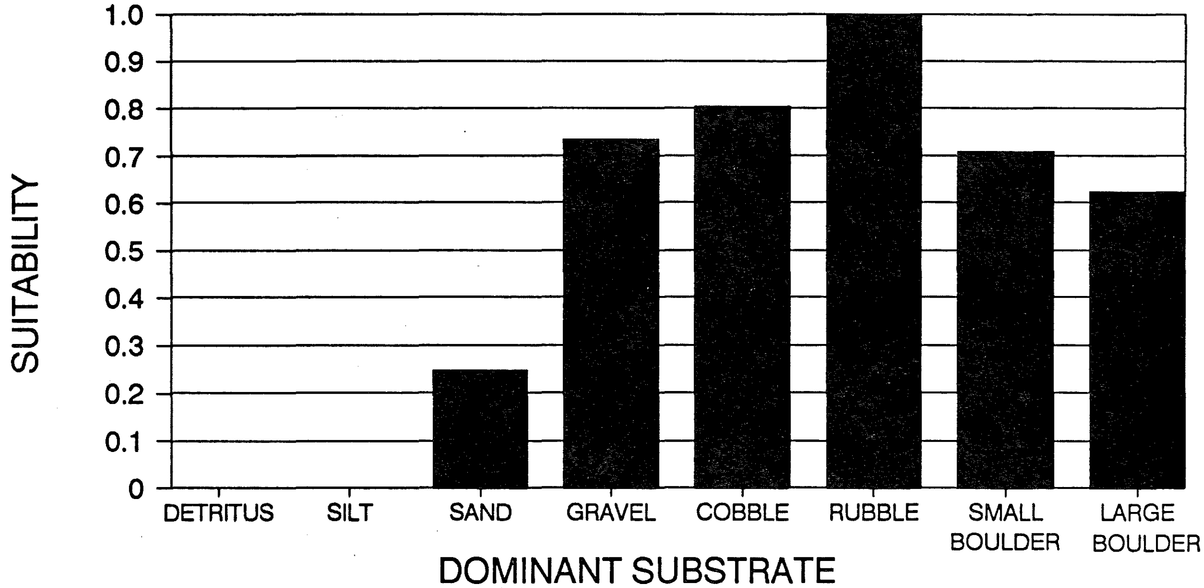


FIGURE 45. Dominant substrate preference of spawning banded darter in the Zumbro and Yellow Medicine rivers (number of individuals=57, number of samples=25).

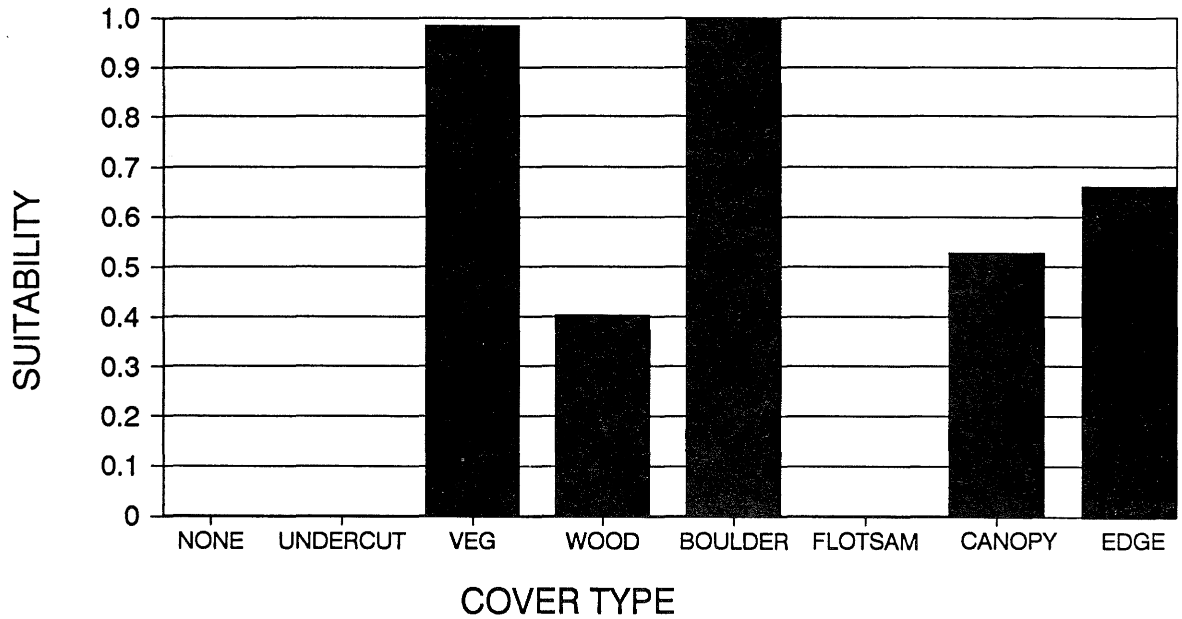


FIGURE 46. Cover preference of spawning banded darter in the Zumber and Yellow Medicine rivers (number of individuals=57, number of samples=25).

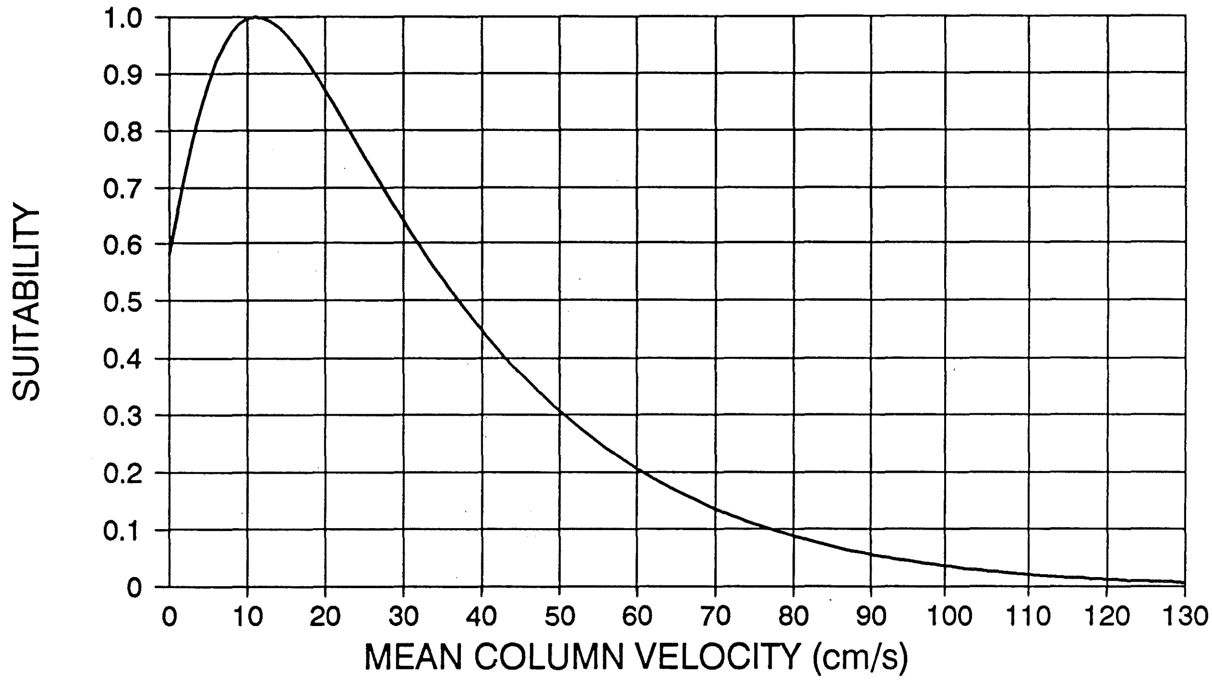


FIGURE 47. Velocity preference of young-of-the-year bluntnose minnow (<50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=431, number of samples=42).

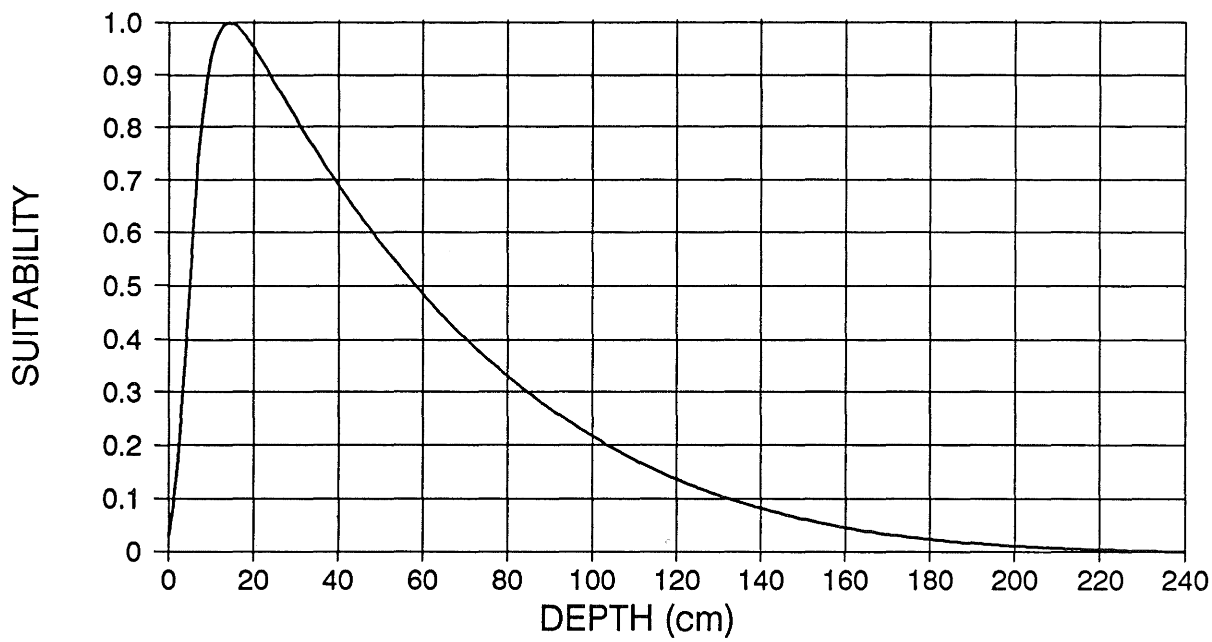


FIGURE 48. Depth preference of young-of-the-year bluntnose minnow (<50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=431, number of samples=42).

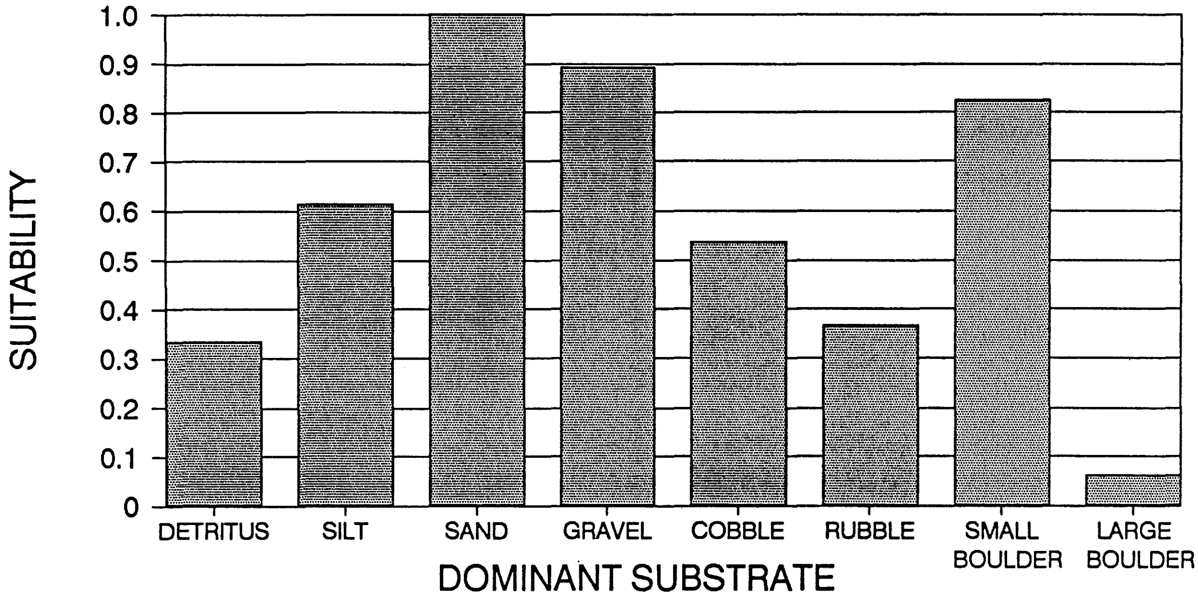


FIGURE 49. Dominant substrate preference of young-of-the-year bluntnose minnow (<50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals =431, number of samples=42).

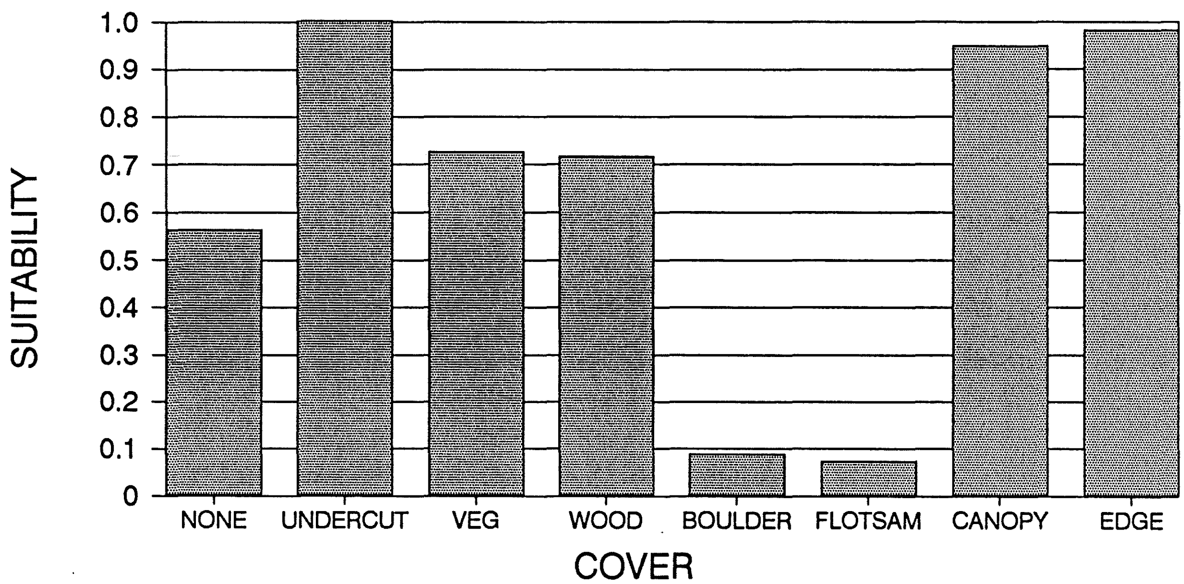


FIGURE 50. Cover preference of young-of-the-year bluntnose minnow (<50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=431, number of samples=42).

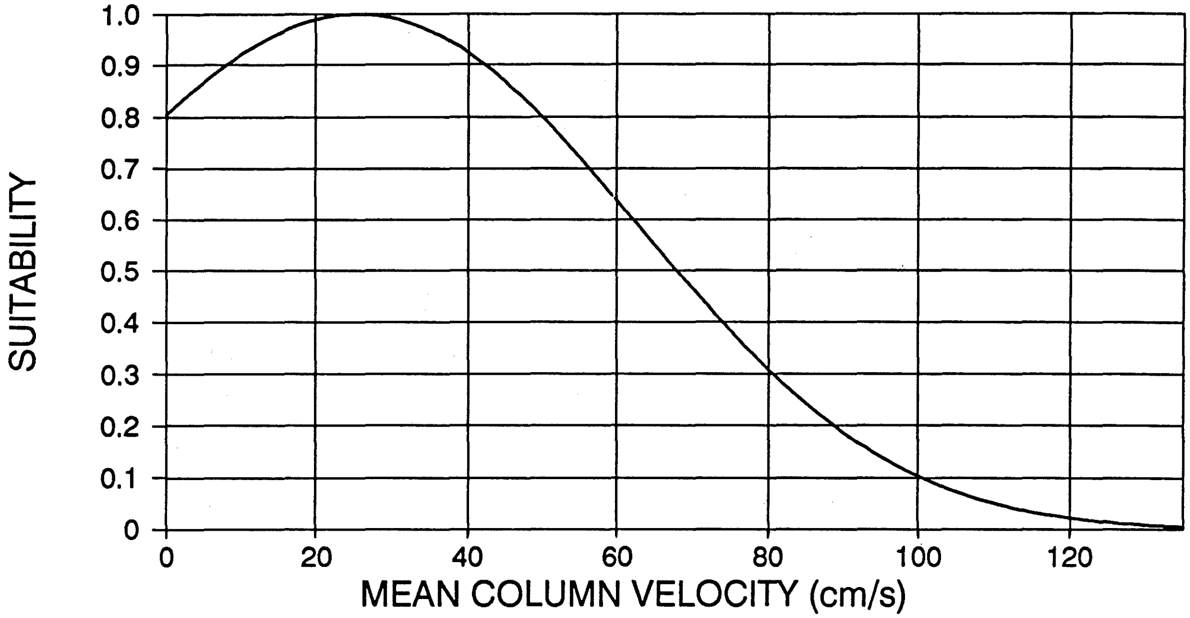


FIGURE 51. Velocity preference of adult bluntnose minnow (>or=50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=307, number of samples=68).

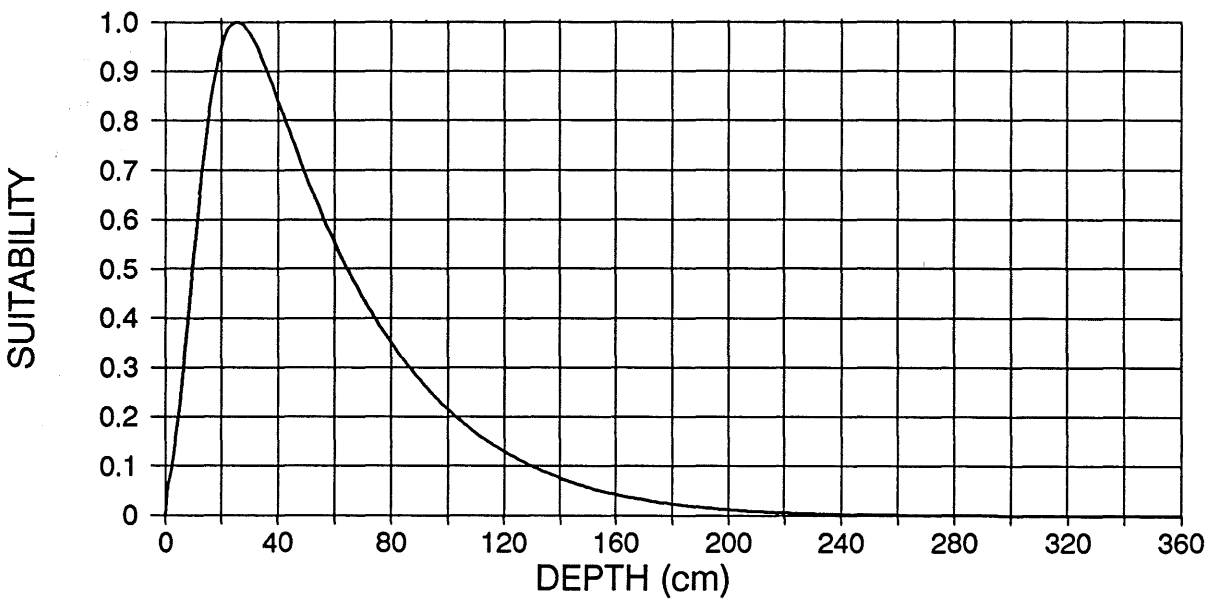


FIGURE 52. Depth preference of adult bluntnose minnow (>or=50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=307, number of samples=68).

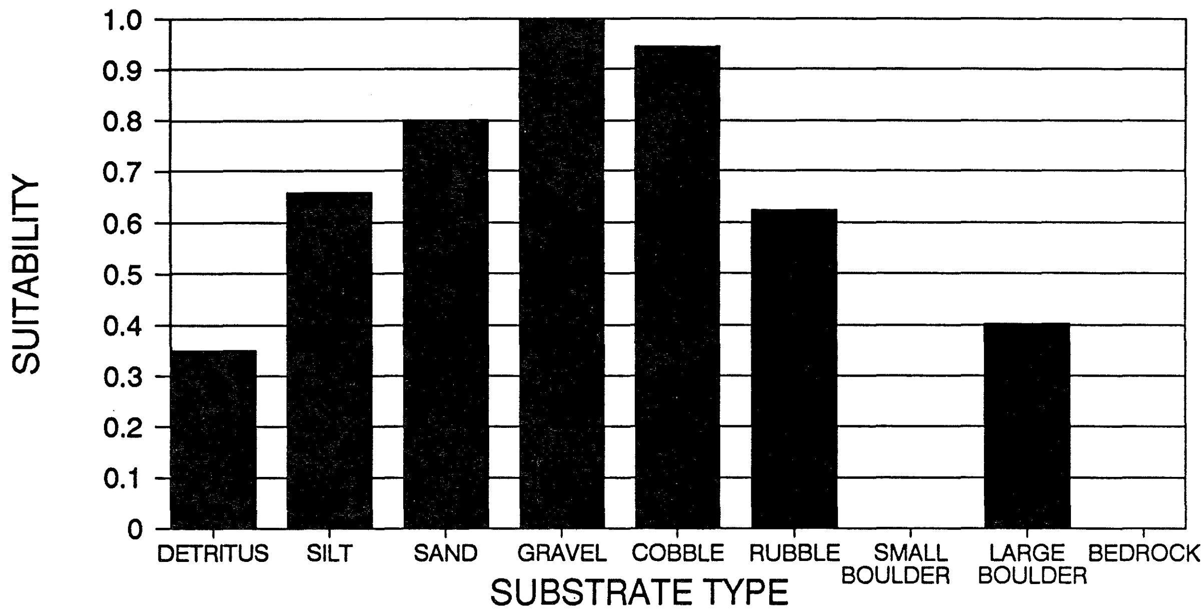


FIGURE 53. Dominant substrate preference of adult bluntnose minnow (>or=50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=307, number of samples=68).

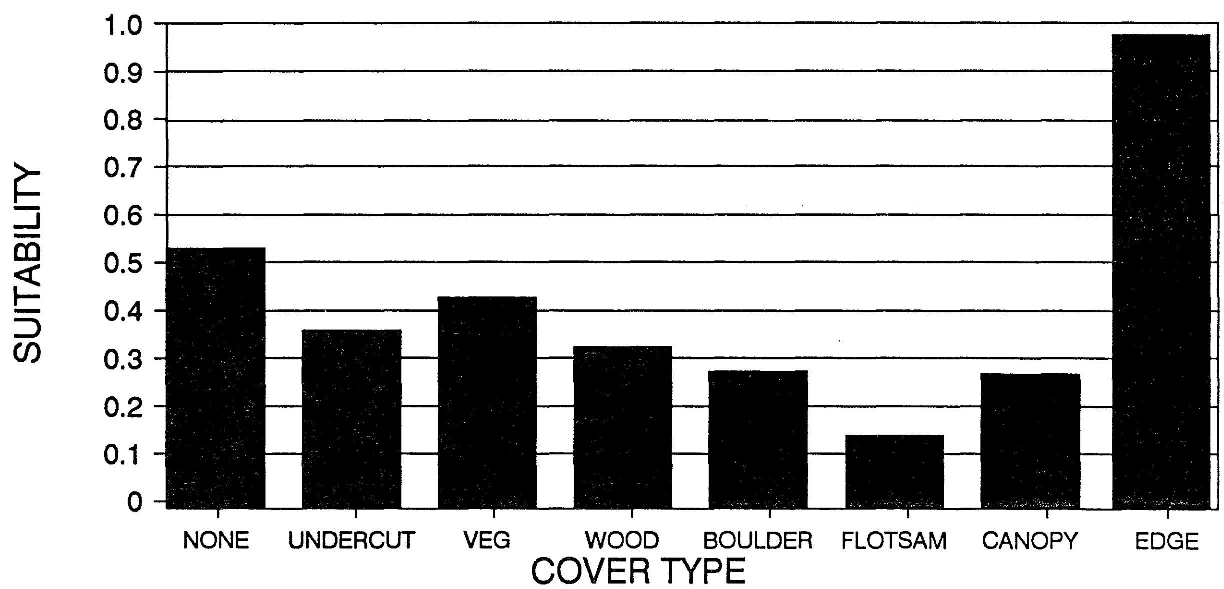


FIGURE 54. Cover preference of adult bluntnose minnow (>or=50 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=307, number of samples=68).

Central Stoneroller (*Campostoma anomalum*).

Central stonerollers were collected most frequently in shallow riffles with gravel substrates. Young-of-the-year, juveniles and adults used very similar habitat (Figs. 55-66). Adults and juveniles were most abundant in slow riffles while young-of-the-year had the highest densities in fast riffles. The velocity curves are based on unweighted (presence/absence) data and consequently do not directly correspond to density. Spawning occurred at temperatures ranging from 16-21°C in shallow riffle areas with gravel substrates.

Emerald Shiner (*Notropis atherinoides*).

Both young of the year and adult emerald shiners belong to the shallow pool guild. Emerald shiners are facultative riverine fishes and do well in large lakes as well as streams. Their importance as forage fishes in many of Minnesota's streams warrant their inclusion here.

Young-of-the-year emerald shiners were found in very shallow pool and channel margin areas. Areas only a few centimeters deep which had an abundance of matted algae often had high densities of emerald shiner fry (Figs. 67 - 70). Adults are relatively ubiquitous in their habitat preferences and were found in a variety of habitat types (Figs. 71-74).

Log Perch (*Percina caprodes*).

Log perch were found in the Zumbro and Snake rivers in riffles and runs (Figs. 75-78). They are found in all three drainages in Minnesota and are one of the more abundant riffle species in the Lake Superior Drainage.

Spawning condition log perch were collected in fast runs (mean velocity = 88 cm/s, mean depth = 60.3 cm) with gravel substrates at water temperatures between 17 and 21.5°C. Since only 8 spawning condition log perch were collected, reliable suitability curves could not be developed for this life stage.

Longnose Dace (*Rhinichthys cataractae*).

Longnose dace are an important forage species in many of Minnesota' streams and is found in all three of its drainages.

Spawning longnose dace (25) were collected in riffles

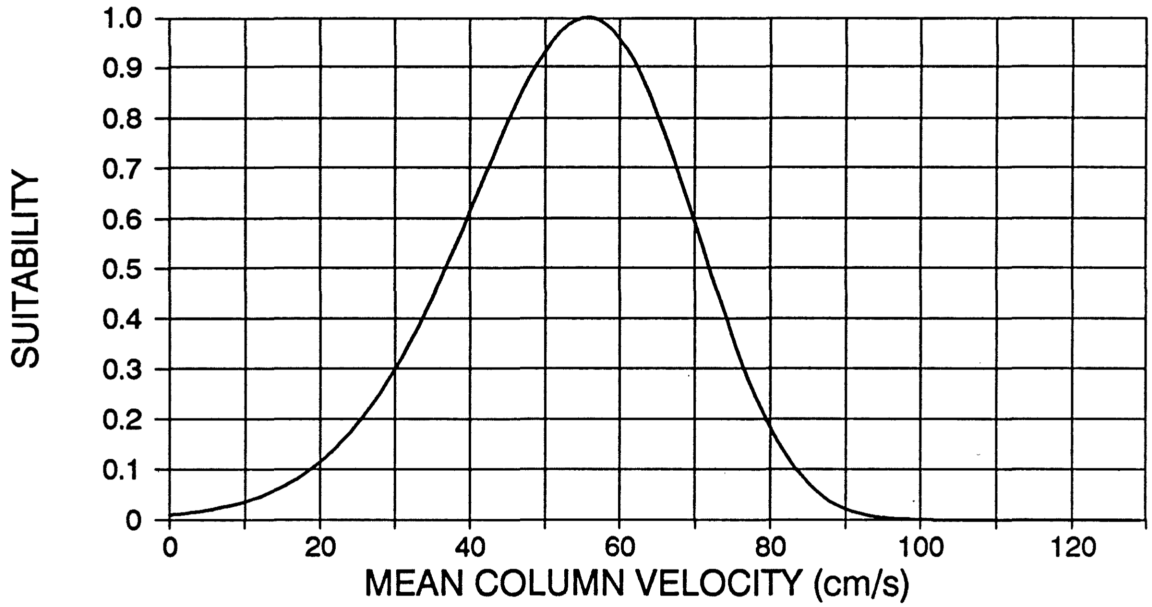


FIGURE 55. Velocity preference of young-of-the-year central stoneroller (<65 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1179, number of samples=37).

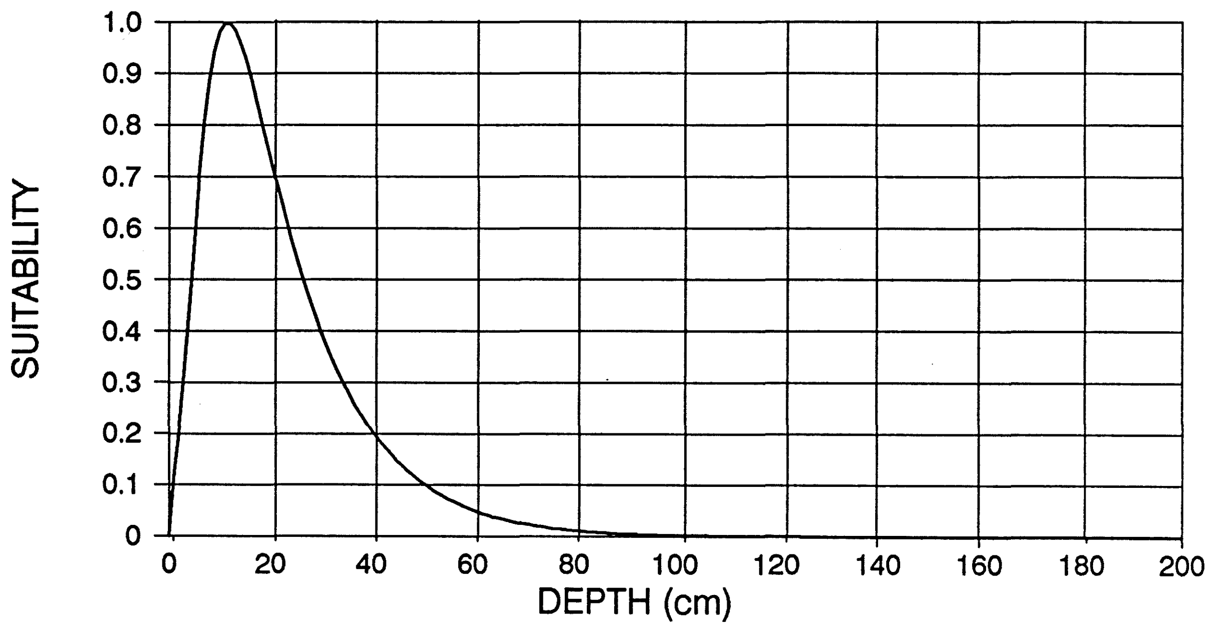


FIGURE 56. Depth preference of young-of-the-year central stoneroller (<65 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1179, number of samples=37).

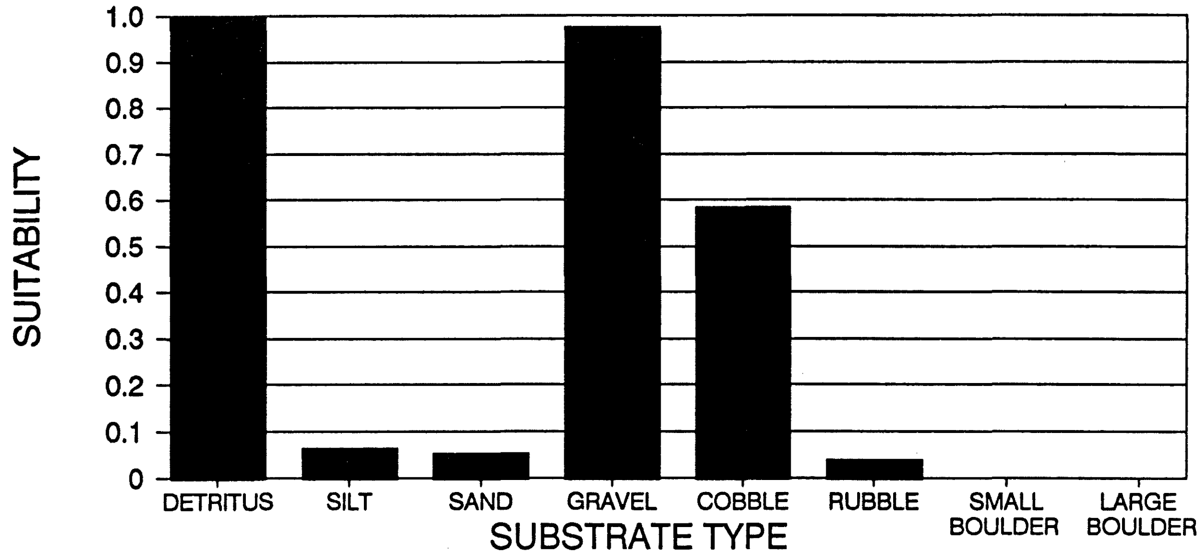


FIGURE 57. Dominant substrate preference of young-of-the-year central stoneroller (<65 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1179, number of samples=37).

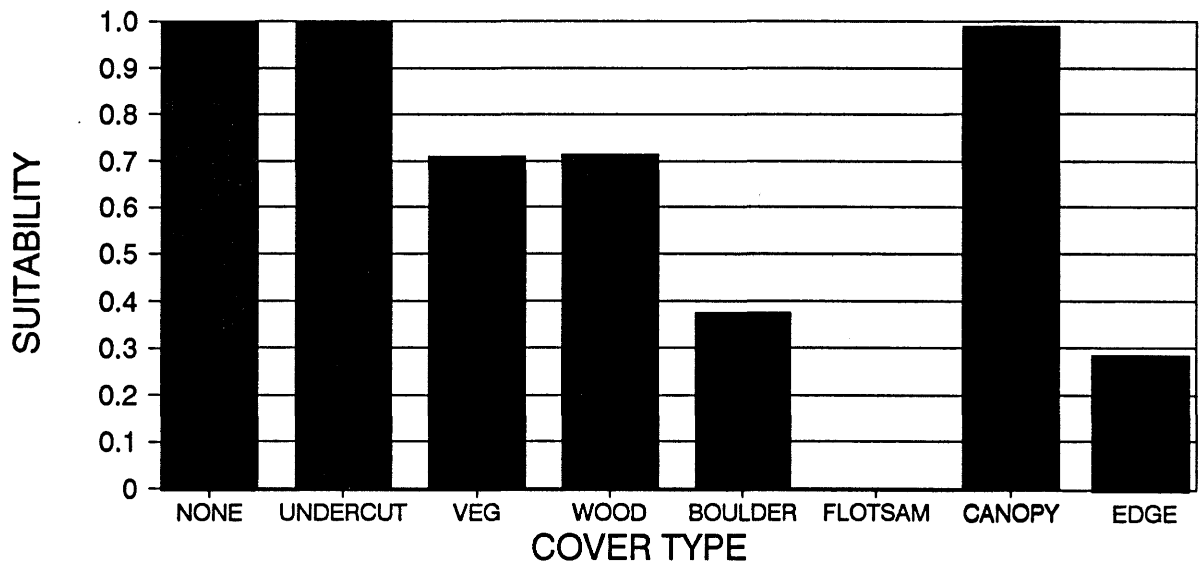


FIGURE 58. Cover preference of young-of-the-year central stoneroller (<65 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1179, number of samples=37).

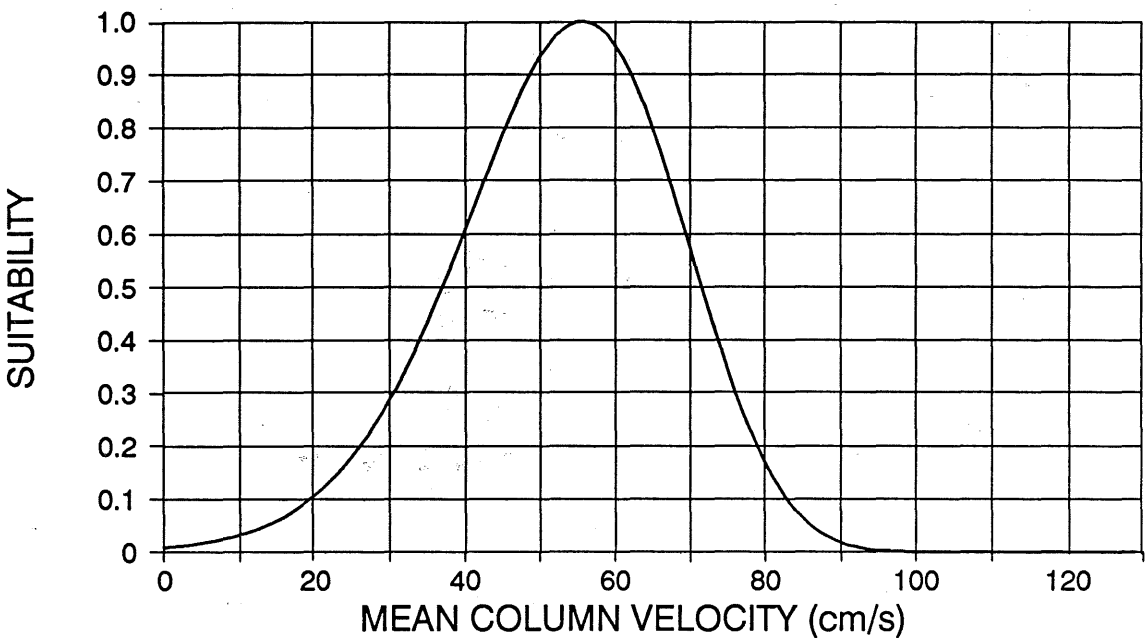


FIGURE 59. Velocity preference of juvenile central stoneroller (65-78 mm) in the Zumbro and Yellow Medicine rivers(number of individuals=895, number of samples=70).

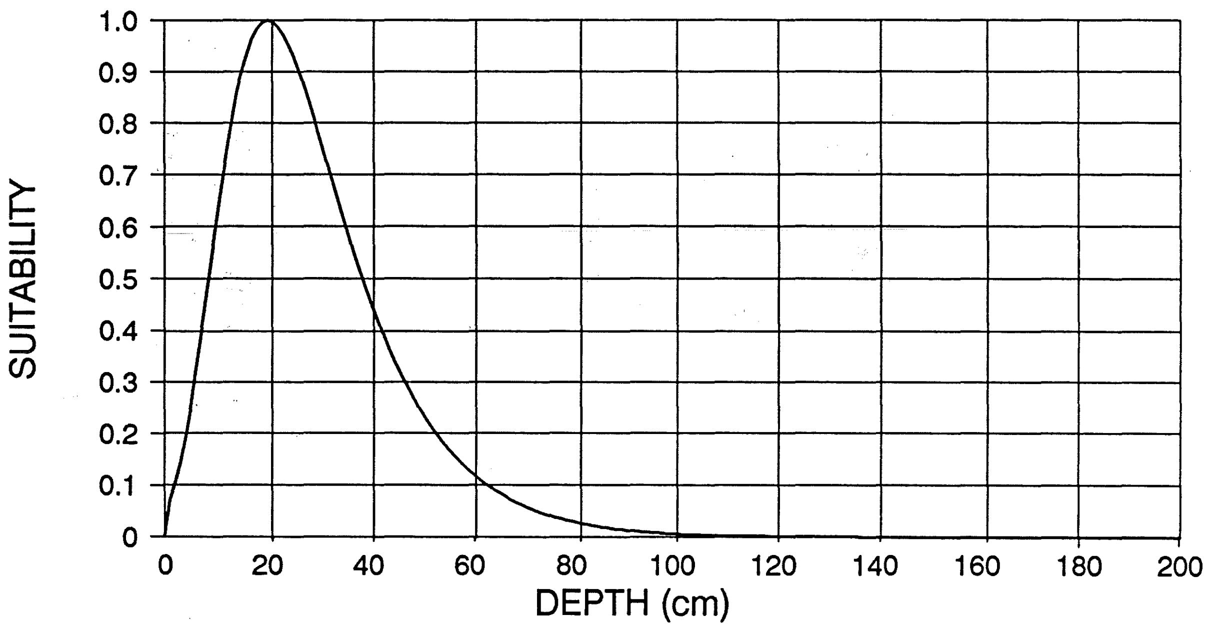


FIGURE 60. Depth preference of juvenile central stoneroller (65-78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=895, number of samples=70).

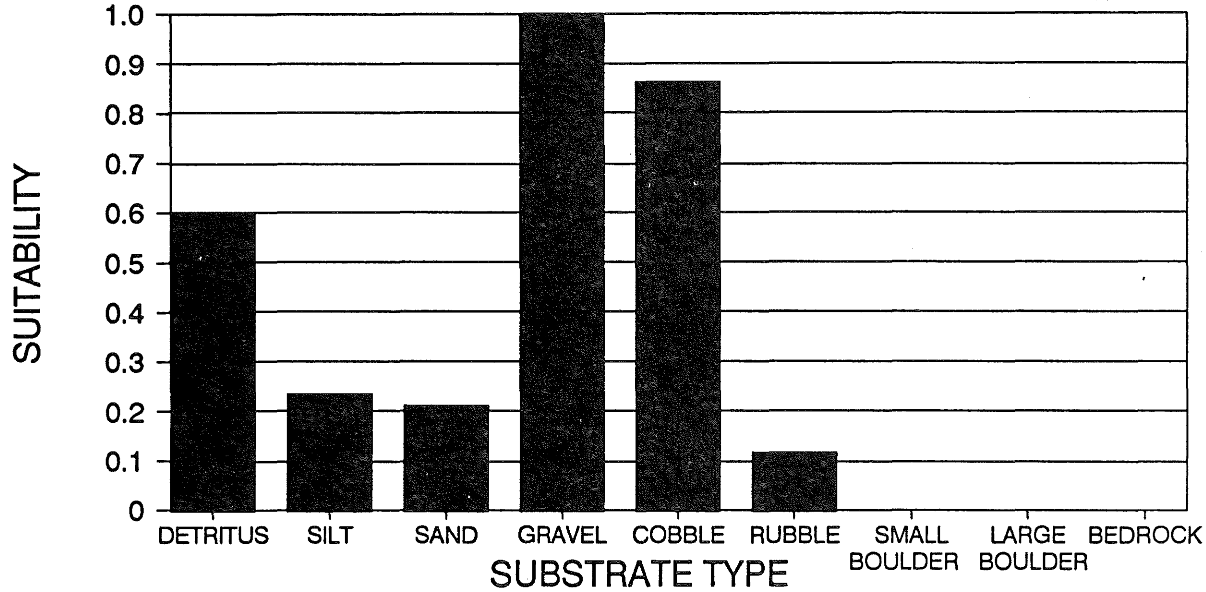


FIGURE 61. Dominant substrate preference of juvenile central stoneroller (65-78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=895, number of samples=70).

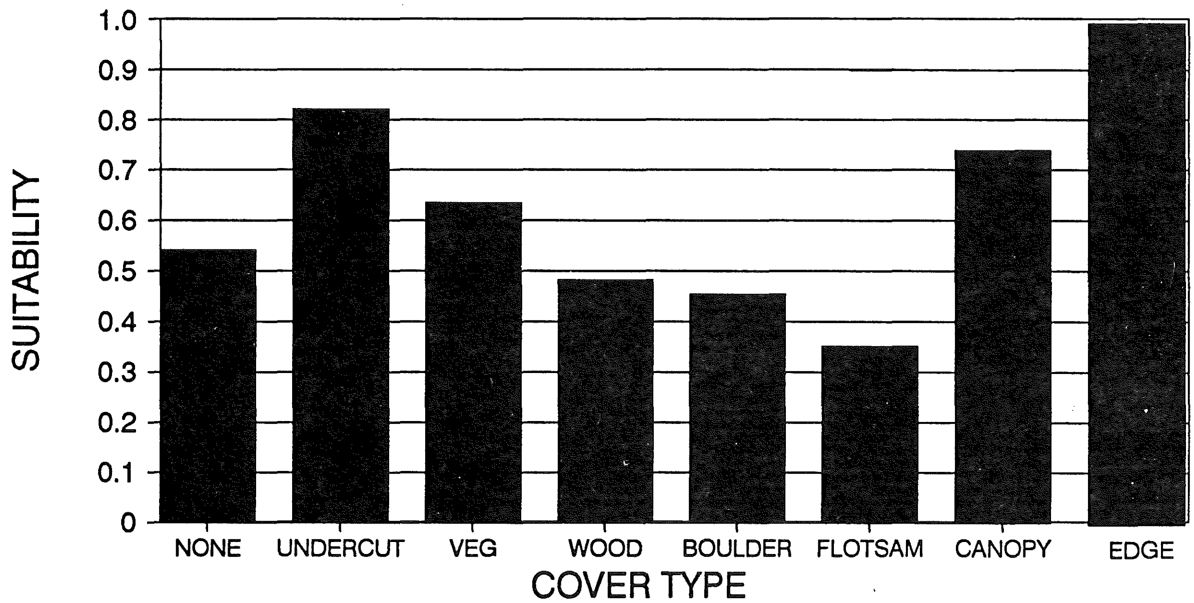


FIGURE 62. Cover preference of juvenile central stoneroller (65-78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=895, number of samples=70).

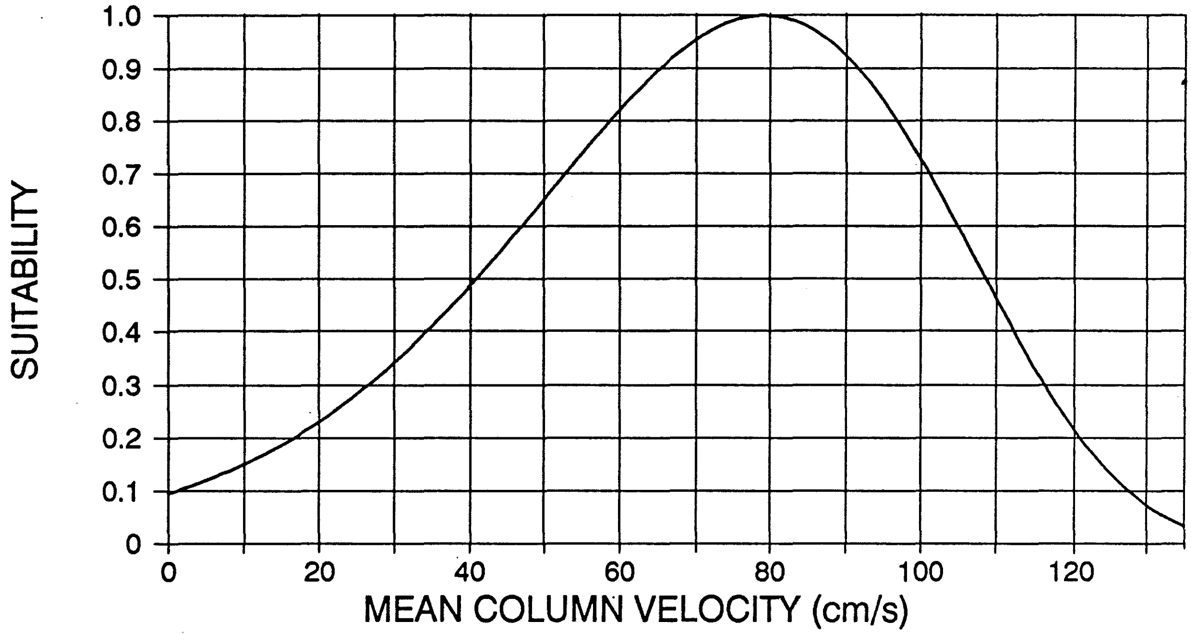


FIGURE 63. Velocity preference of adult central stoneroller (>or=78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1979, number of samples=105).

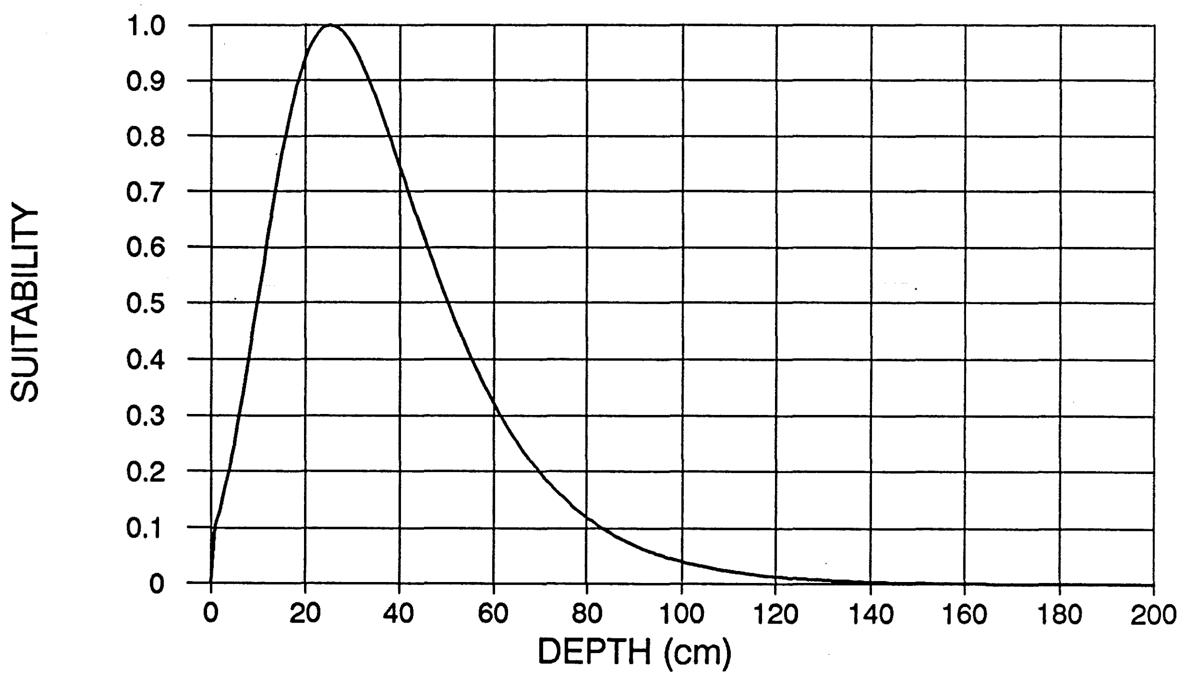


FIGURE 64. Depth preference of adult central stoneroller (>or=78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1979, number of samples=105).

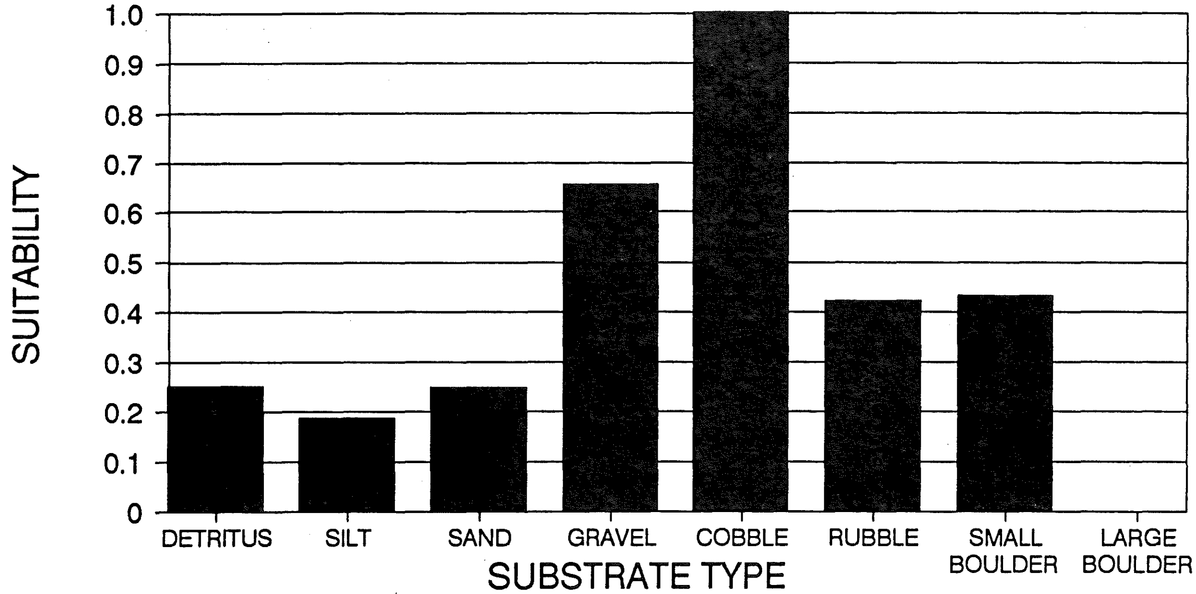


FIGURE 65. Dominant substrate preference of adult central stoneroller (>or=78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals= 1979, number of samples=105).

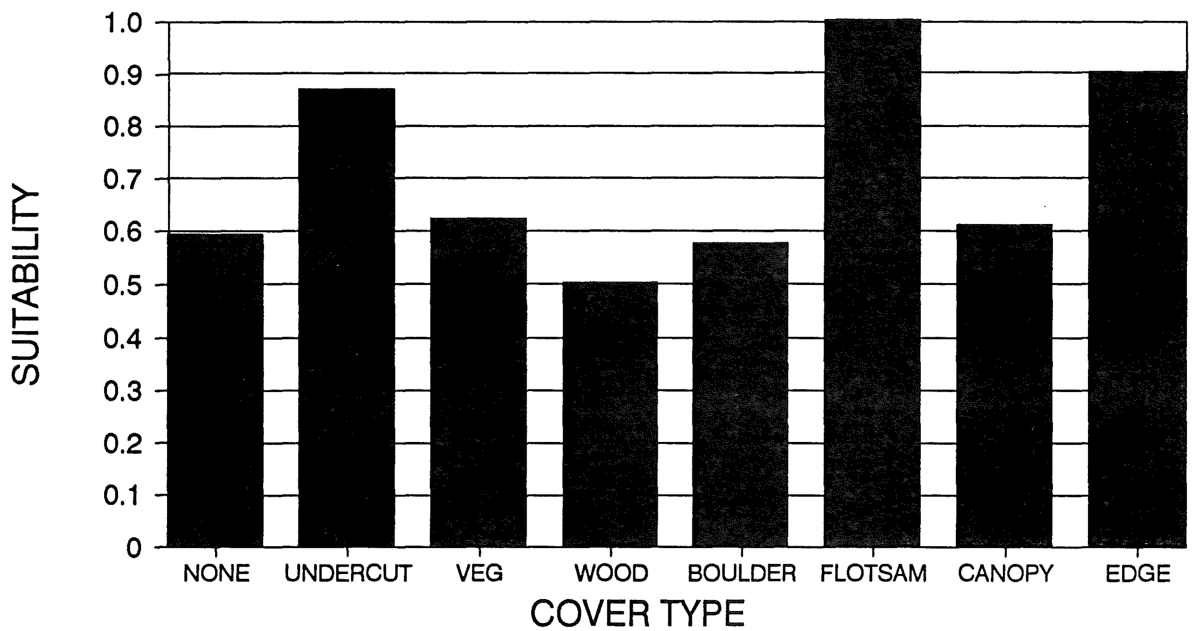


FIGURE 66. Cover preference of adult central stoneroller (>or=78 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1979, number of samples=105).

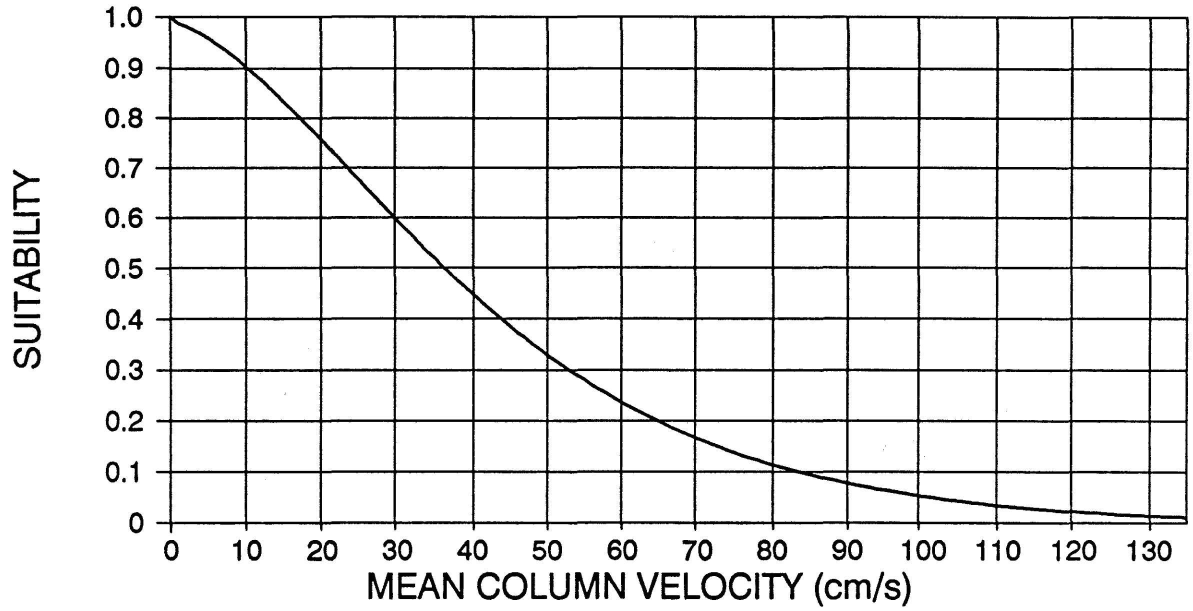


FIGURE 67. Velocity preference of young-of-the-year emerald shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=842, number of samples=64).

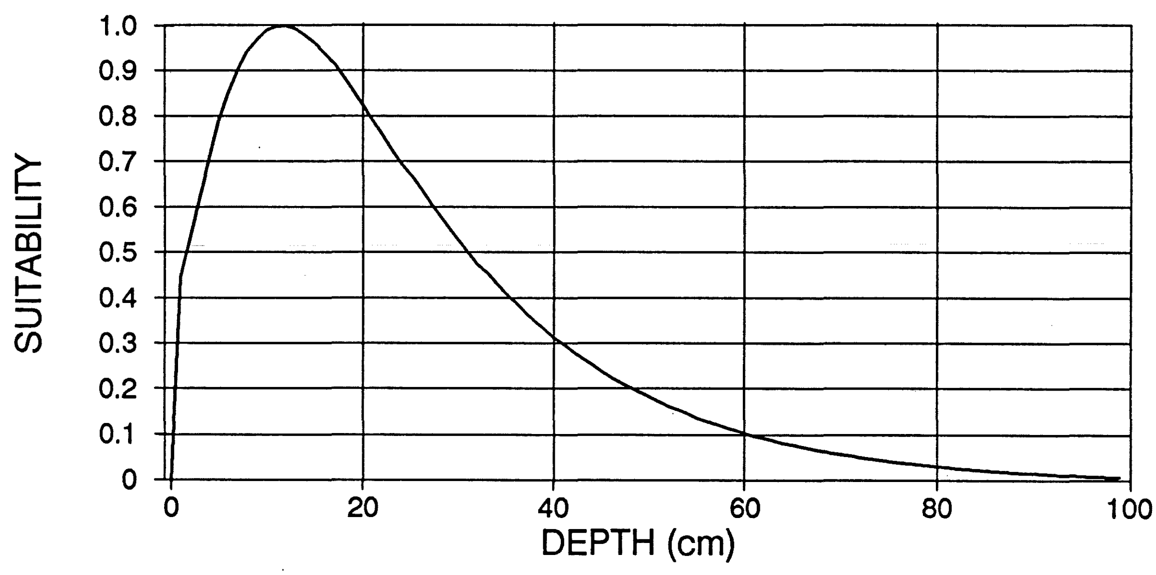


FIGURE 68. Depth preference of young-of-the year emerald shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=842, number of samples=64).

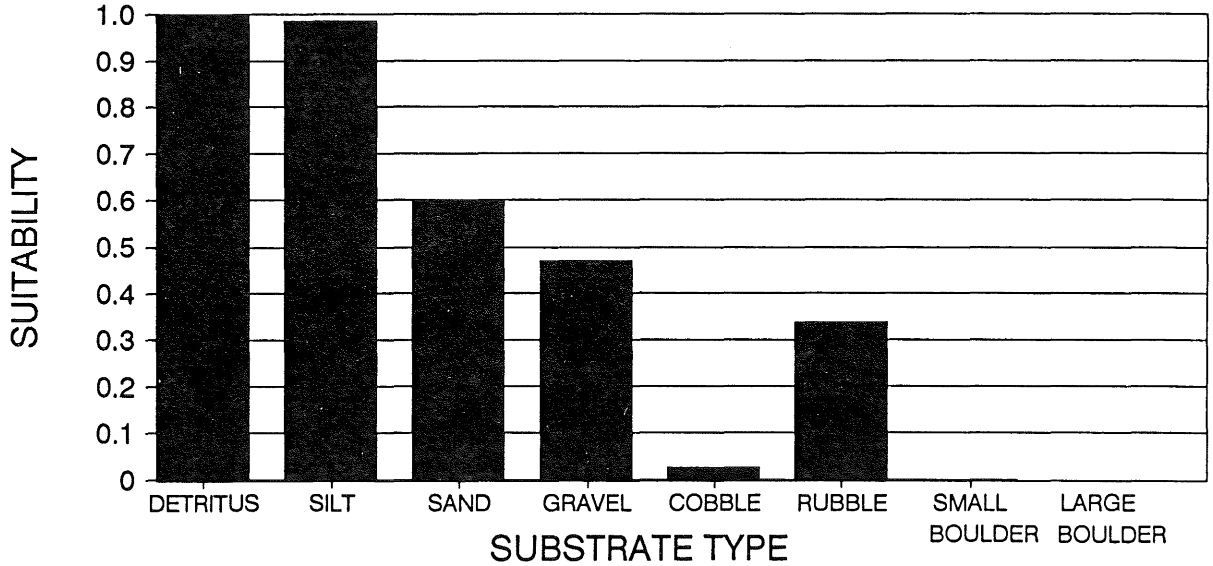


FIGURE 69. Dominant substrate preference of young-of-the-year emerald shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=842, number of samples=64).

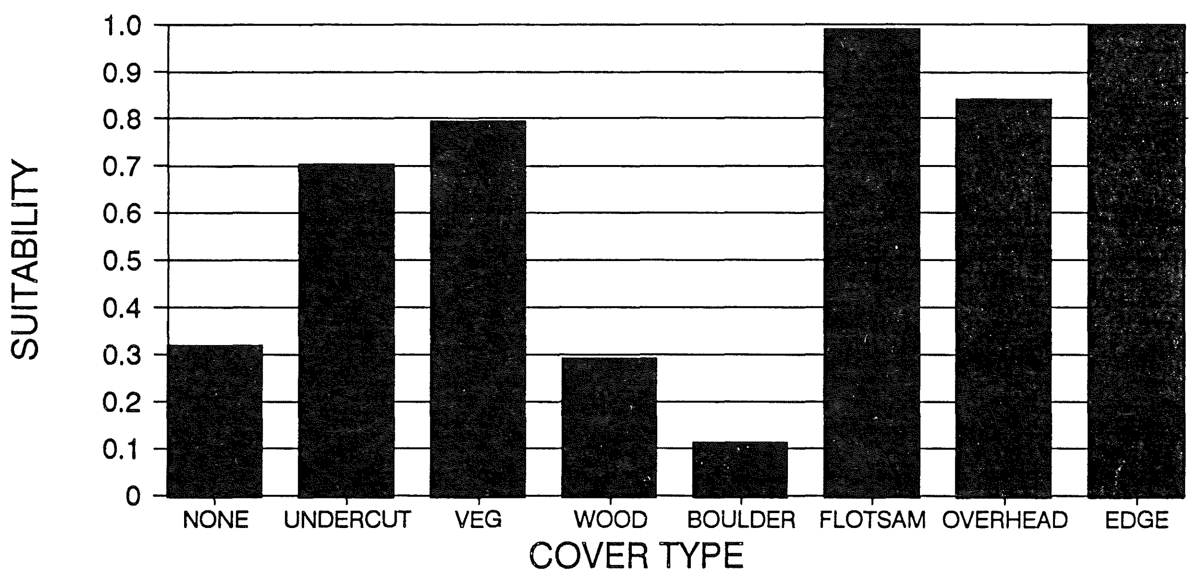


FIGURE 70. Cover preference of young-of-the-year emerald shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=842, number of samples= 64).

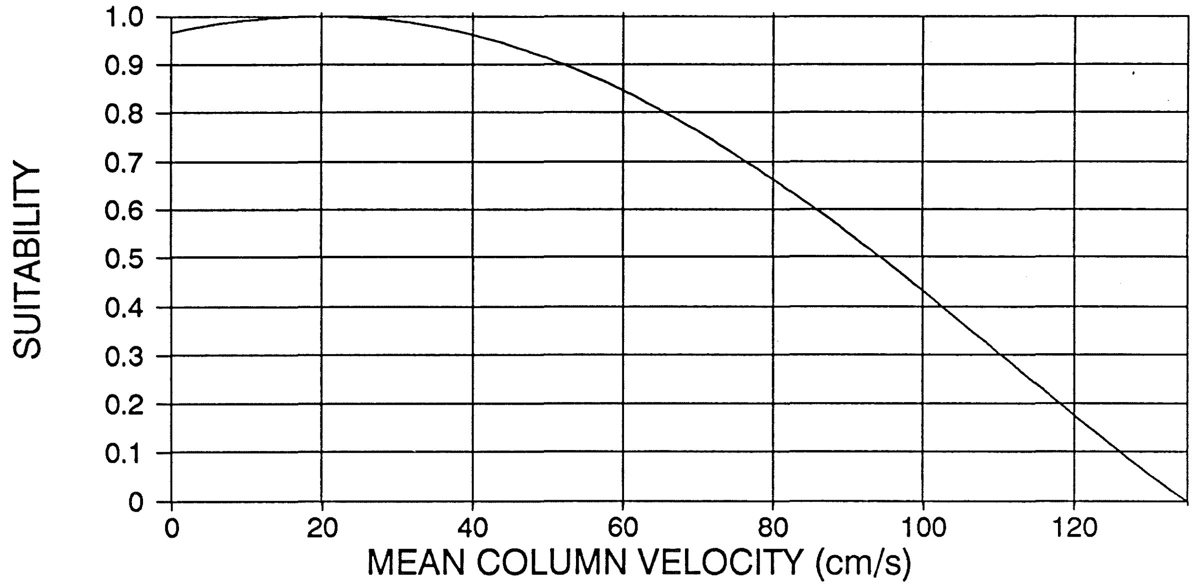


FIGURE 71. Velocity preference of adult emerald shiner (>or=40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=4065, number of samples =190).

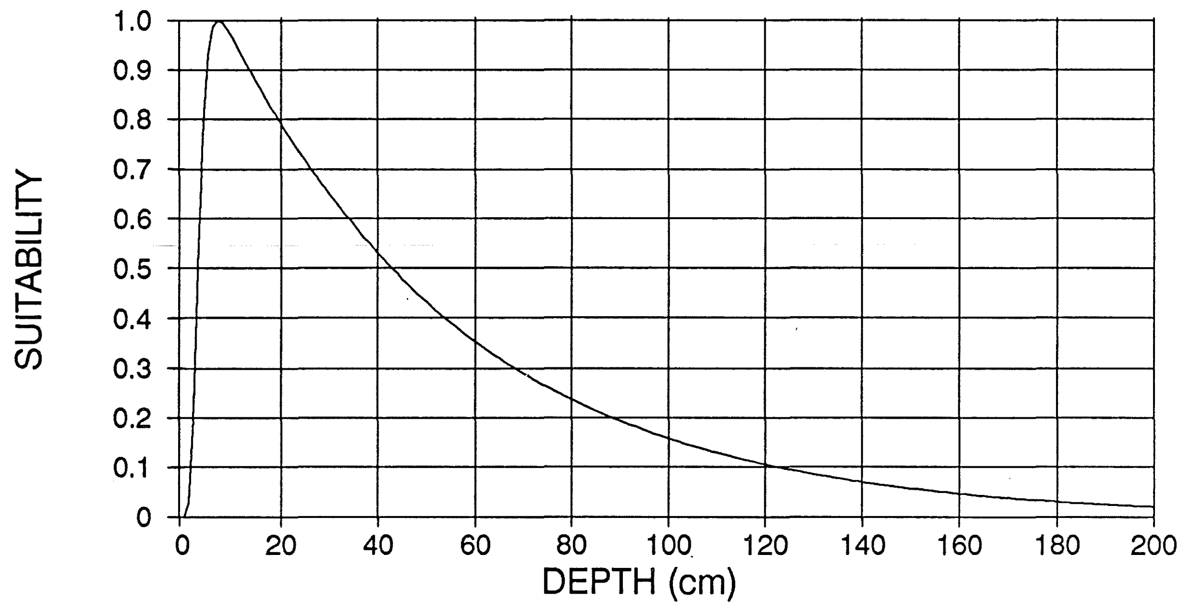


FIGURE 72. Depth preference of adult emerald shiner (>or=40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=4065, number of samples =190).

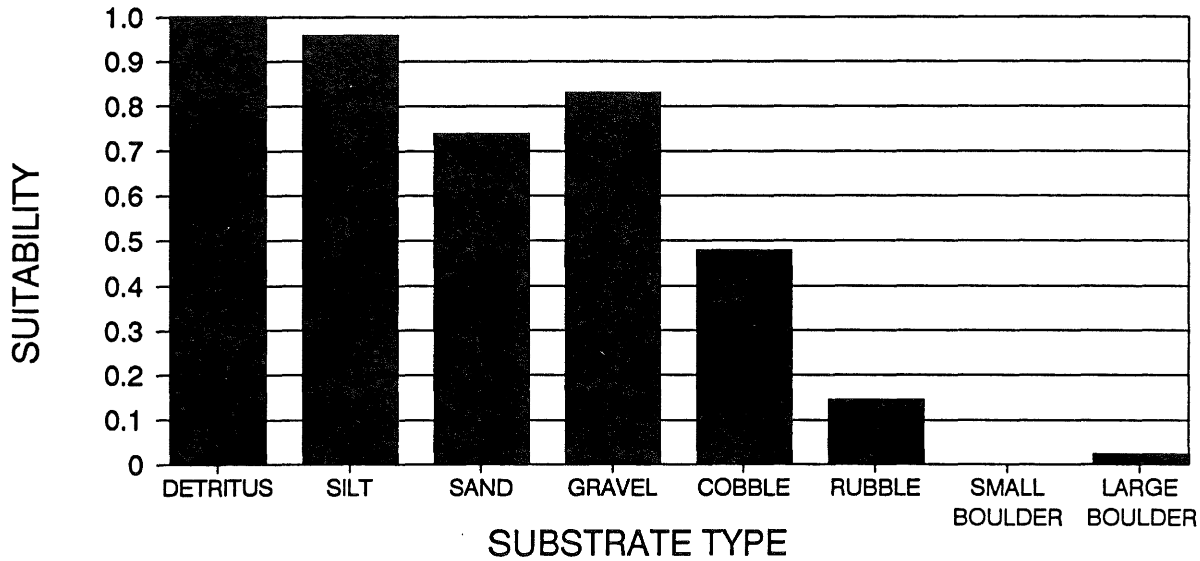


FIGURE 73. Dominant substrate preference of adult emerald shiner (>or=40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=4065, number of samples=190).

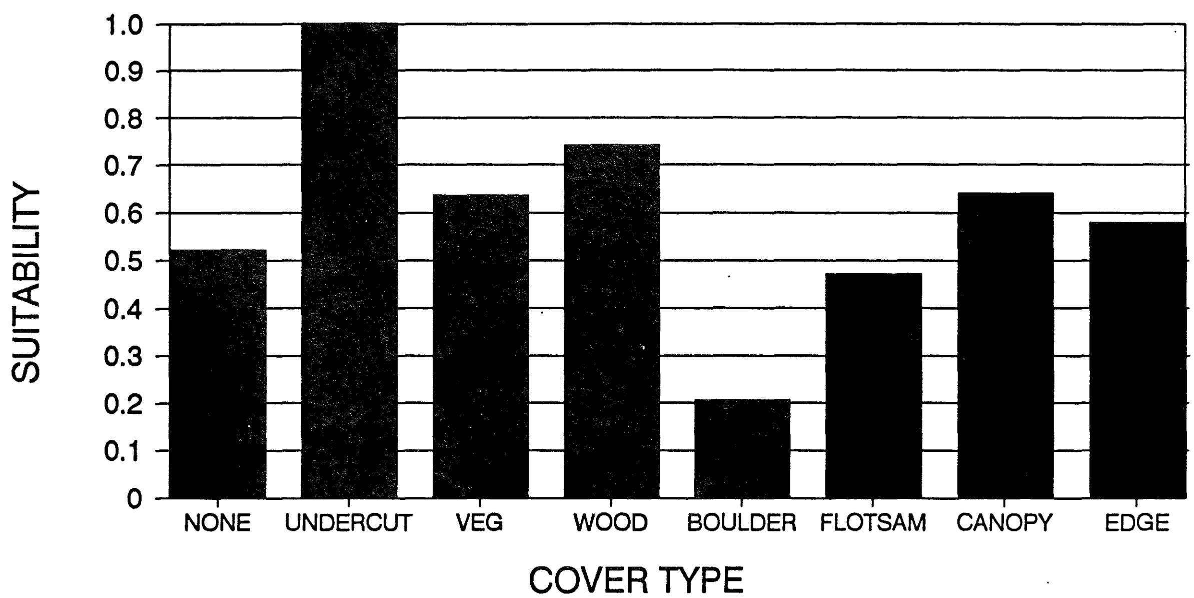


FIGURE 74. Cover preference of adult emerald shiner (>or=40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=4065, number of samples=190).

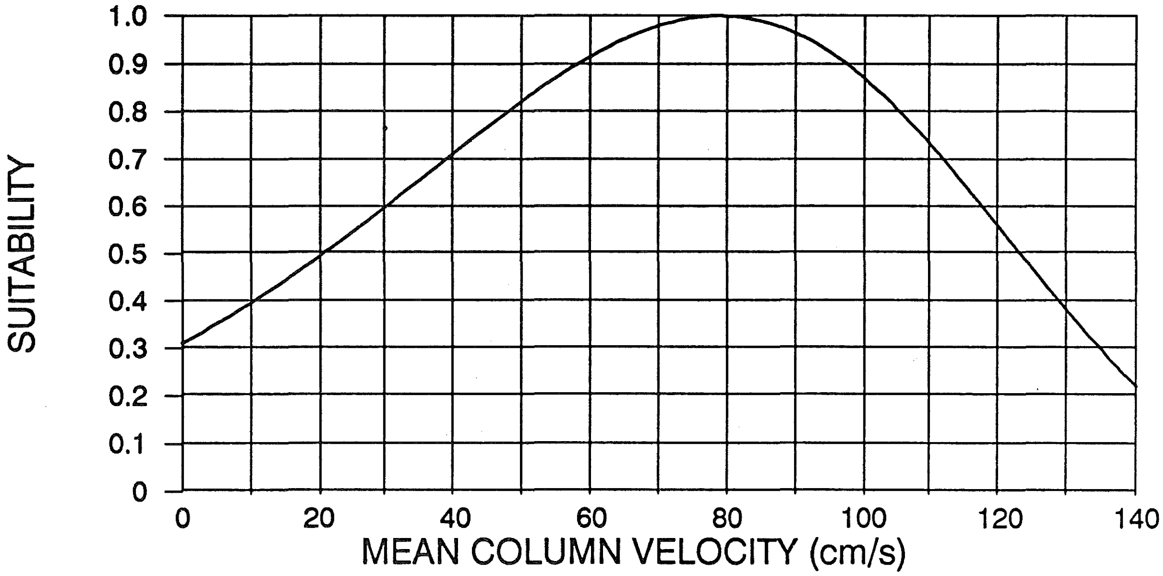


FIGURE 75. Velocity preference of adult log perch (>or=60 mm) in the Zumbro and Snake rivers (number of individuals=736, number of samples=177).

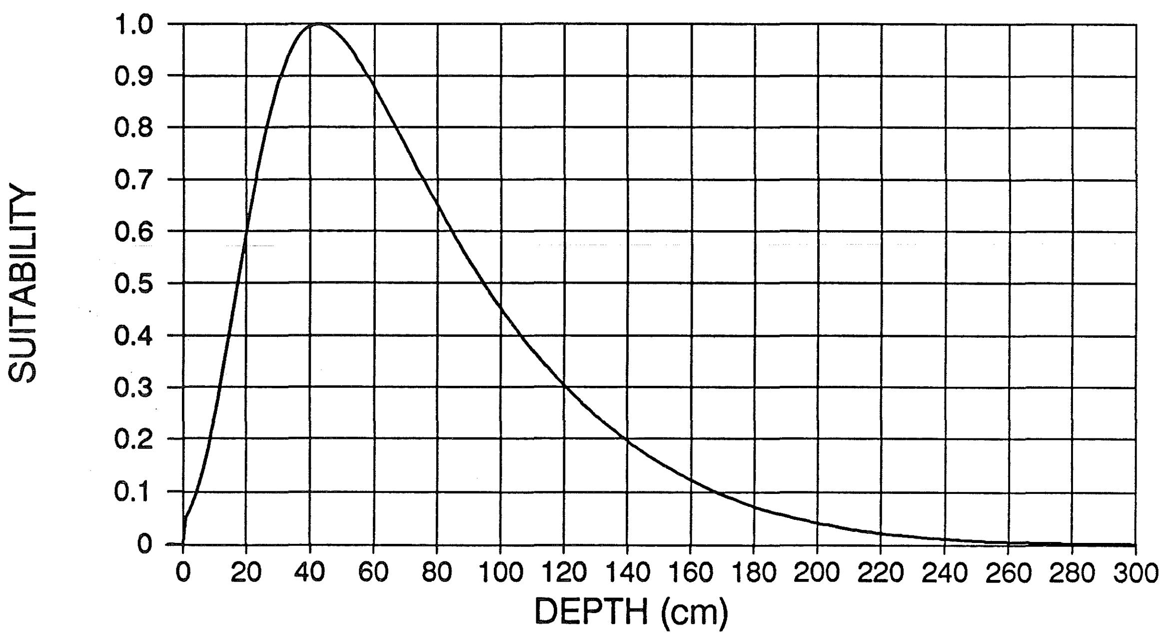


FIGURE 76. Depth preference of adult log perch (>or=60 mm) in the Zumbro and Snake rivers (number of individuals=736, number of samples=177).

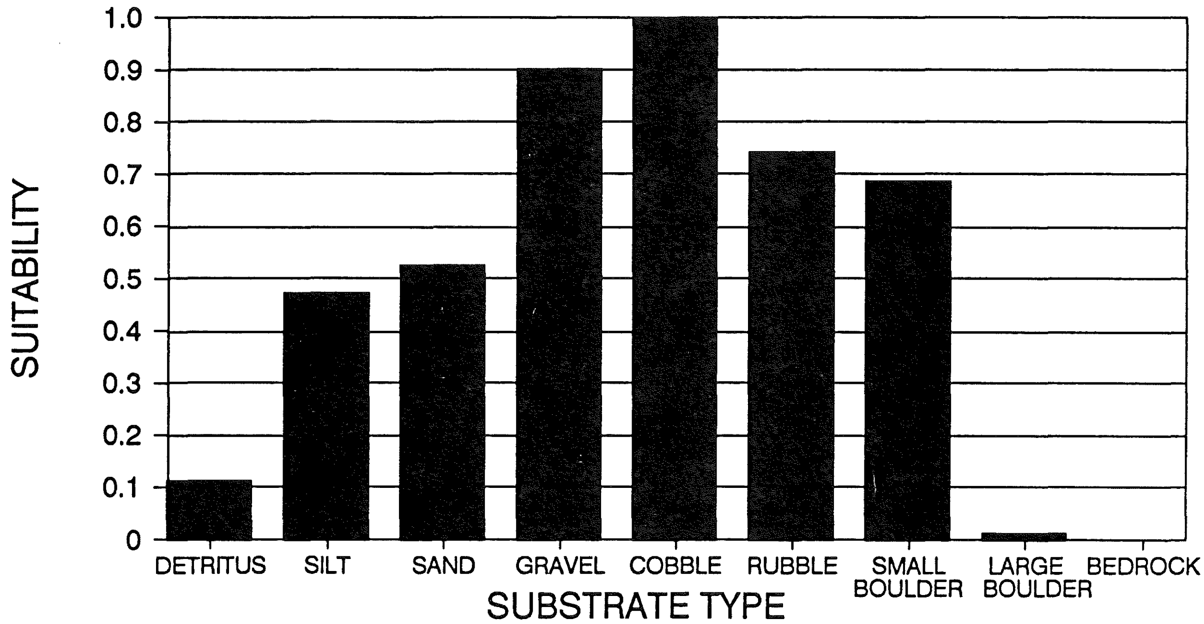


FIGURE 77. Dominant substrate preference of adult log perch (>or=60 mm) in the Zumbro and Snake rivers (number of individuals=736, number of samples=177).

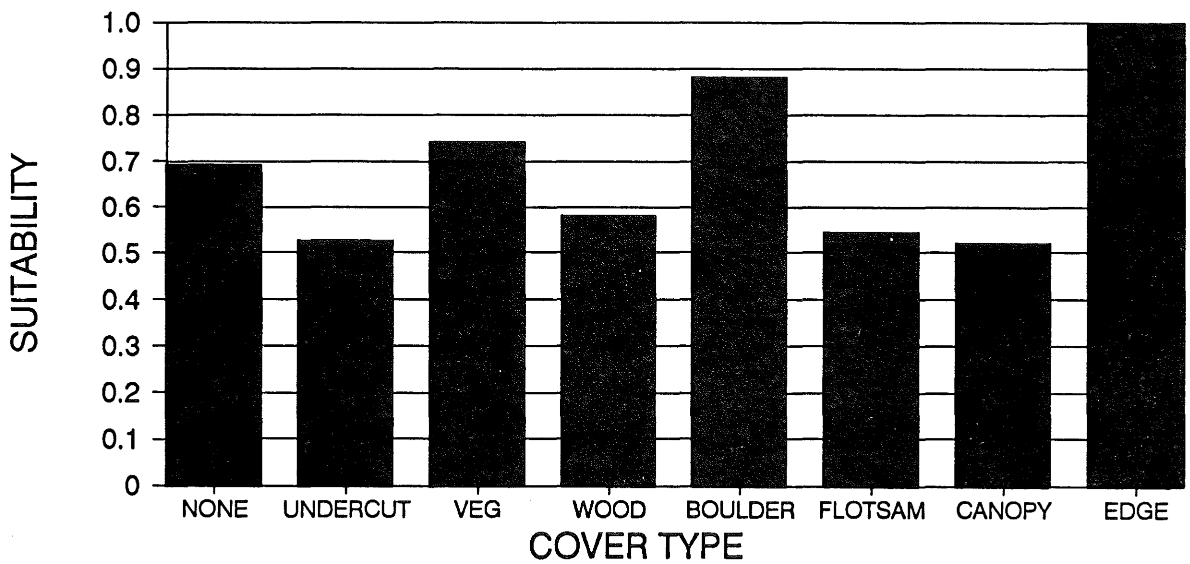


FIGURE 78. Cover preference of adult log perch (>or=60 mm) in the Zumbro and Snake rivers (number of individuals=736, number of samples=177).

(mean velocity = 49 cm/s, mean depth = 20 cm) with gravel bottoms at temperatures ranging from 17-21°C.

Young-of-the-year were collected in fast riffles (mean velocity = 75 cm/s) in the Zumbro river and in shallow pools (mean velocity = 5 cm/s) in the Snake river (Figs. 79-82). The different habitat use in these two streams may be partially due to the low flows during the 1988 sampling period in the Snake River.

Adult longnose dace were collected in fast riffles over gravel or cobble substrates with attached filamentous algae (Figs. 83-86).

Northern Hog Sucker (*Hypentellium nigricans*).

The northern hog sucker was found in all three study streams. It is found throughout most of the tributaries of the Mississippi River south of Hastings but has disappeared from some of the more polluted streams in Minnesota (Eddy and Underhill 1976). Juveniles were found in riffles with gravel substrates (Figs. 87-90). Adults preferred fast run areas with gravel or cobble substrates (Figs. 91-94). Young-of-the-year were found in shallow pools and riffles (mean velocity = 24 cm/s; mean depth = 17 cm) with gravel substrates. Spawning northern hog suckers were sampled in riffles (mean velocity = 64 cm/s; mean depth = 47 cm) with gravel substrates at water temperatures of 16-22.5°C.

Sand Shiner (*Notropis stramineus*)

Sand shiners were common in all three study streams and are found throughout Minnesota. Young-of-the-year sand shiners were most abundant in shallow pools with silt substrates (Figs. 95-98). Adults were found in shallow riffles or pools with sand or gravel substrates (Figs. 99-102). Little is known about the spawning behavior of sand shiners. We collected spawning sand shiners (26) in riffles (mean velocity = 44 cm/s, mean depth = 29 cm) with gravel substrates.

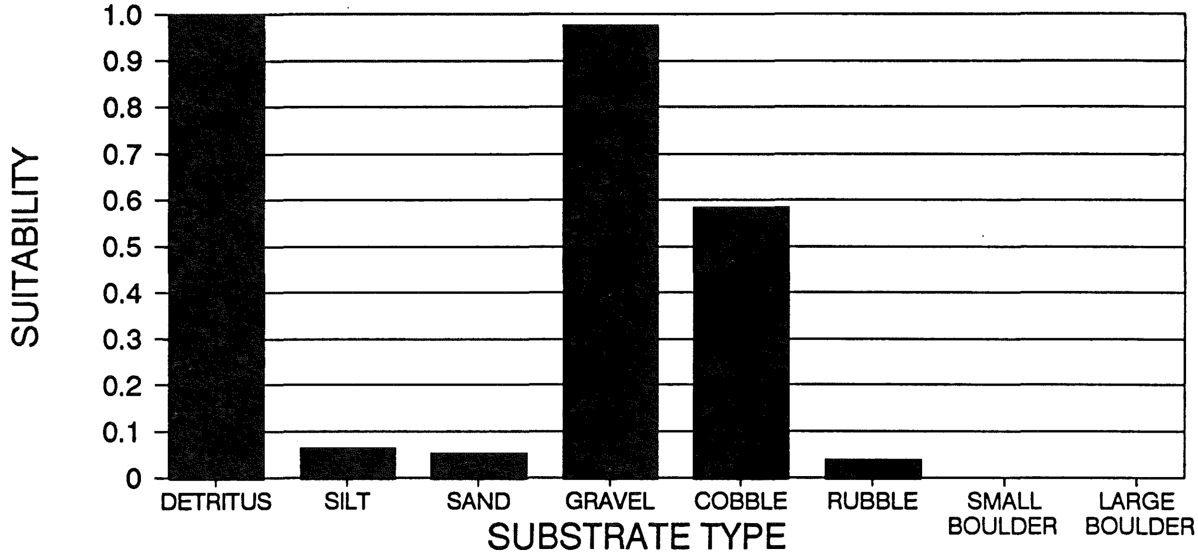


FIGURE 57. Dominant substrate preference of young-of-the-year central stoneroller (<65 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1179, number of samples=37).

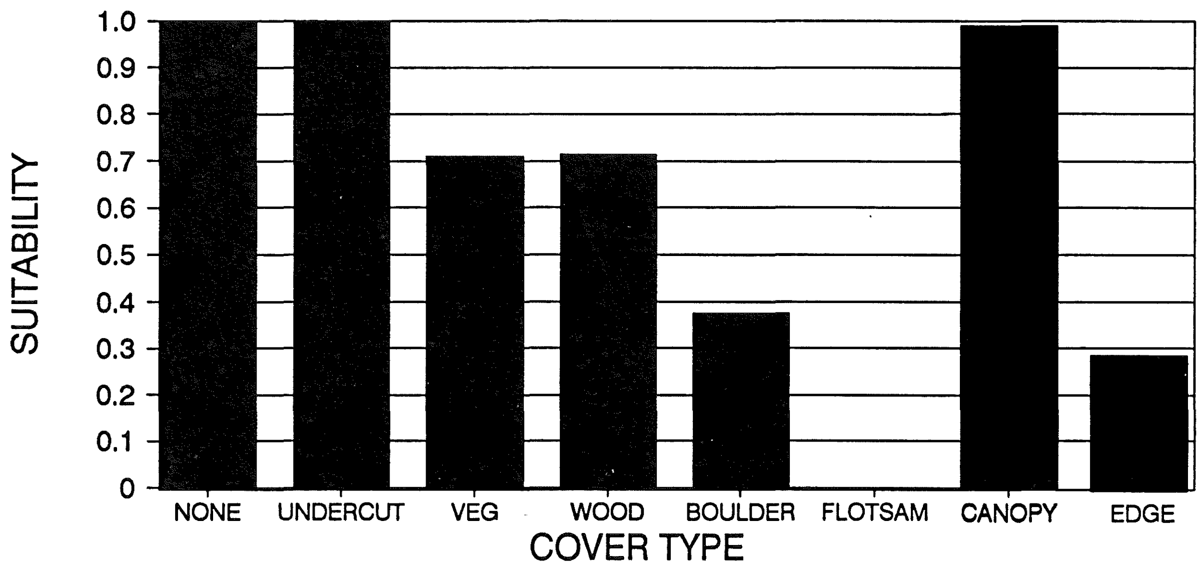


FIGURE 58. Cover preference of young-of-the-year central stoneroller (<65 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1179, number of samples=37).

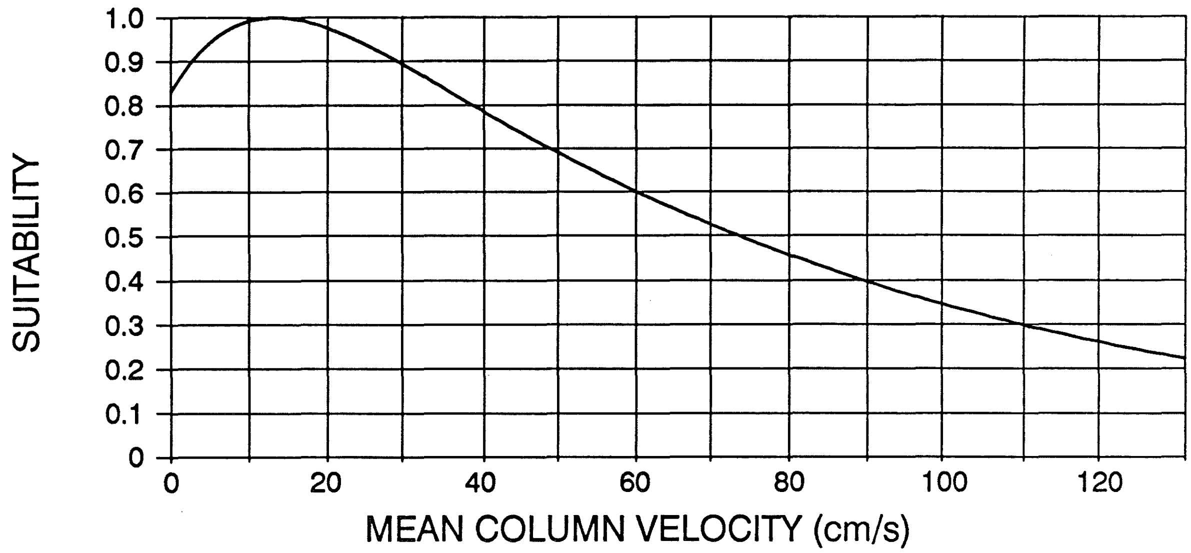


FIGURE 79. Velocity preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

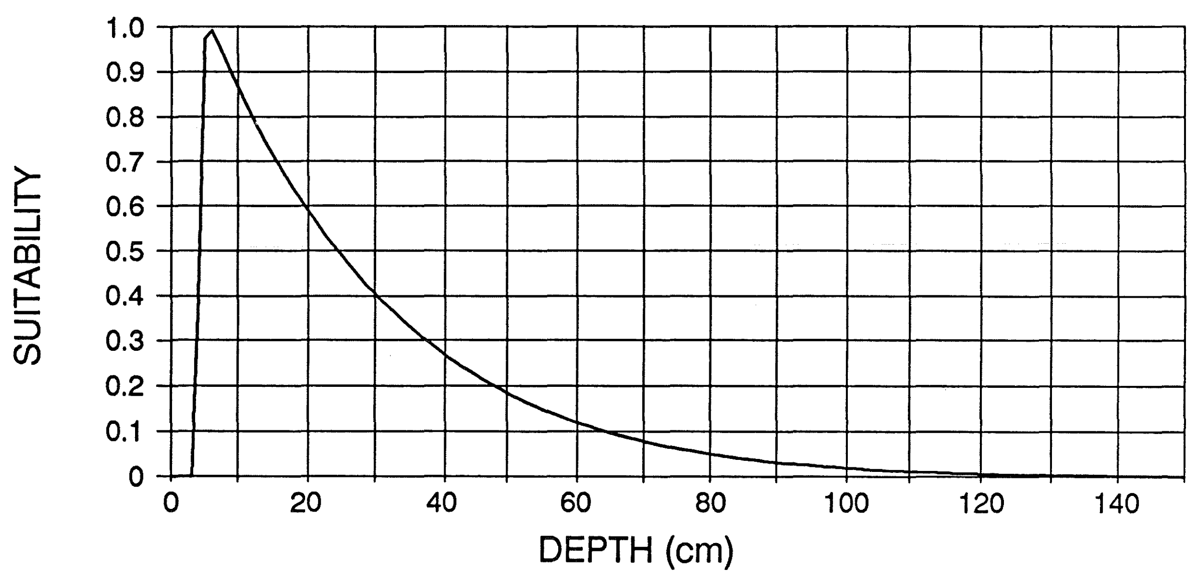


FIGURE 80. Depth preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

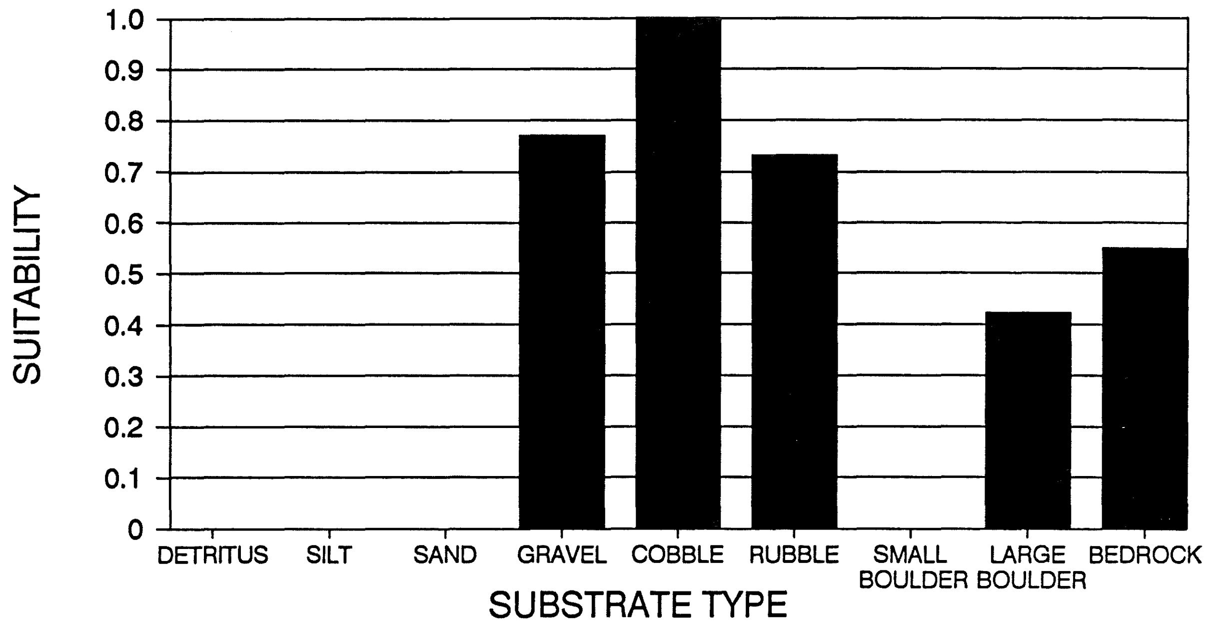


FIGURE 81. Dominant substrate preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

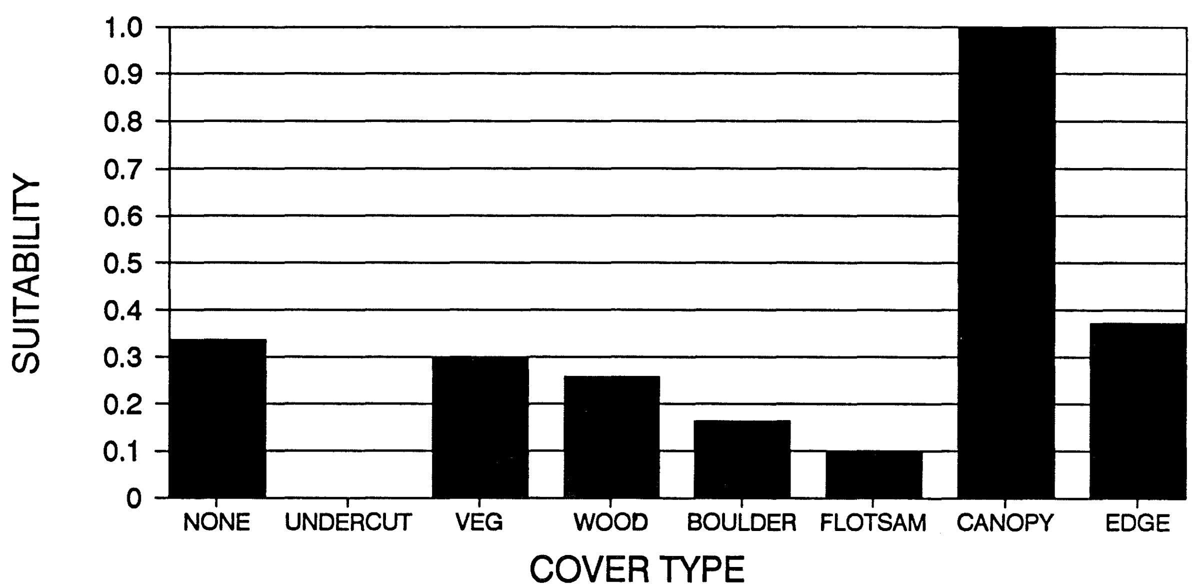


FIGURE 82. Cover preference of young-of-the-year longnose dace (<50 mm) in the Snake and Zumbro rivers (number of individuals=341, number of samples=27).

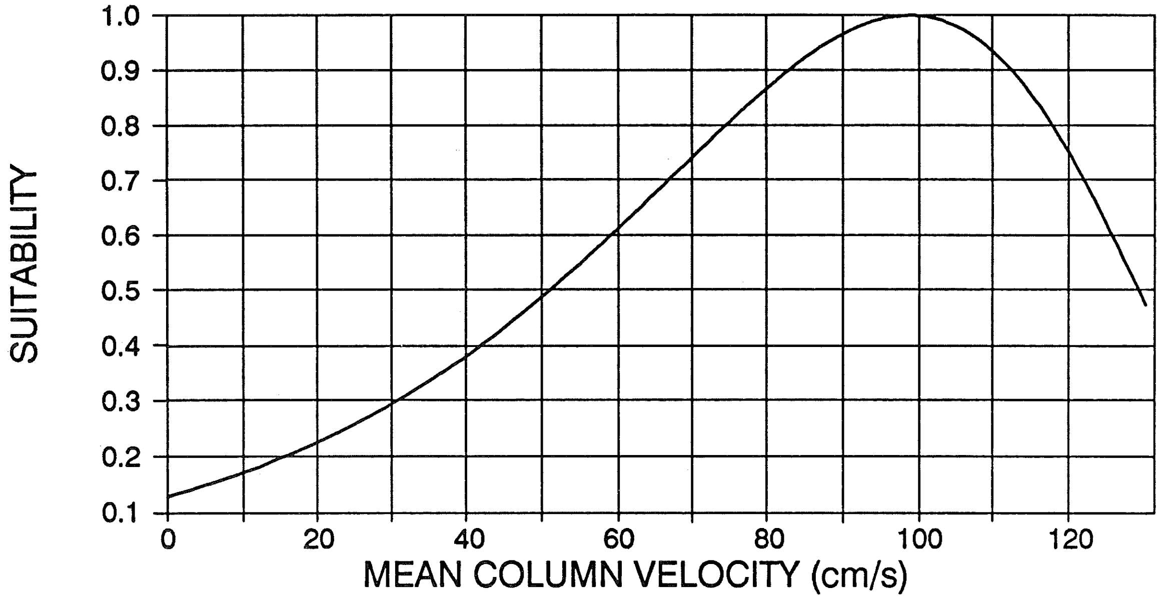


FIGURE 83. Velocity preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

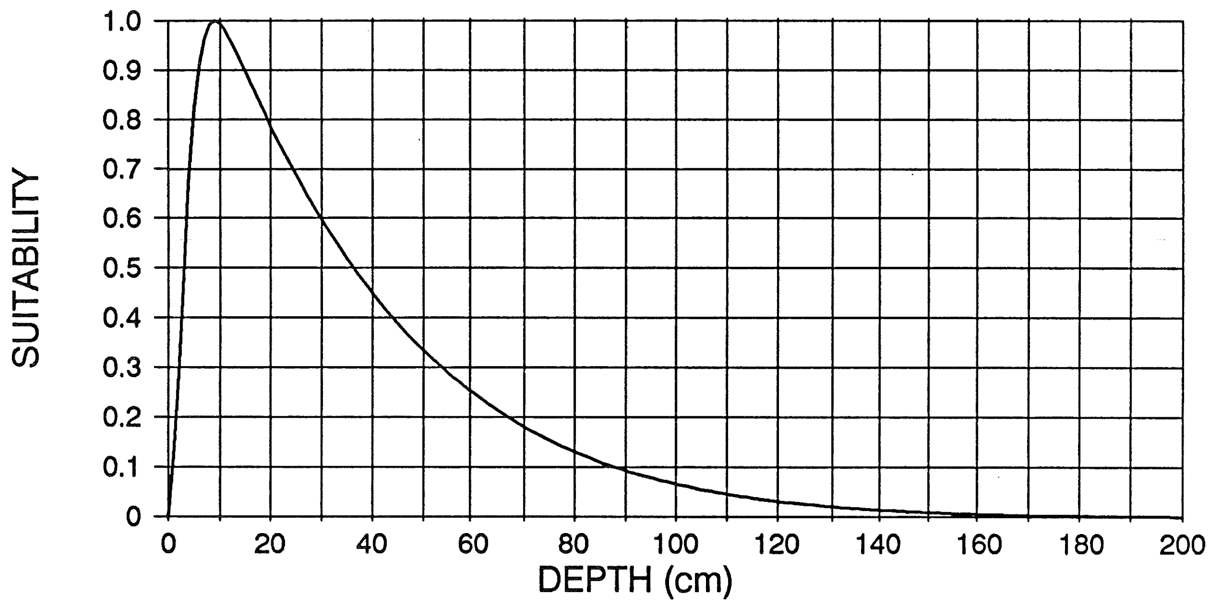


FIGURE 84. Depth preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

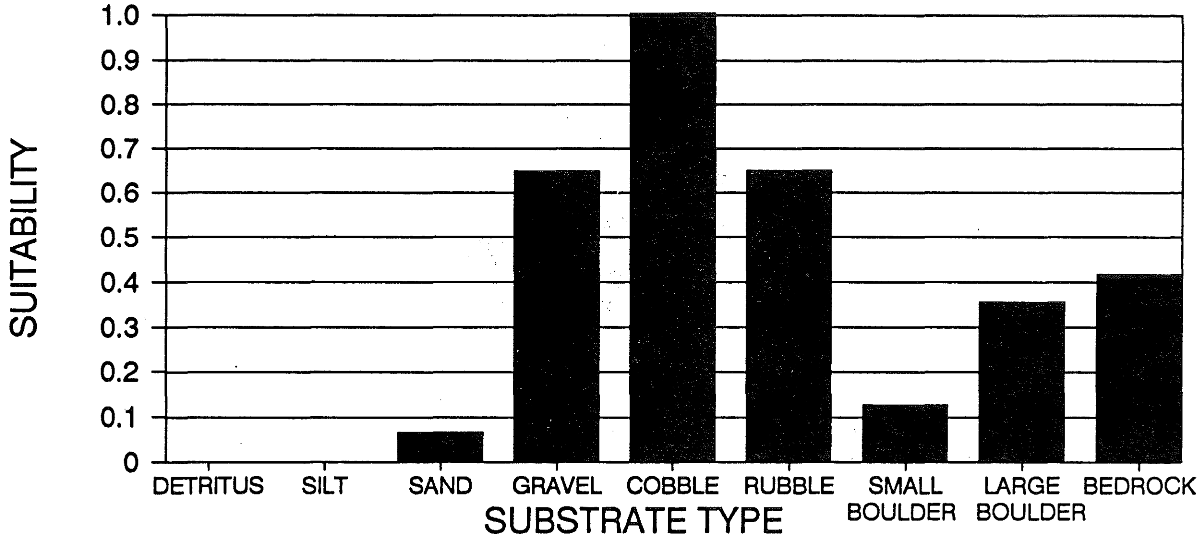


FIGURE 85. Dominant substrate preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

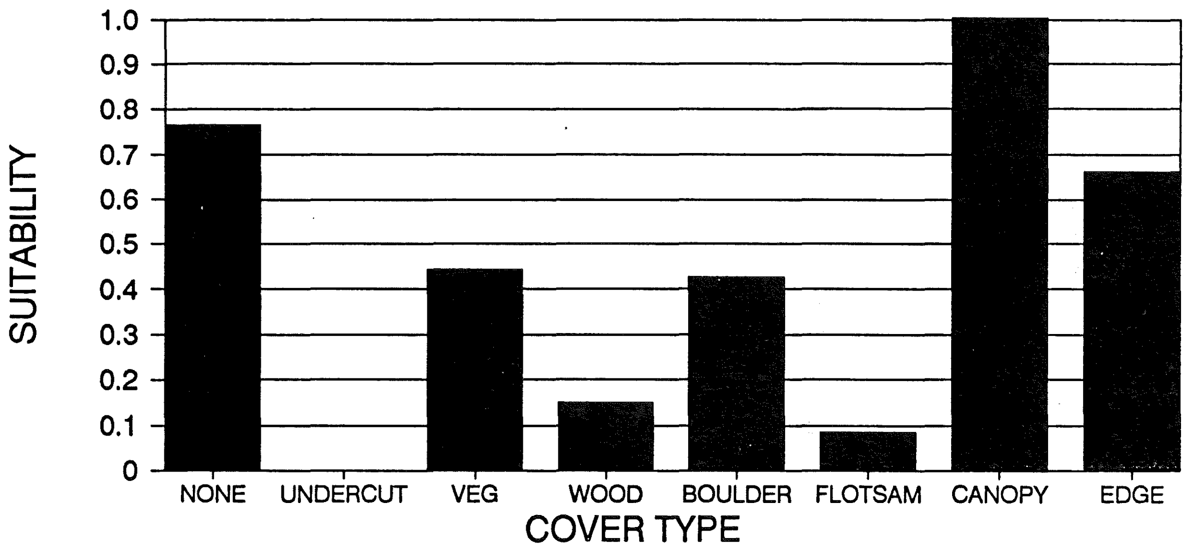


FIGURE 86. Cover preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

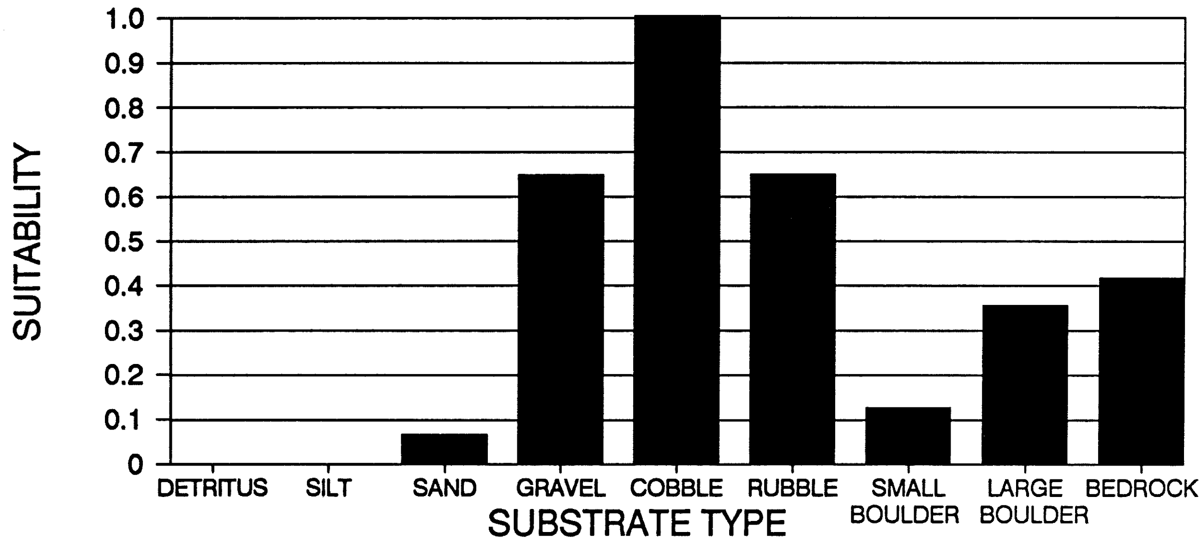


FIGURE 85. Dominant substrate preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

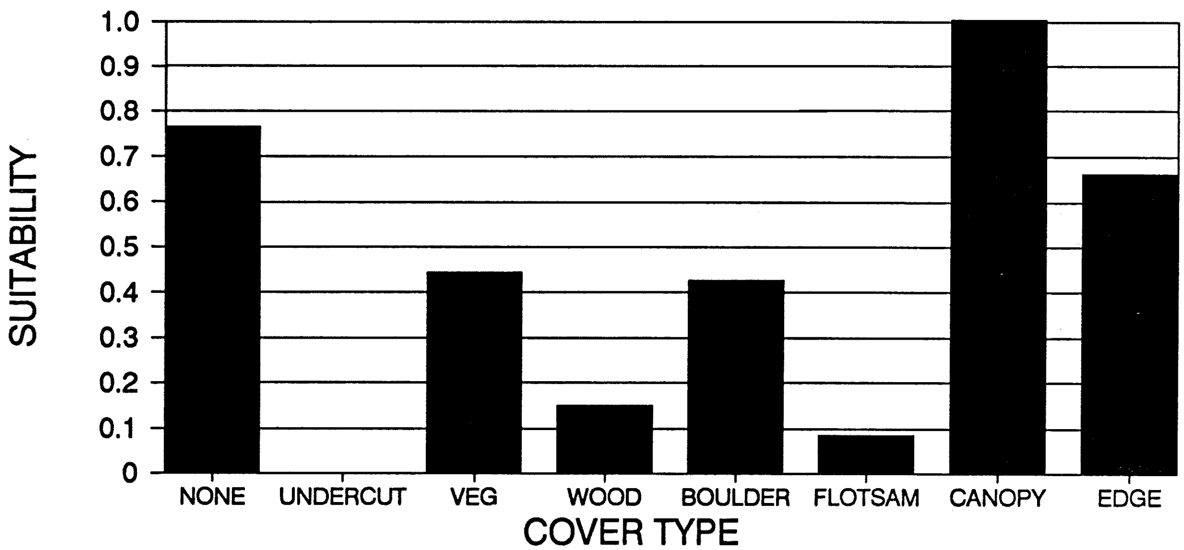


FIGURE 86. Cover preference of adult longnose dace (>or=50 mm) in the Zumbro and Snake rivers (number of individuals=733, number of samples=76).

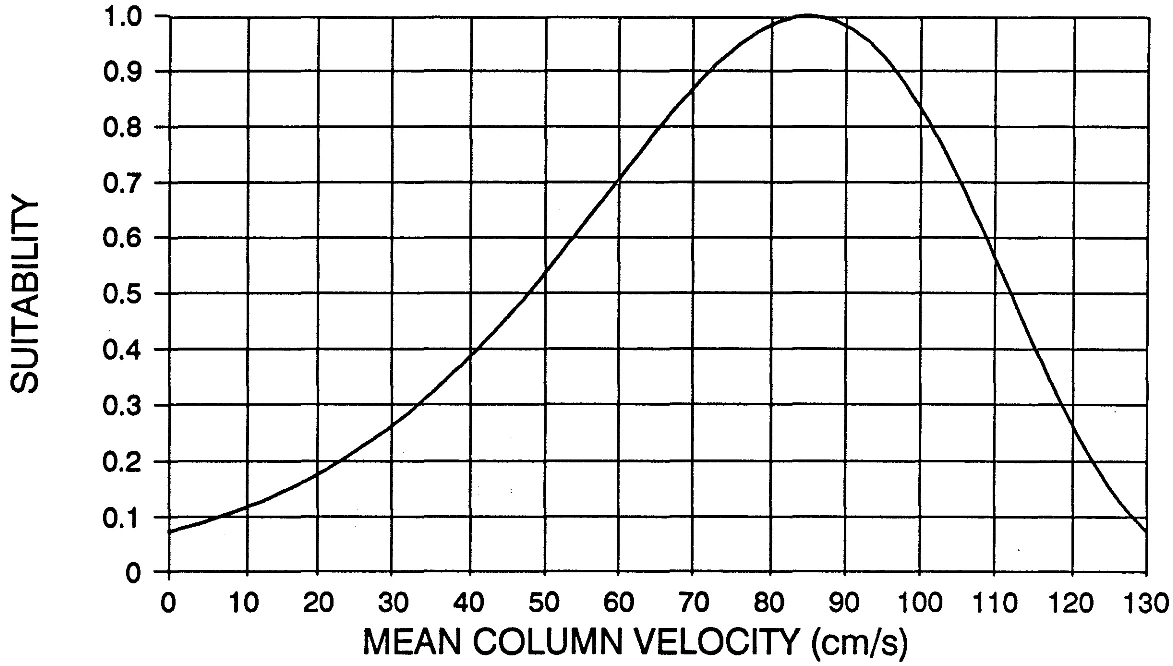


FIGURE 87. Velocity preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

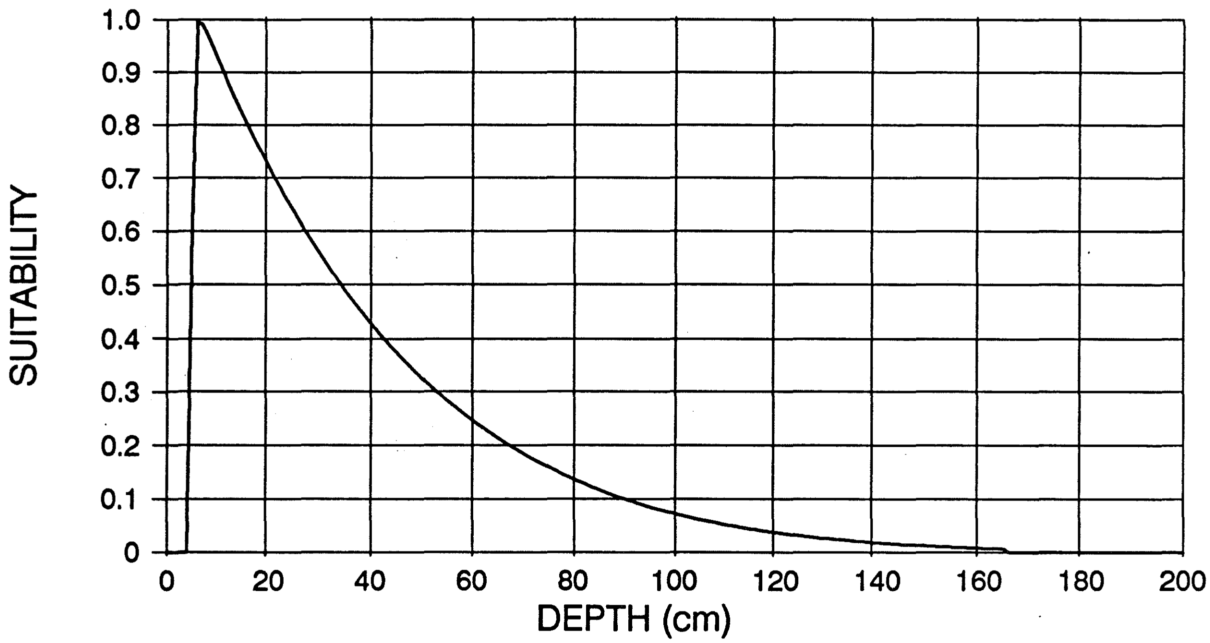


FIGURE 88. Depth preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

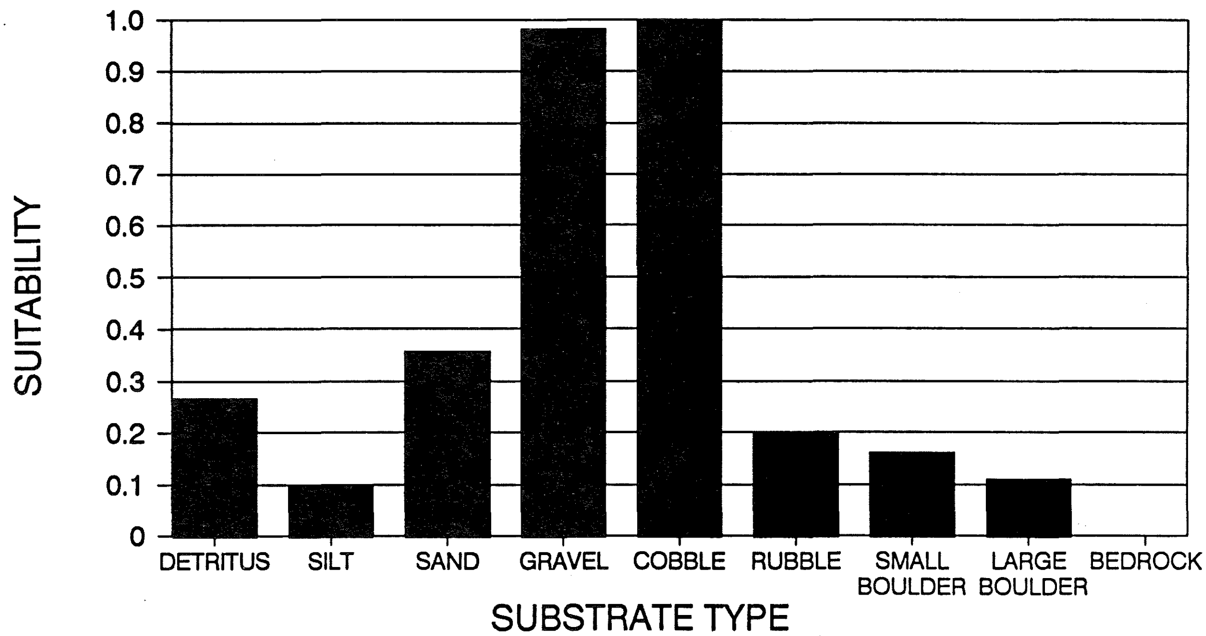


FIGURE 89. Dominant substrate preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

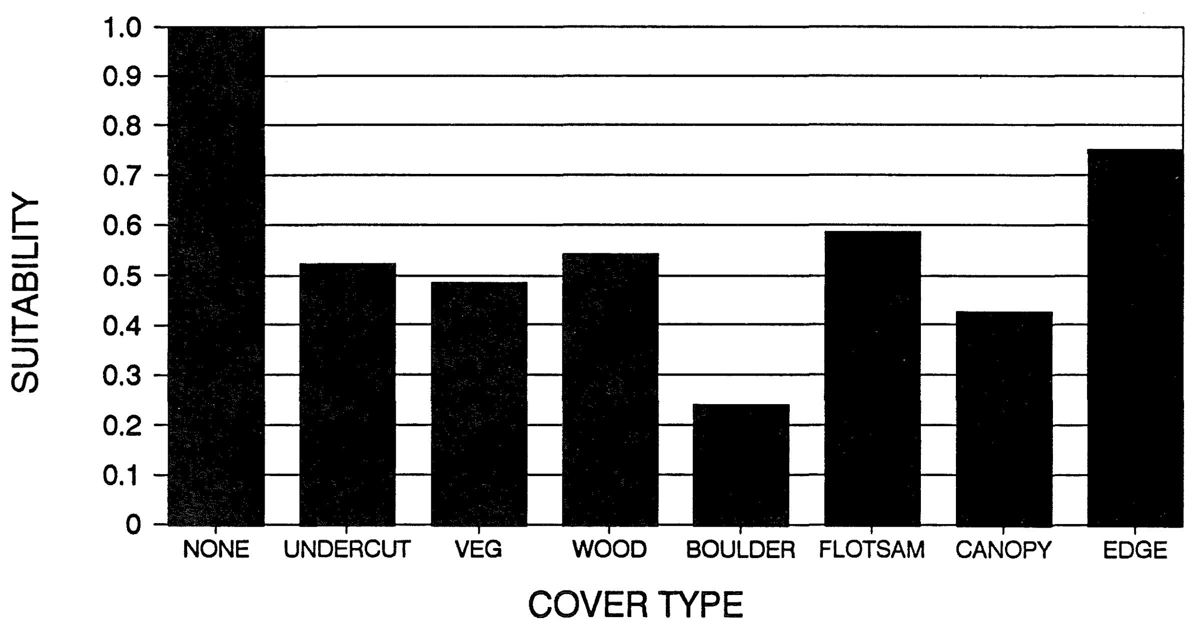


FIGURE 90. Cover preference of juvenile northern hog sucker (70-150 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=178, number of samples=49).

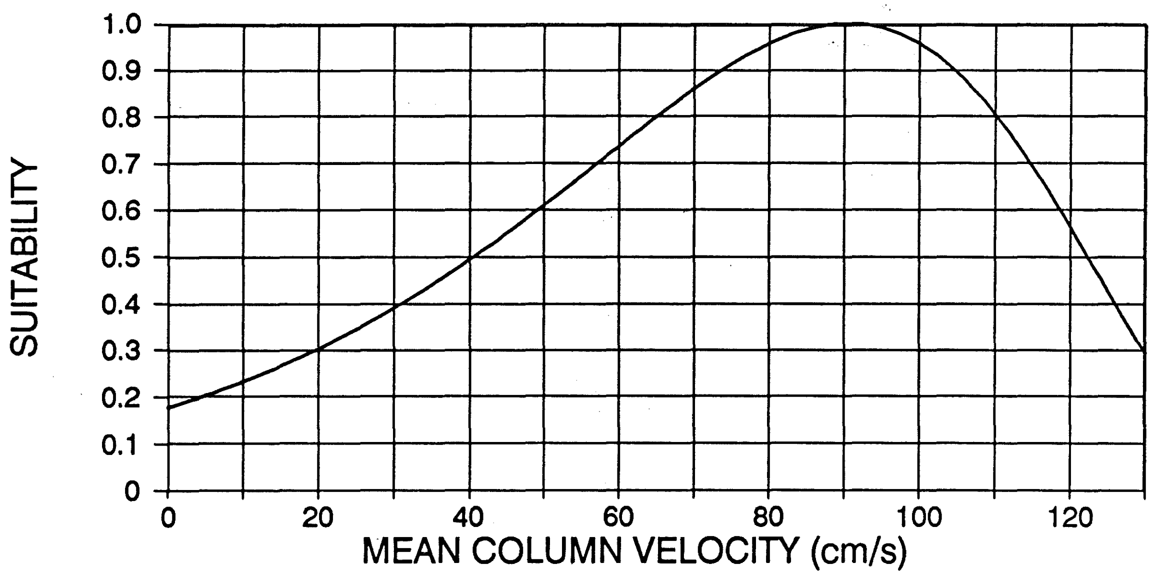


FIGURE 91. Velocity preference of adult northern hog sucker (>150 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=345, number of samples=128).

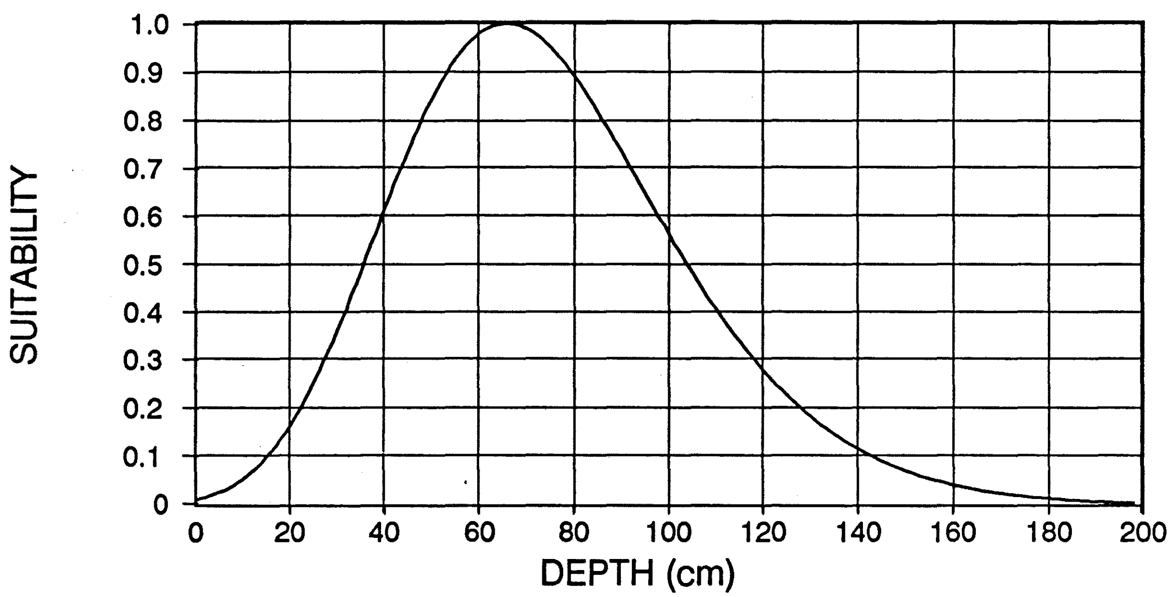


FIGURE 92. Depth preference of adult northern hog sucker (>150 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=345, number of samples=128).

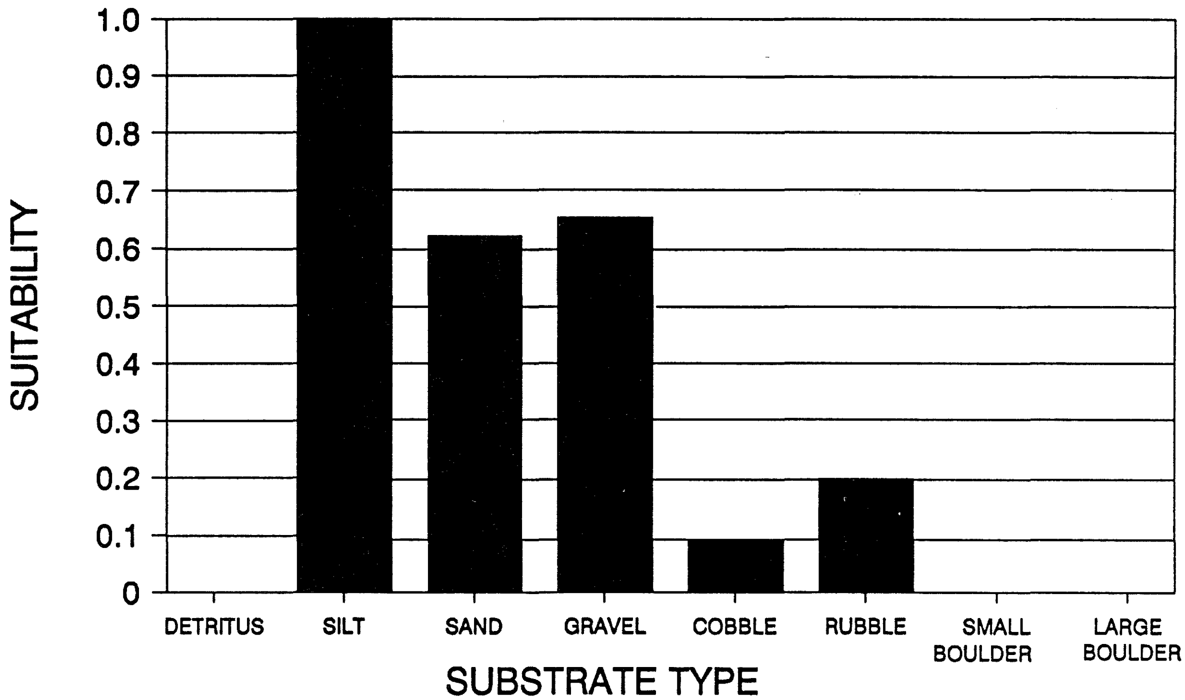


FIGURE 97. Dominant substrate preference of young-of-the-year sand shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=796, number of samples=47).

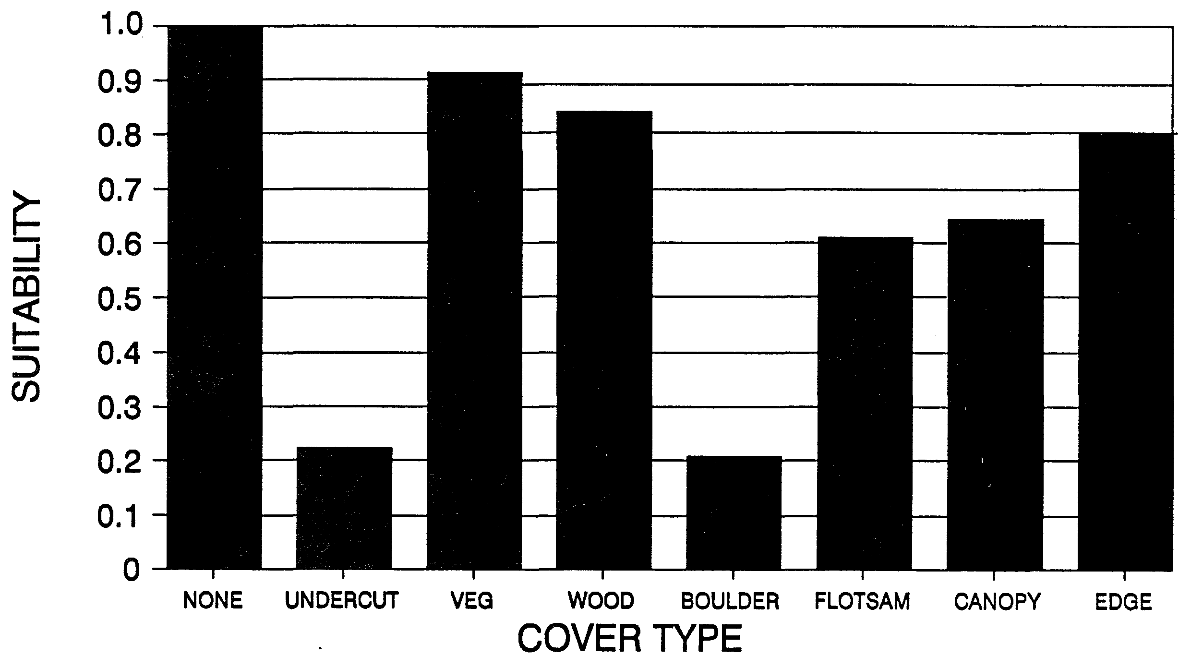


FIGURE 98. Cover preference of young-of-the-year sand shiner (<40 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=796, number of samples=47).

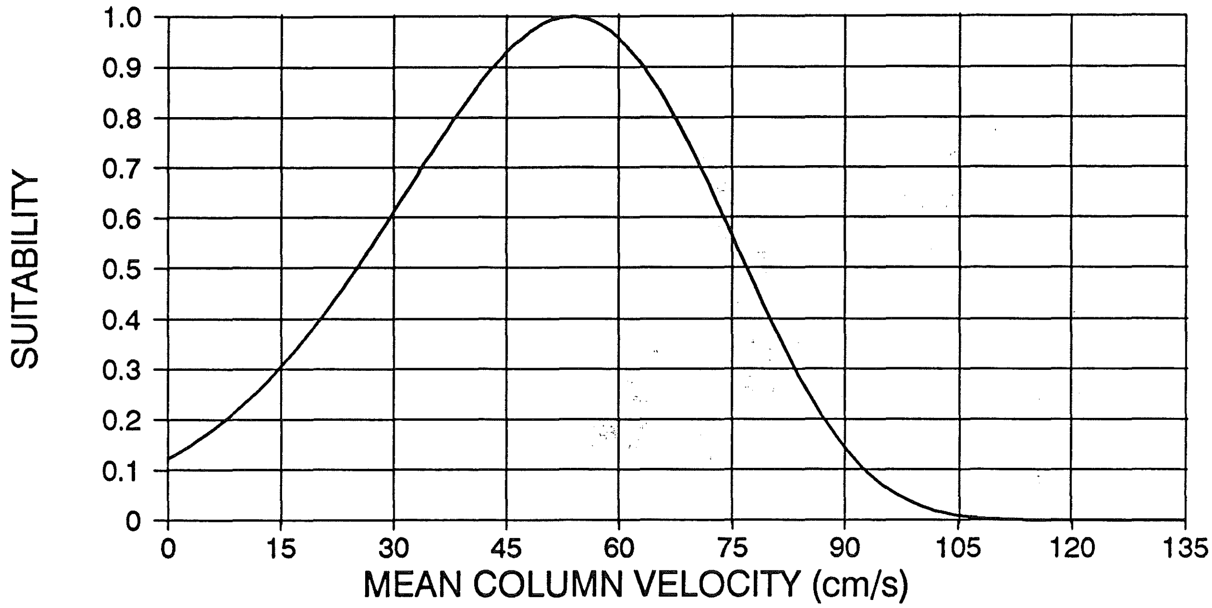


FIGURE 99. Velocity preference of adult sand shiner (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1590, number of samples=112).

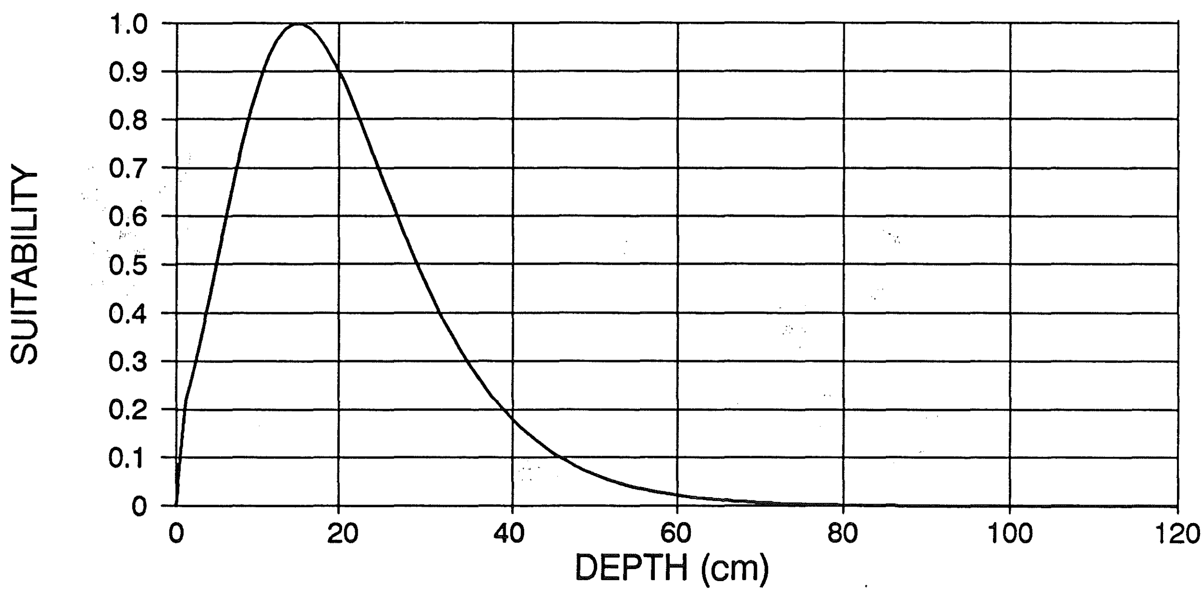


FIGURE 100. Depth preference of adult sand shiner (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1590, number of samples=112).

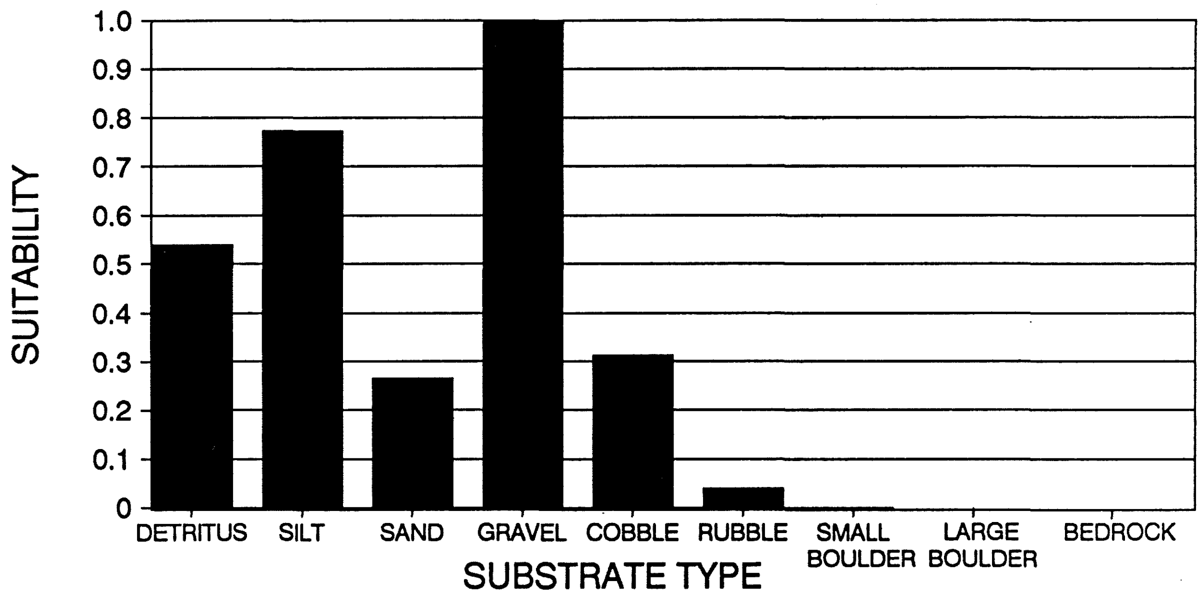


FIGURE 101. Dominant substrate preference of adult sand shiner (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1590, number of samples=112).

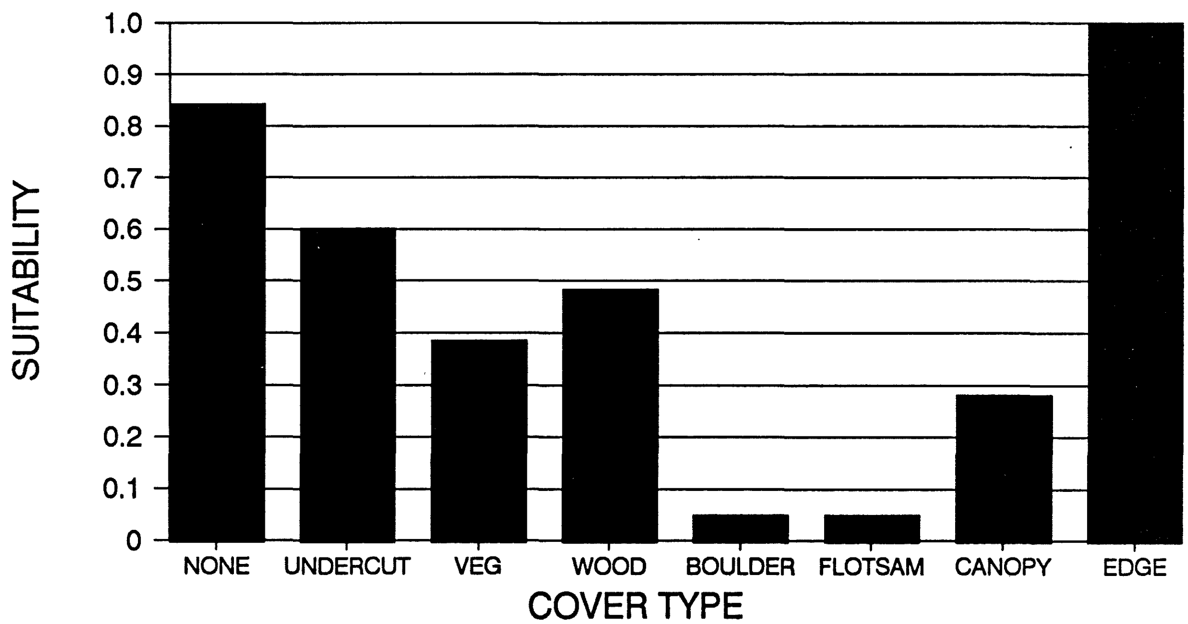


FIGURE 102. Cover preference of adult sand shiner (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1590, number of samples=112).

Slenderhead Darter (*Percina phoxocephala*)

The slenderhead darter was collected in all three study streams and was one of the more common riffle species. Only 5 young-of-the-year were sampled in the three streams and these were found in riffles with rubble substrates (mean velocity = 16-64 cm/s; mean depth = 28-40 cm). Adults were most abundant in fast riffles with cobble substrates (Figs. 103-106). Spawning slenderhead darters were collected in the Zumbro and Yellow Medicine rivers. Fast riffles with rubble substrates were the preferred habitat type and we sampled spawning condition adults at temperatures ranging from 8-23.5°C (Figs. 107-110).

Shorthead Redhorse (*Moxostoma macrolepidotum*)

The shorthead redhorse is a common species throughout Minnesota and was abundant in all three of our study streams. Young-of-the-year preferred riffles with gravel substrates (Figs. 111-114). Juveniles preferred run habitat with gravel substrates (Figs. 115-118). Adults preferred raceways with cobble or rubble substrates (Figs. 119-122). Spawning was observed from 21 April to 6 May in the Yellow Medicine River and on 20 May in the Zumbro. Spawning took place in fast riffles over gravel substrates at temperatures ranging from 9-21.5°C (Figs. 123-126).

White Sucker (*Catastomus commersoni*)

White suckers are an important bait and forage fish and are found throughout Minnesota. Although adults are often common in lakes, they typically spawn in streams. Young-of-the-year and juveniles were well represented in our three study streams whereas relatively few adults were collected. Young-of-the-year were found in riffles or shallow pools with sand or silt substrates (Figs. 127-130). Juvenile white suckers were most abundant in riffles which had gravel substrates (Figs. 131-134).

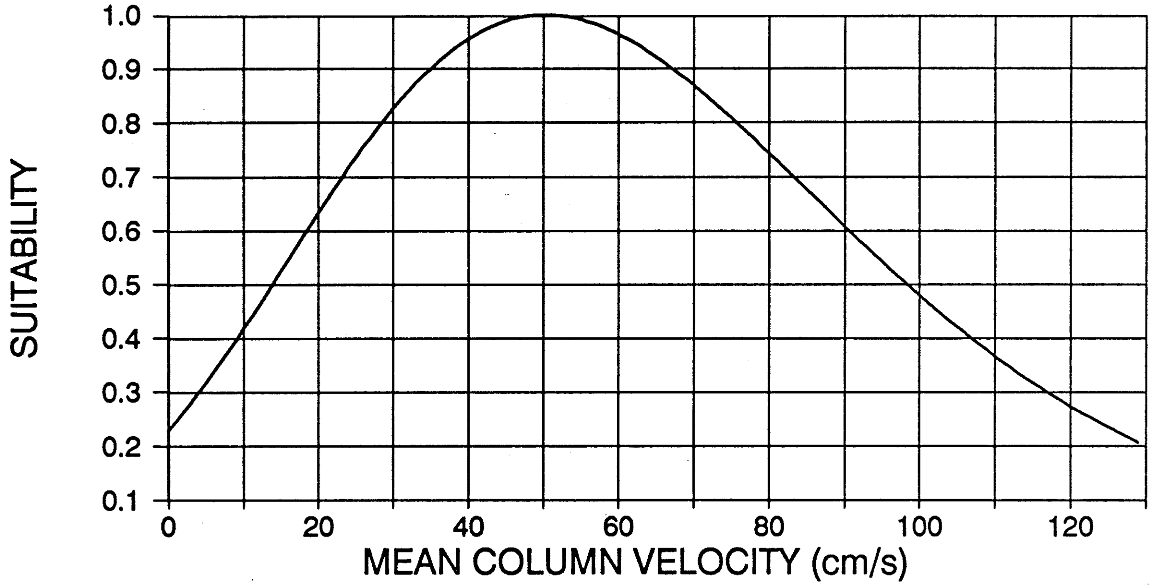


FIGURE 103. Velocity preference of adult slenderhead darter (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=257, number of samples=126).

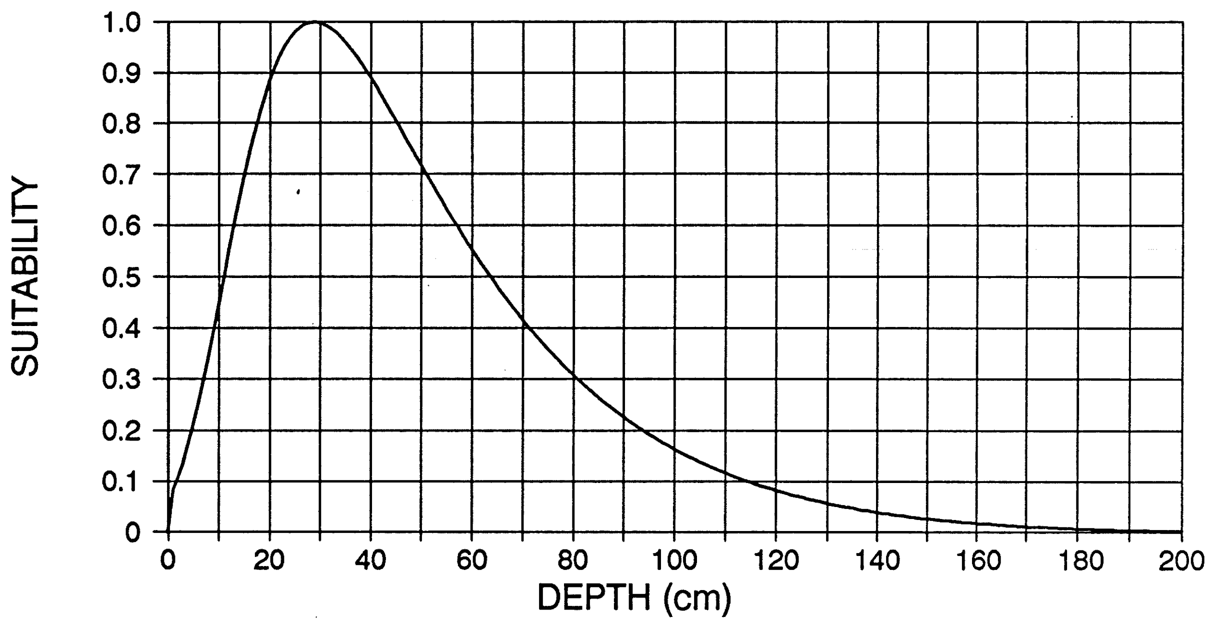


FIGURE 104. Depth preference of adult slenderhead darter (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=257, number of samples=126).

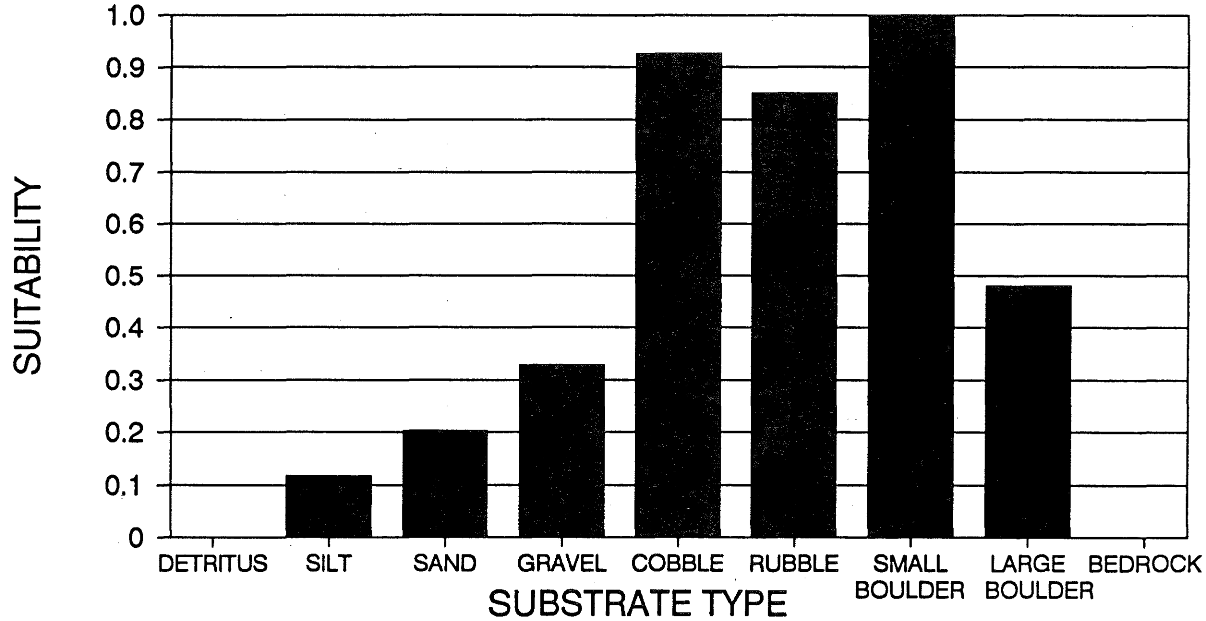


FIGURE 105. Dominant substrate preference of adult slenderhead darters (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=257, number of samples=126).

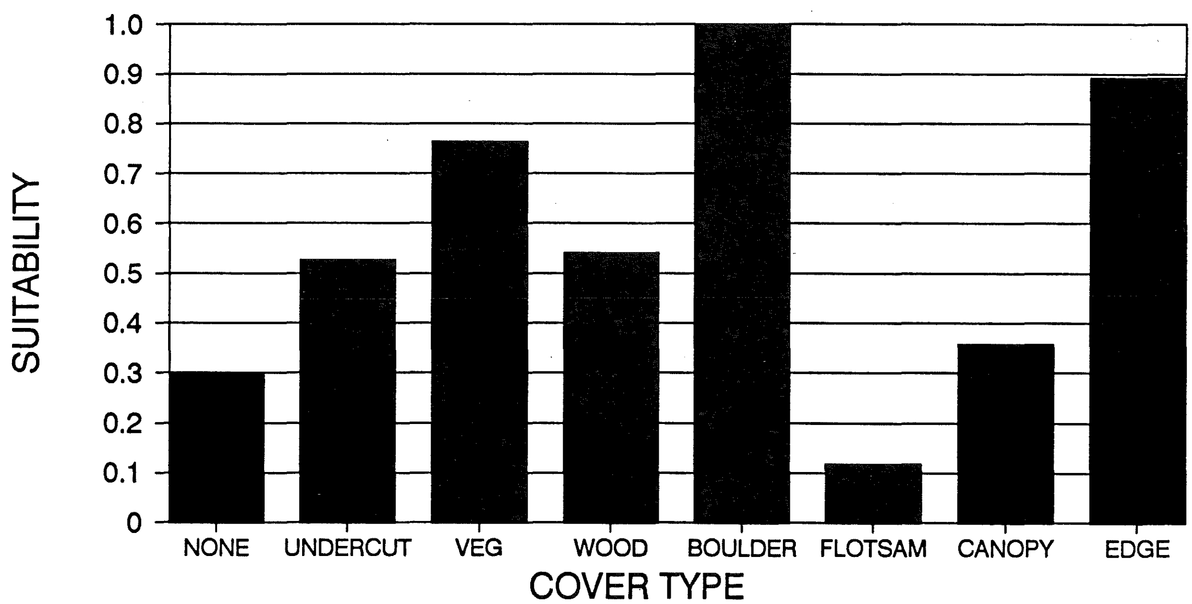


FIGURE 106. Cover preference of adult slenderhead darters (>or=40 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=257, number of samples=126).

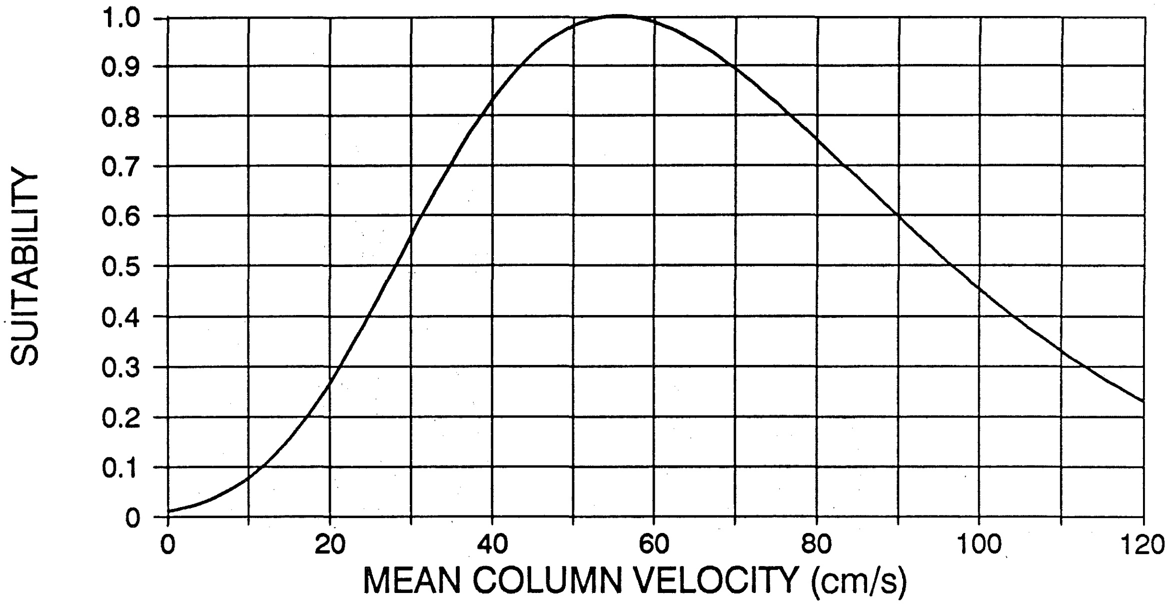


FIGURE 107. Velocity preference of spawning slenderhead darter in the Yellow Medicine and Zumbro rivers (number of individuals=42, number of samples=19).

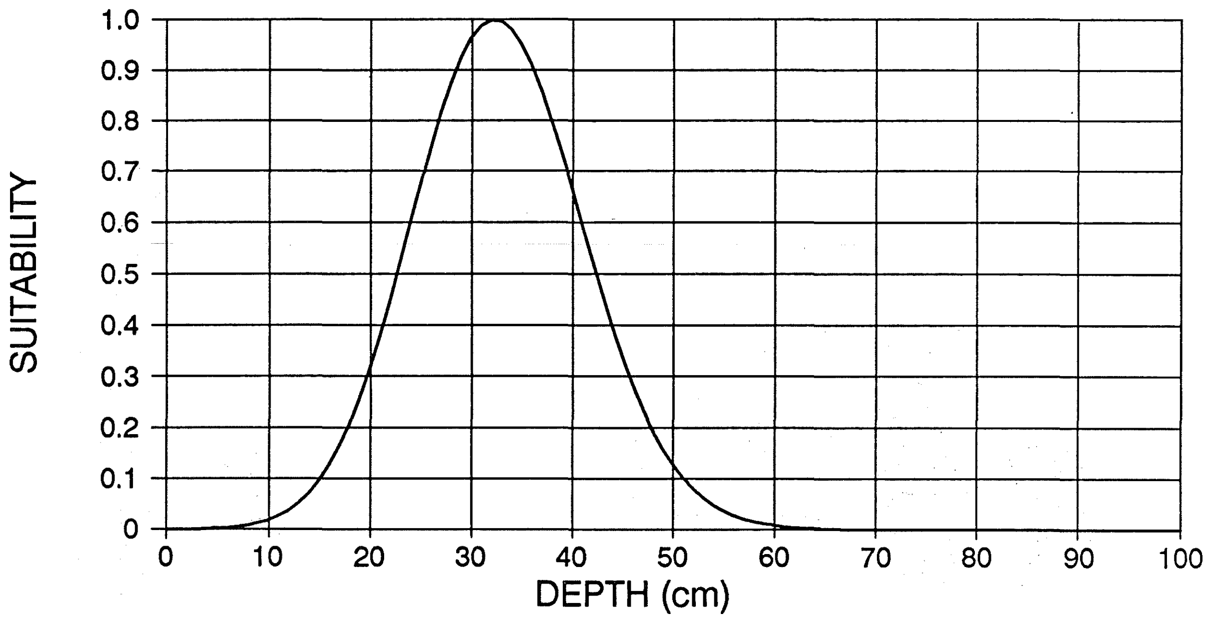


FIGURE 108. Depth preference of spawning slenderhead darter in the Yellow Medicine and Zumbro rivers (number of individuals=42, number of samples=19).

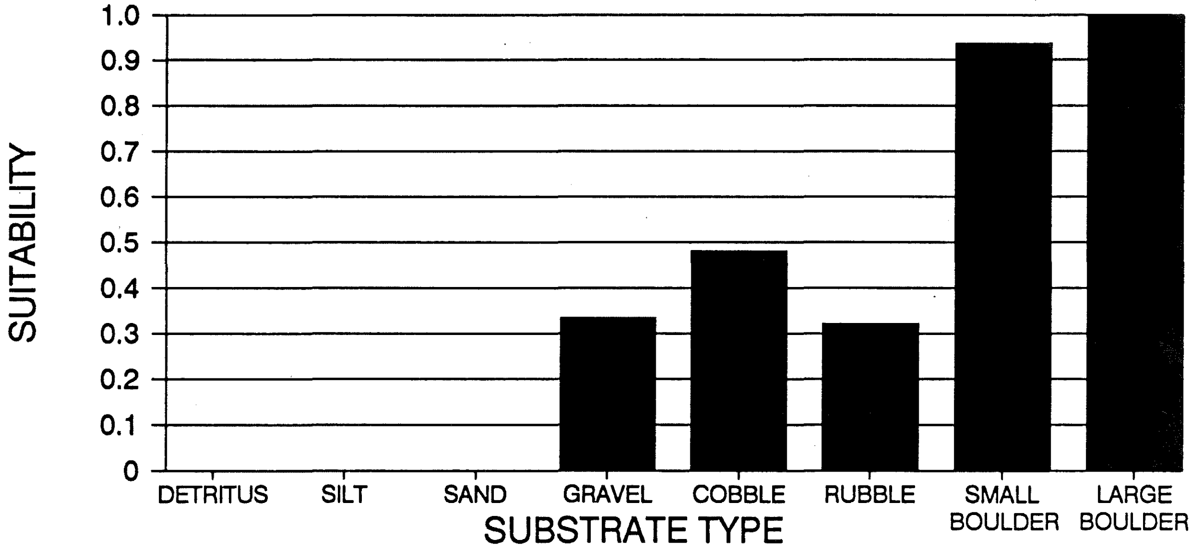


FIGURE 109. Dominant substrate preference of spawning slenderhead darter in the Yellow Medicine and Zumbro rivers (number of individuals=42, number of samples=19).

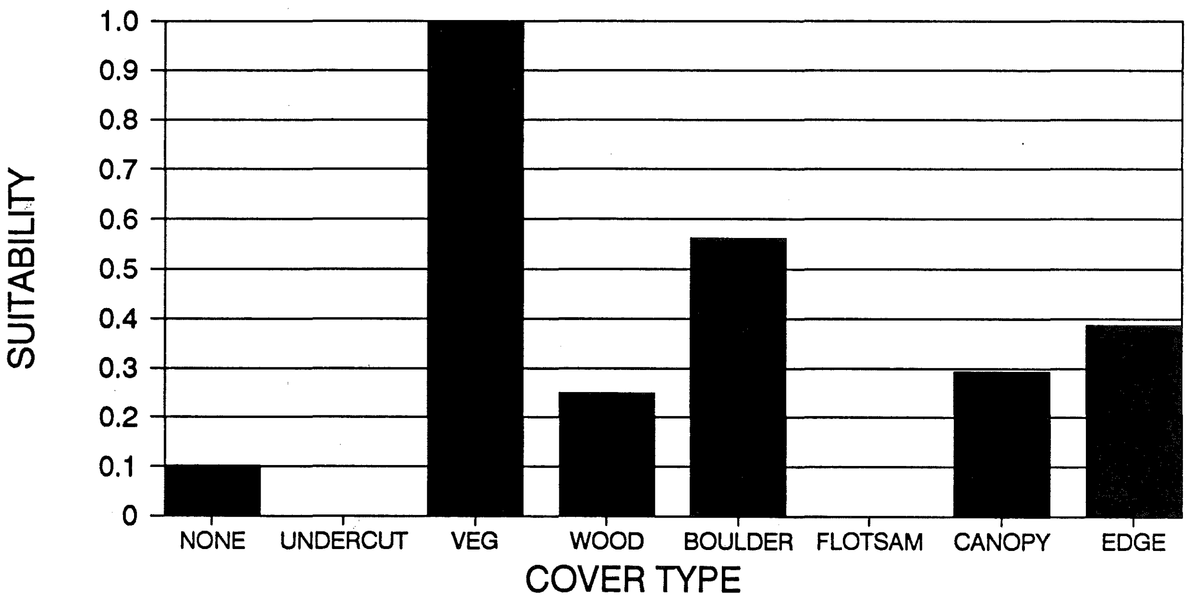


FIGURE 110. Cover preference of spawning slenderhead darter in the Yellow Medicine and Zumbro rivers (number of individuals=42, number of samples=19).

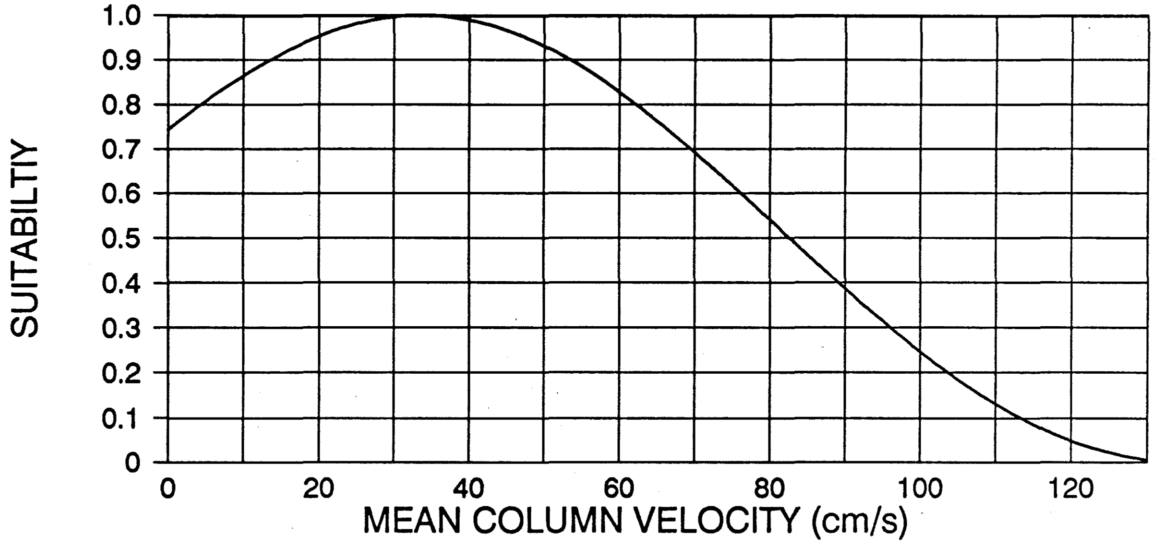


FIGURE 111. Velocity preference of young-of-the-year shorthead redhorse (<100 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=628, number of samples=89).

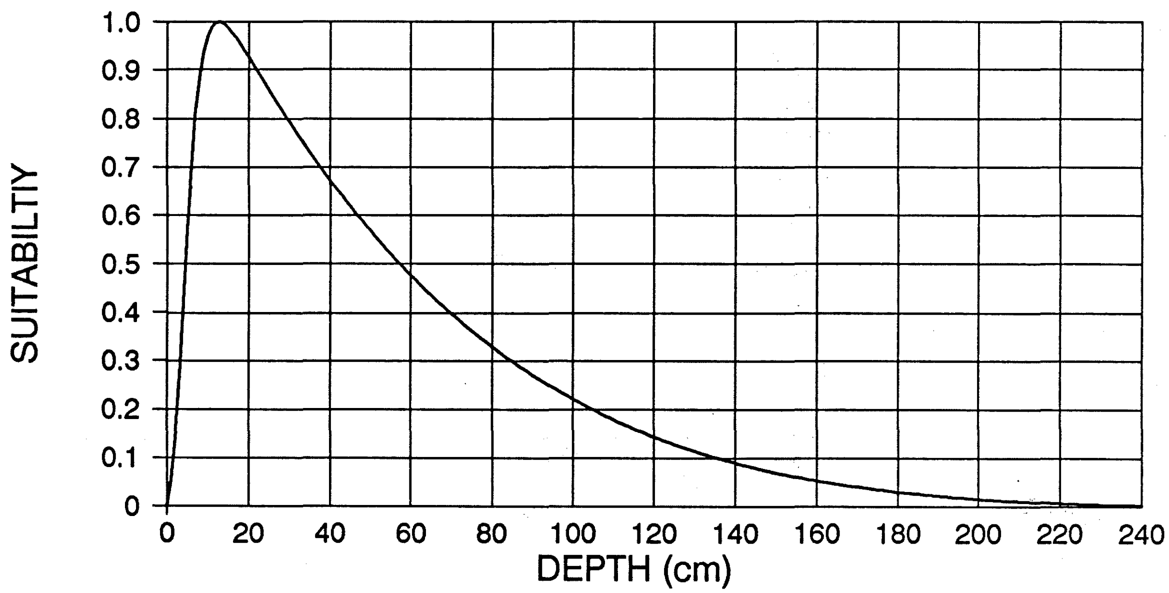


FIGURE 112. Depth preference of young-of-the-year shorthead redhorse (<100 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=628, number of samples=89).

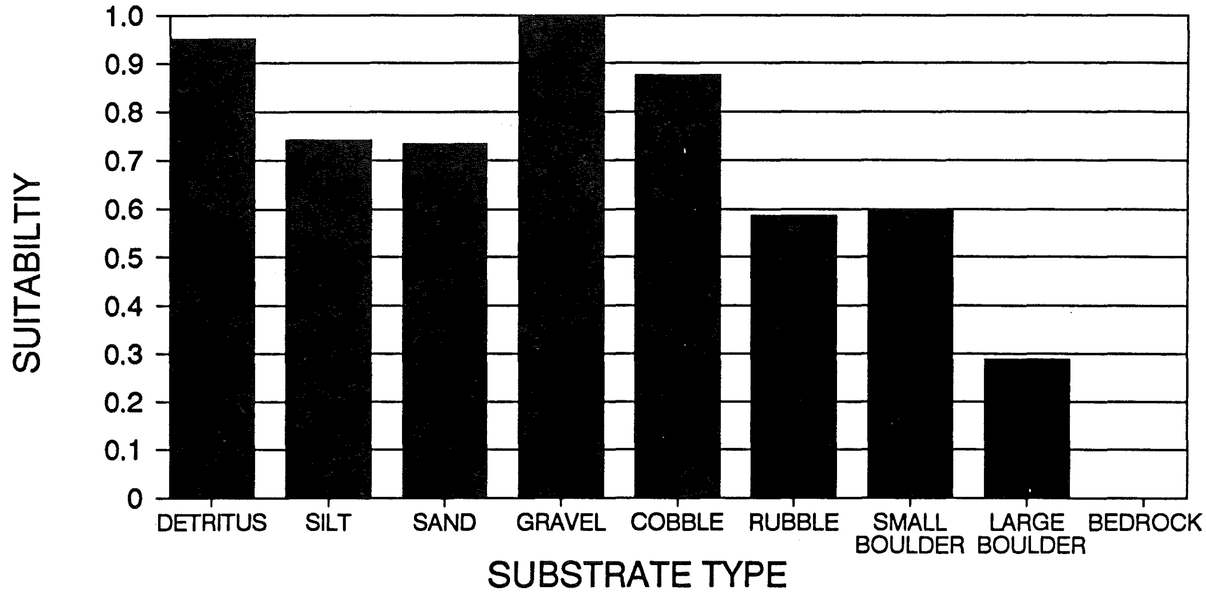


FIGURE 113. Dominant substrate preference of young-of-the-year shorthead redhorse (<100 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=628, number of samples=89).

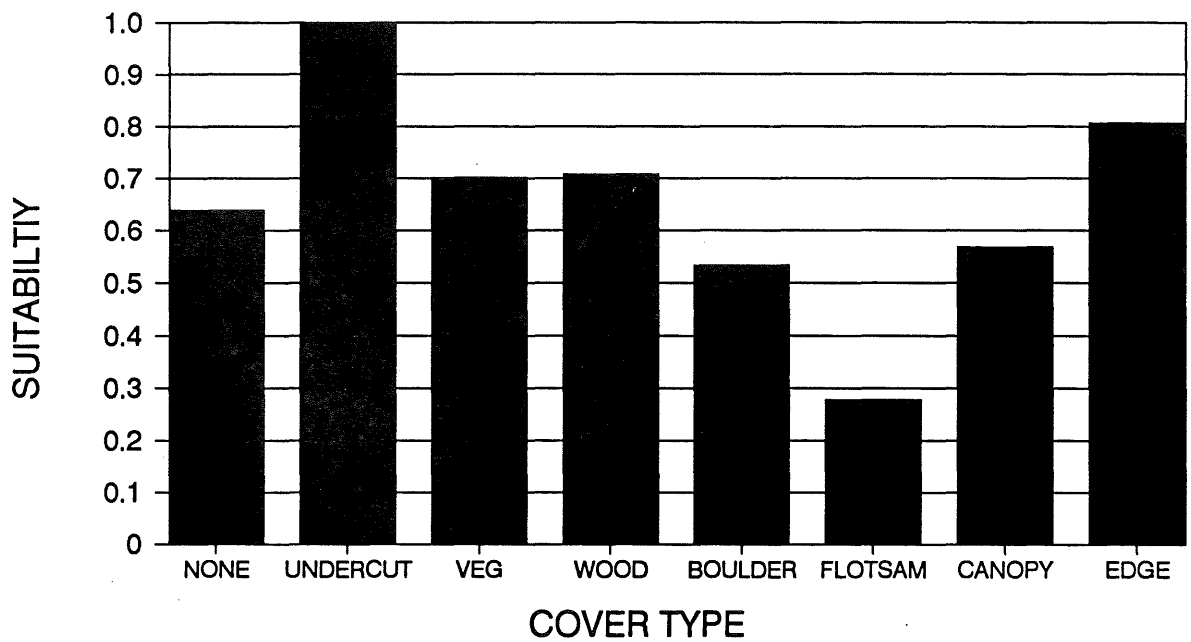


FIGURE 114. Cover preference of young-of-the-year shorthead redhorse (<100 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=628, number of samples=89).

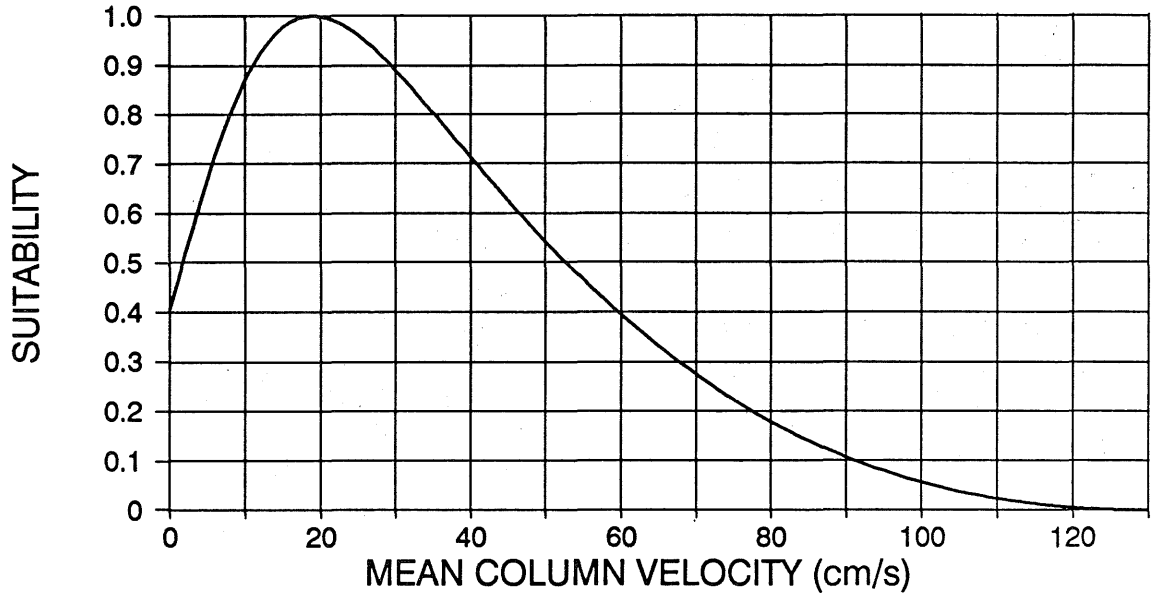


FIGURE 115. Velocity preference of juvenile shorthead redhorse (100-250 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=224, number of samples=89).

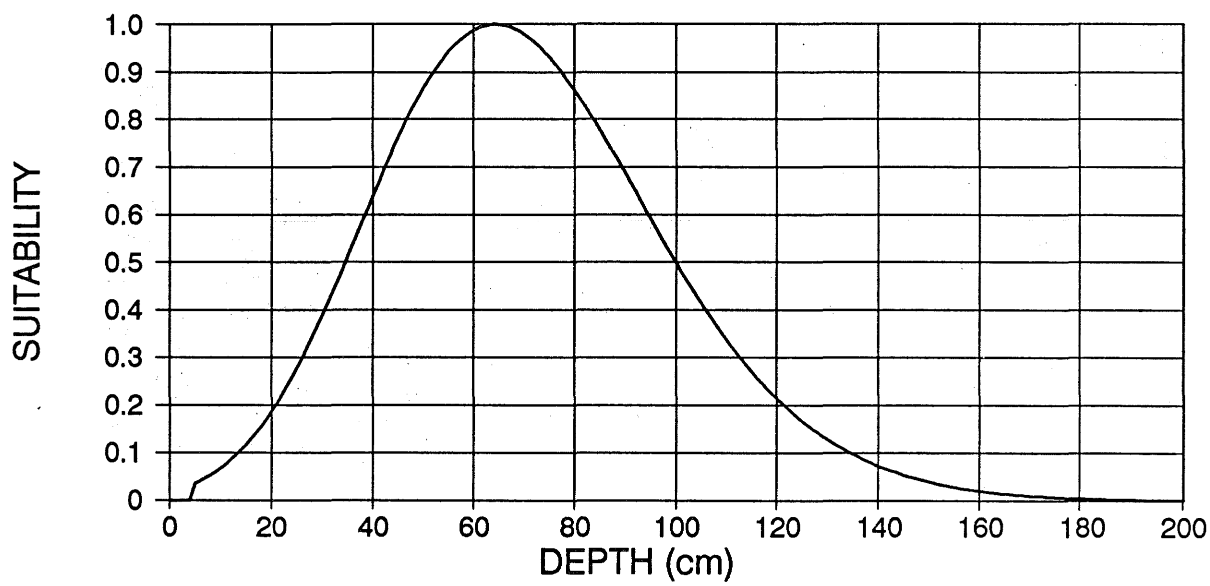


FIGURE 116. Depth preference of juvenile shorthead redhorse (100-250 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=224, number of samples=89).

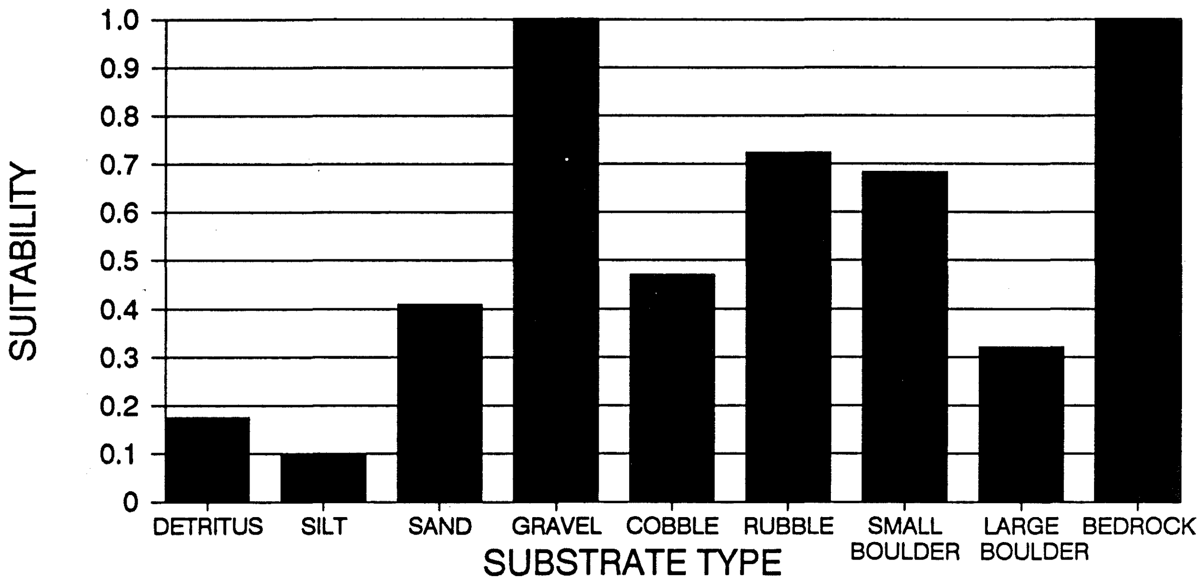


FIGURE 117. Dominant substrate preference of juvenile shorthead redhorse (100-250 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=224, number of samples=89).

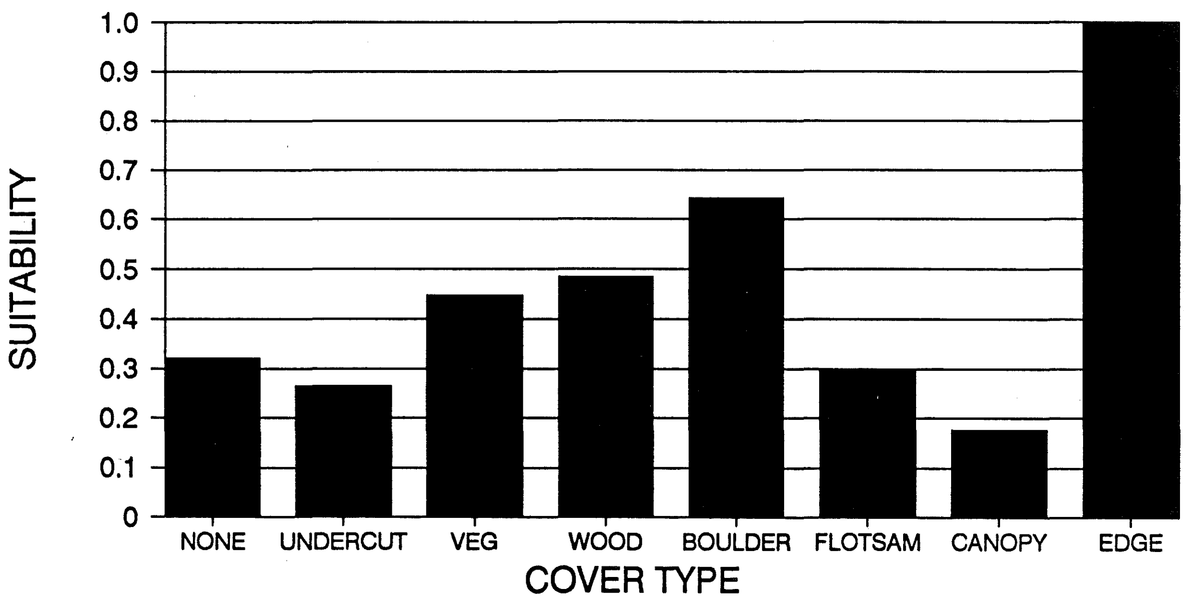


FIGURE 118. Cover preference of juvenile shorthead redhorse (100-250 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=224, number of samples=89).

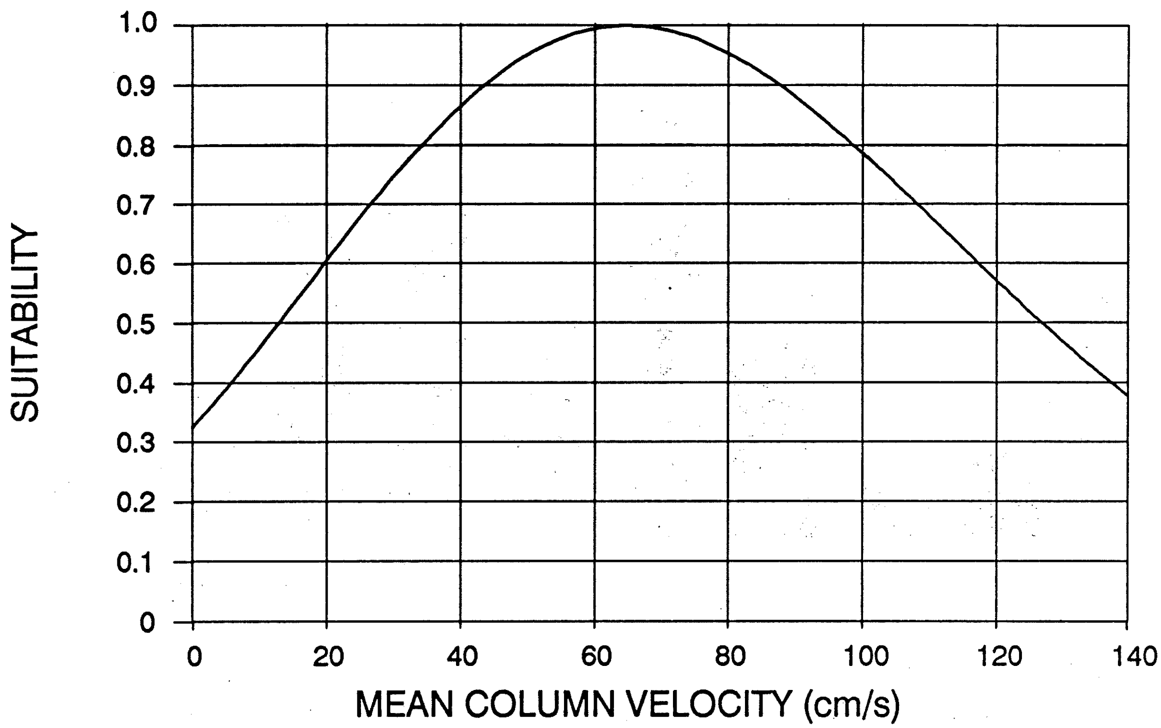


FIGURE 119. Velocity preference of adult shorthead redhorse (>250 mm) in the Zumbro river (number of individuals=357, number of samples=106; weighted data).

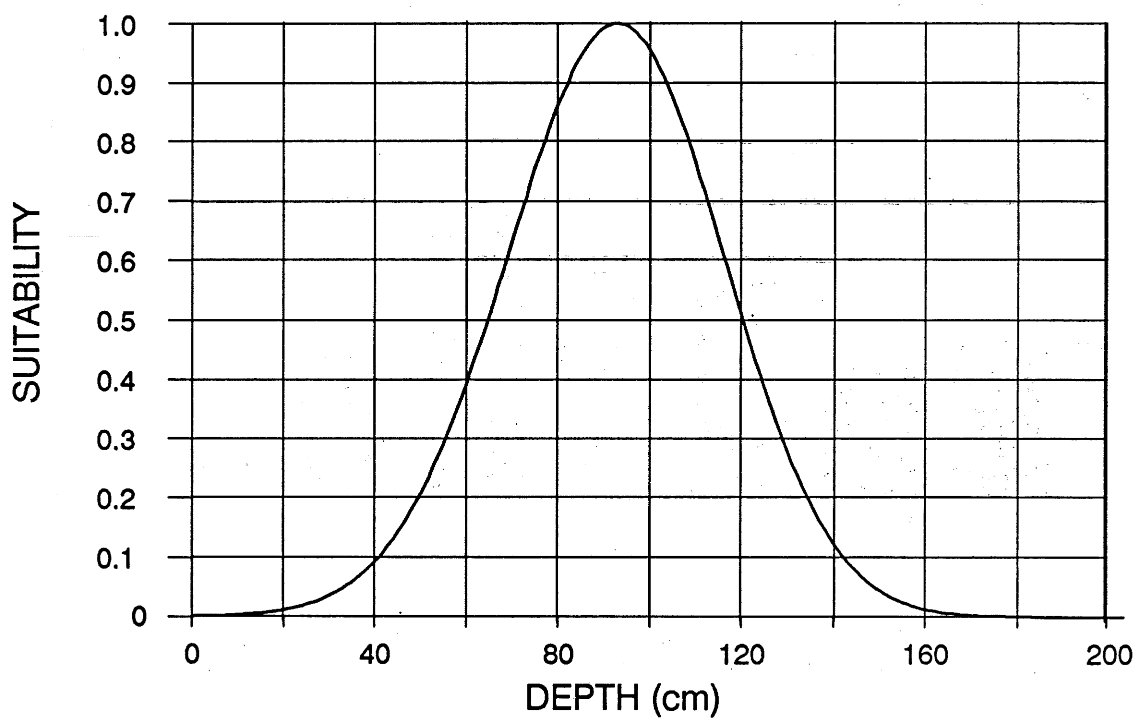


FIGURE 120. Depth preference of adult shorthead redhorse (>250 mm) in the Zumbro river (number of individuals=357, number of samples=106; weighted data).

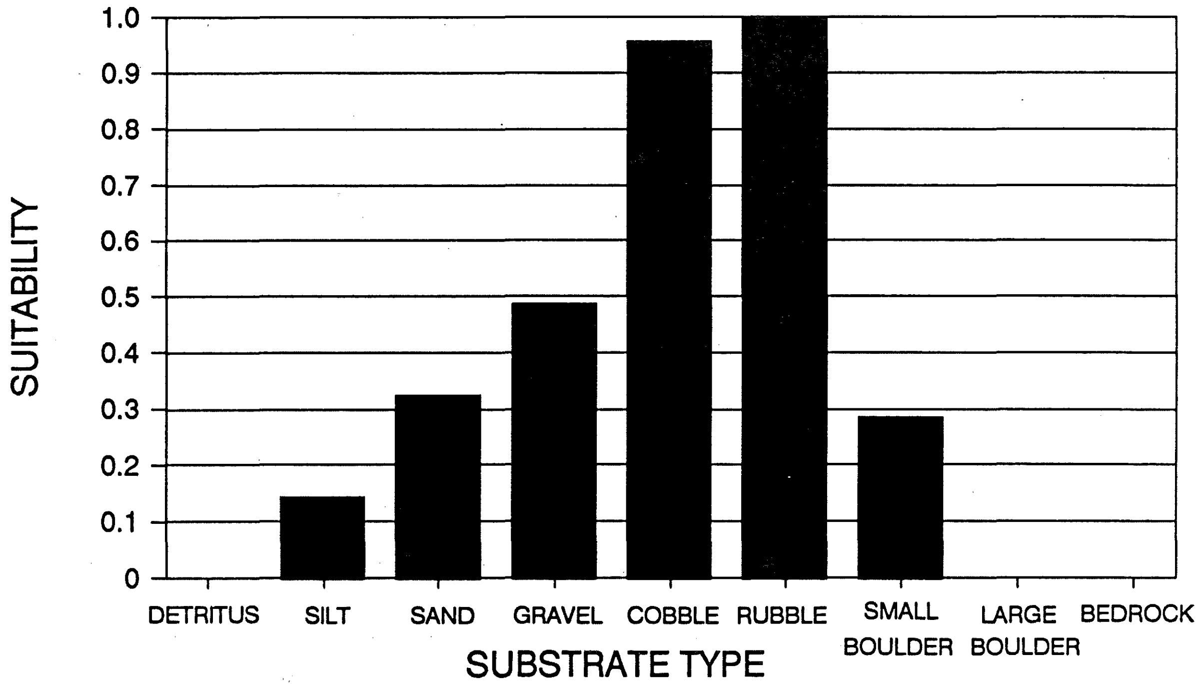


FIGURE 121. Dominant substrate preference of adult shorthead redhorse (>250 mm) in the Zumbro river (number of individuals=357, number of samples=106; weighted data).

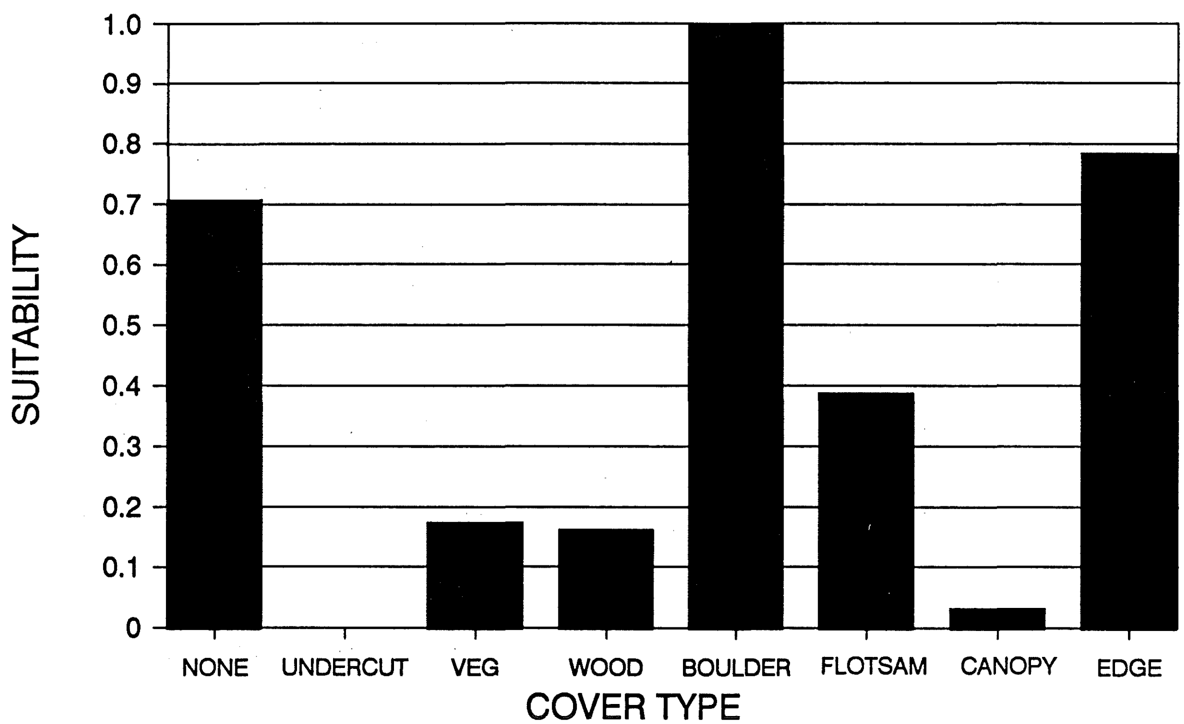


FIGURE 122. Cover preference of adult shorthead redhorse (>250 mm) in the Zumbro river (number of individuals=357, number of samples=106; weighted data).

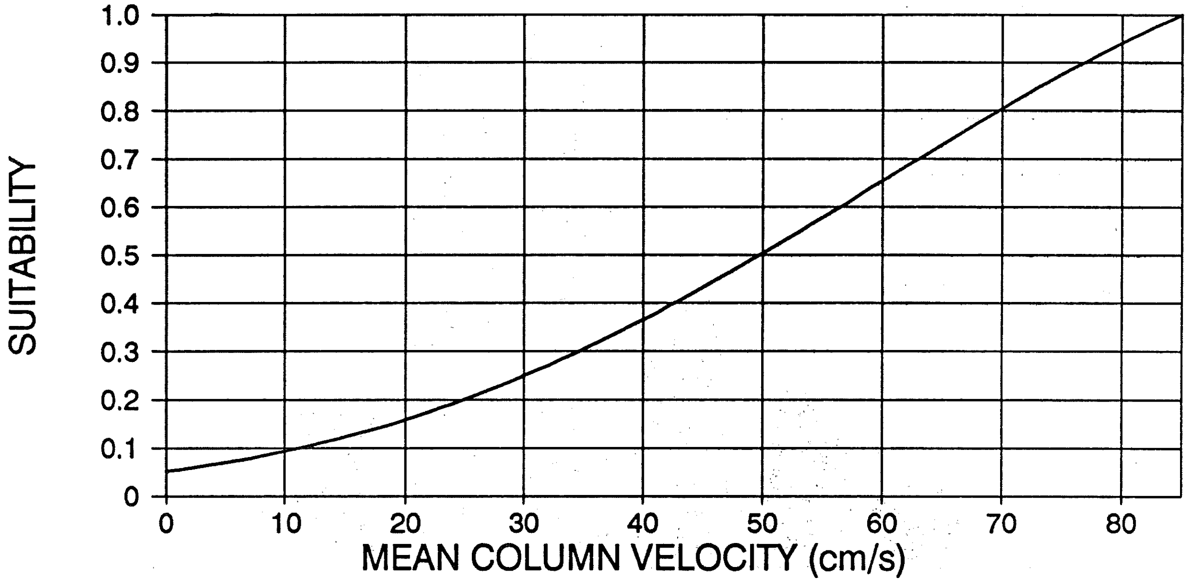


FIGURE 123. Velocity preference of spawning shorthead redhorse in the Yellow Medicine and Zumbro rivers (number of individuals=160, number of samples=20).

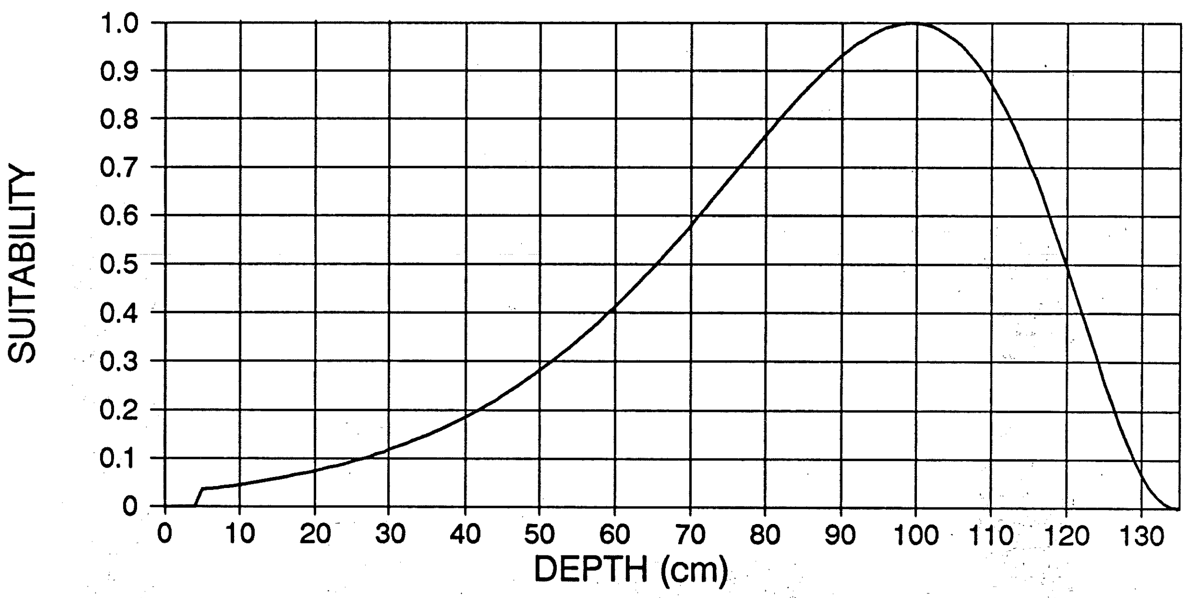


FIGURE 124. Depth preference of spawning shorthead redhorse in the Yellow Medicine and Zumbro rivers (number of individuals=160, number of samples=20).

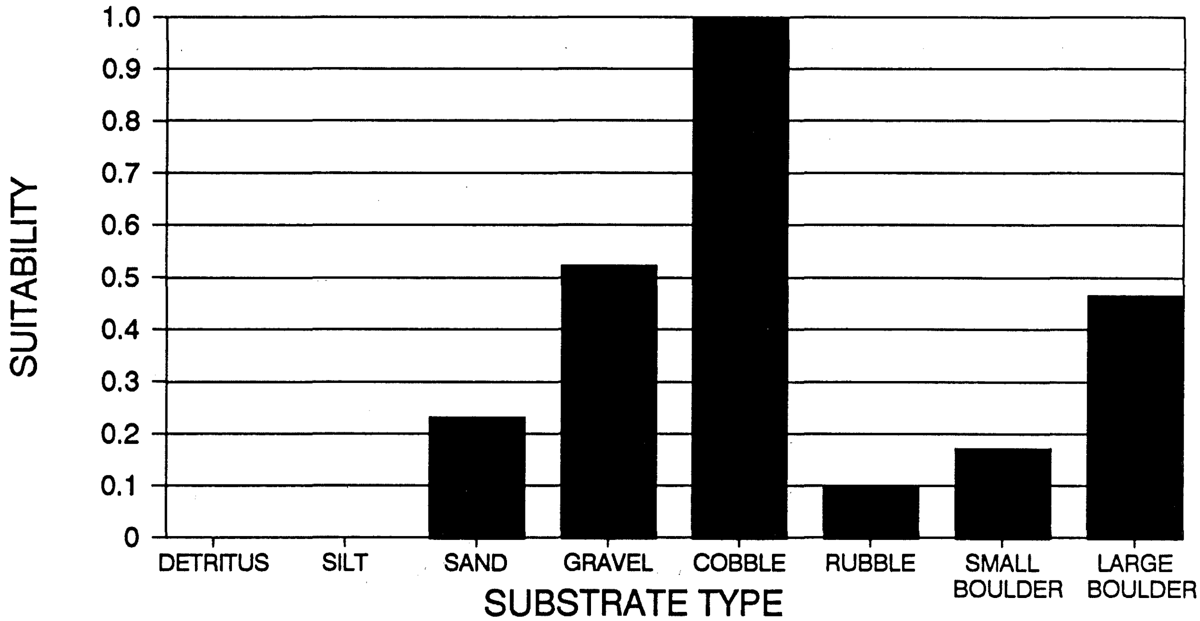


FIGURE 125. Dominant substrate preference of spawning shorthead redhorse in the Yellow Medicine and Zumbro rivers (number of individuals=160, number of samples=20).

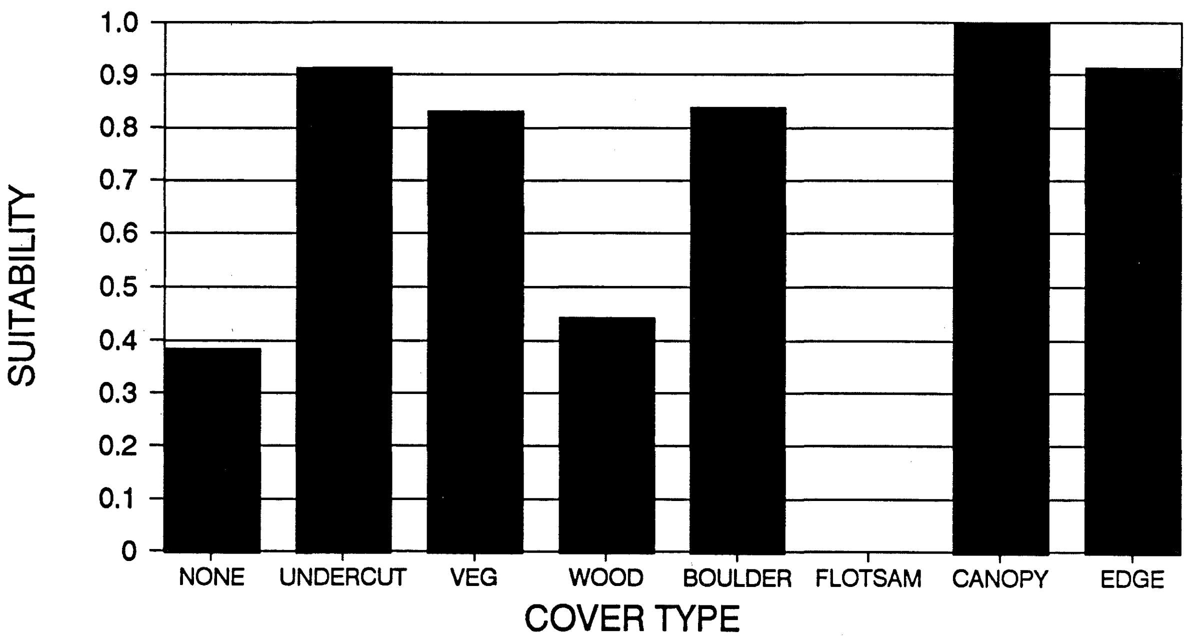


FIGURE 126. Cover preference of spawning shorthead redhorse in the Yellow Medicine and Zumbro rivers (number of individuals=160, number of samples=20).

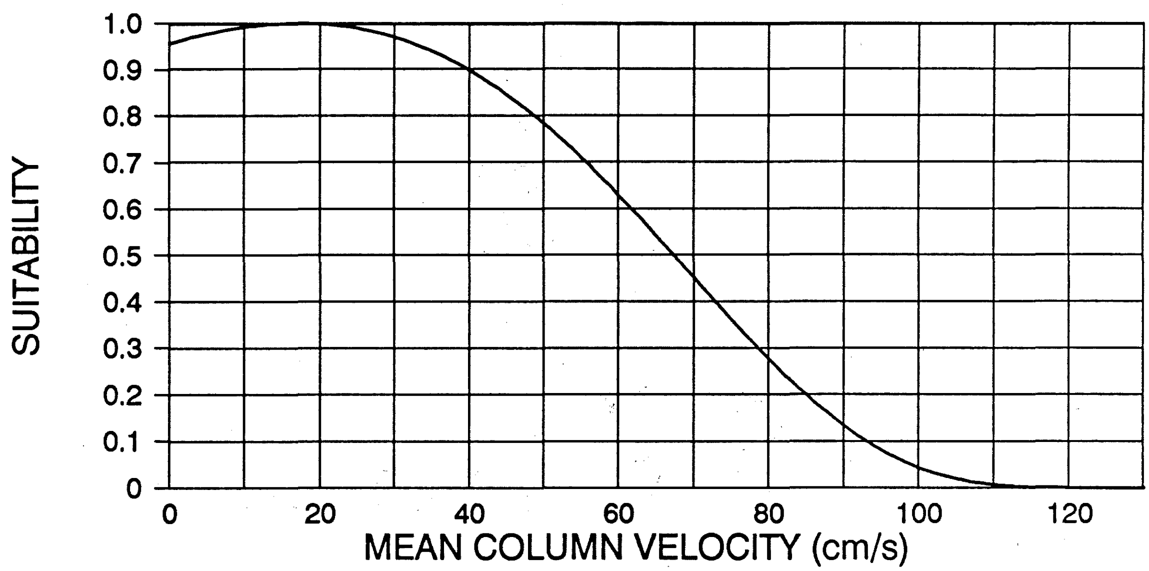


FIGURE 127. Velocity preference of young-of-the-year white sucker (<75 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1649, number of samples=101).

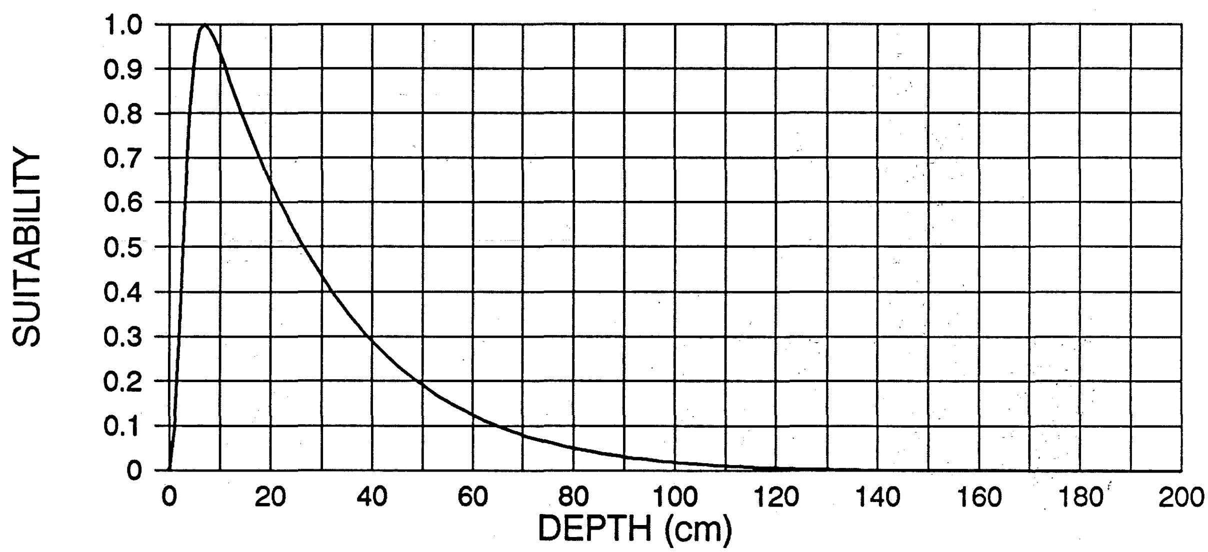


FIGURE 128. Depth preference of young-of-the-year white sucker (<75 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1649, number of samples=101).

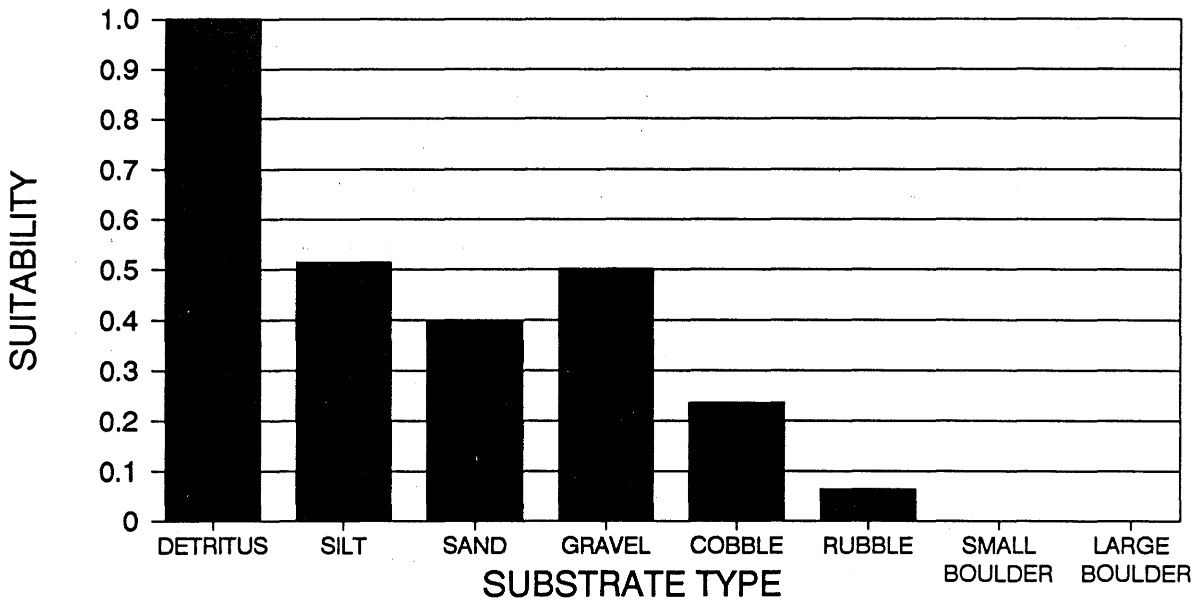


FIGURE 129. Dominant substrate preference of young-of-the-year white sucker (<75 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1649, number of samples=101).

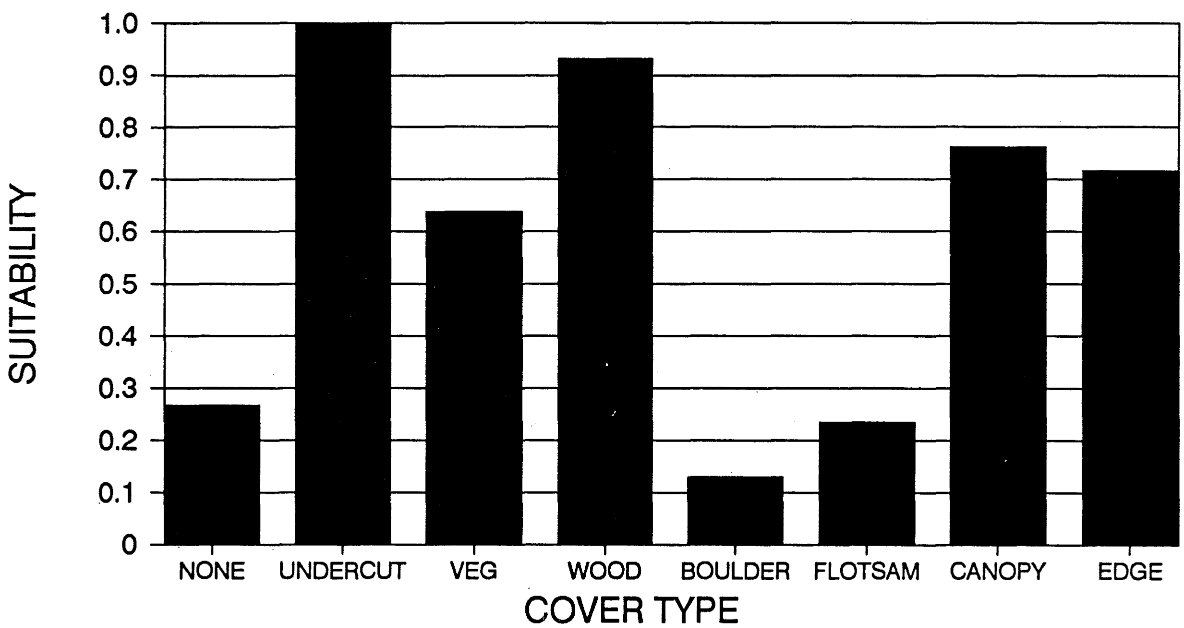


FIGURE 130. Cover preference of young-of-the-year white sucker (<75 mm) in the Zumbro and Yellow Medicine rivers (number of individuals=1649, number of samples=101).

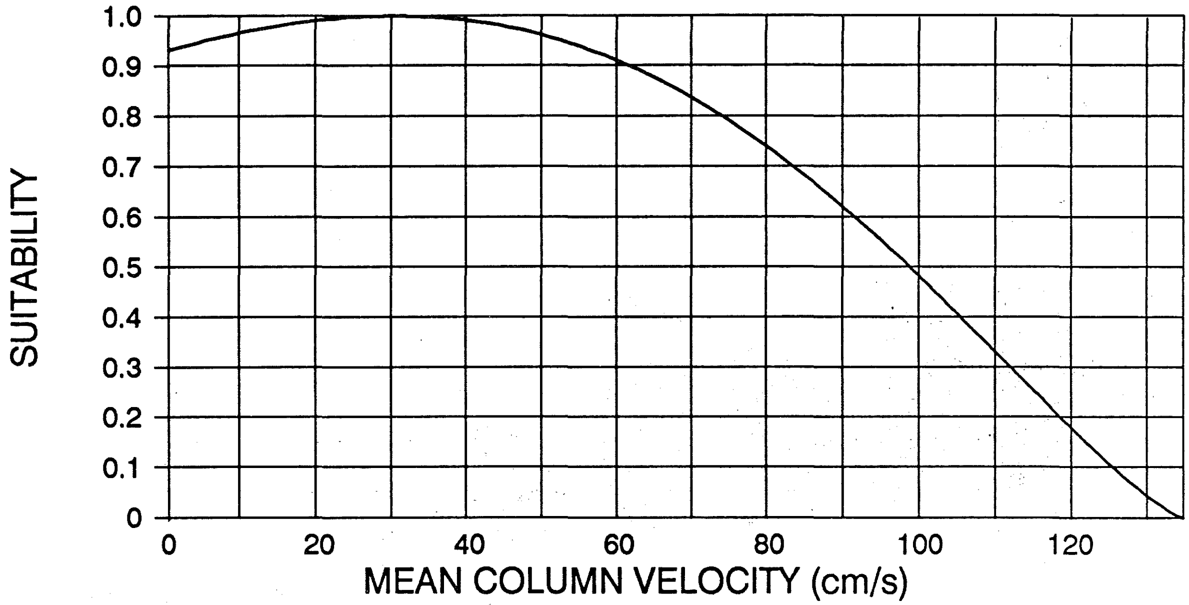


FIGURE 131. Velocity preference of juvenile white sucker (75-300 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1274, number of samples=156).

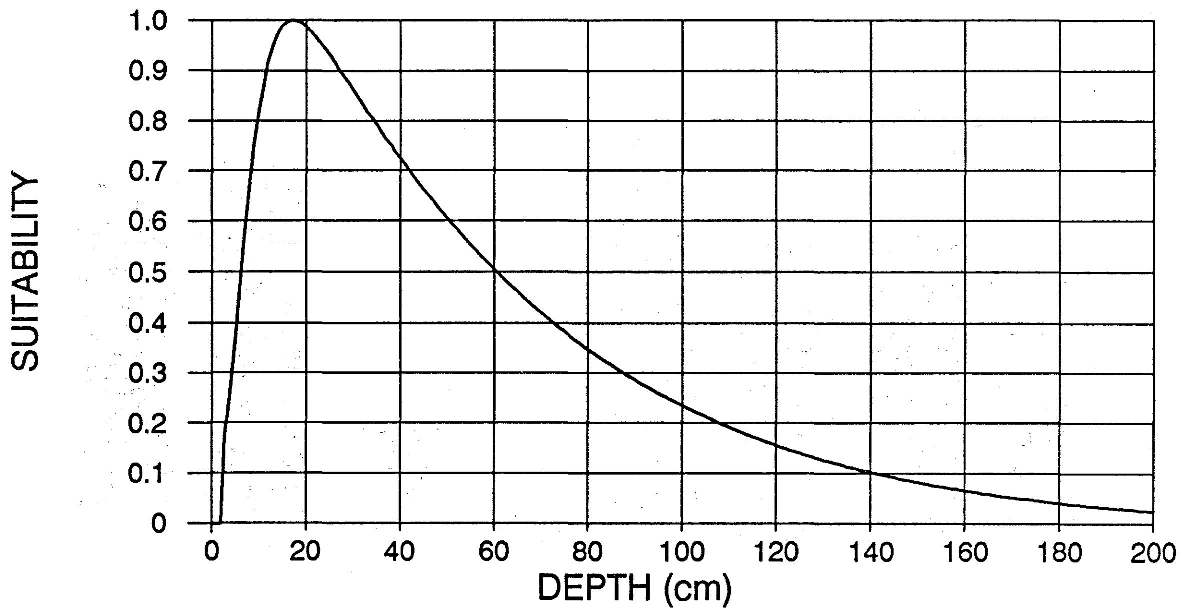


FIGURE 132. Depth preference of juvenile white sucker (75-300 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1274, number of samples=156).

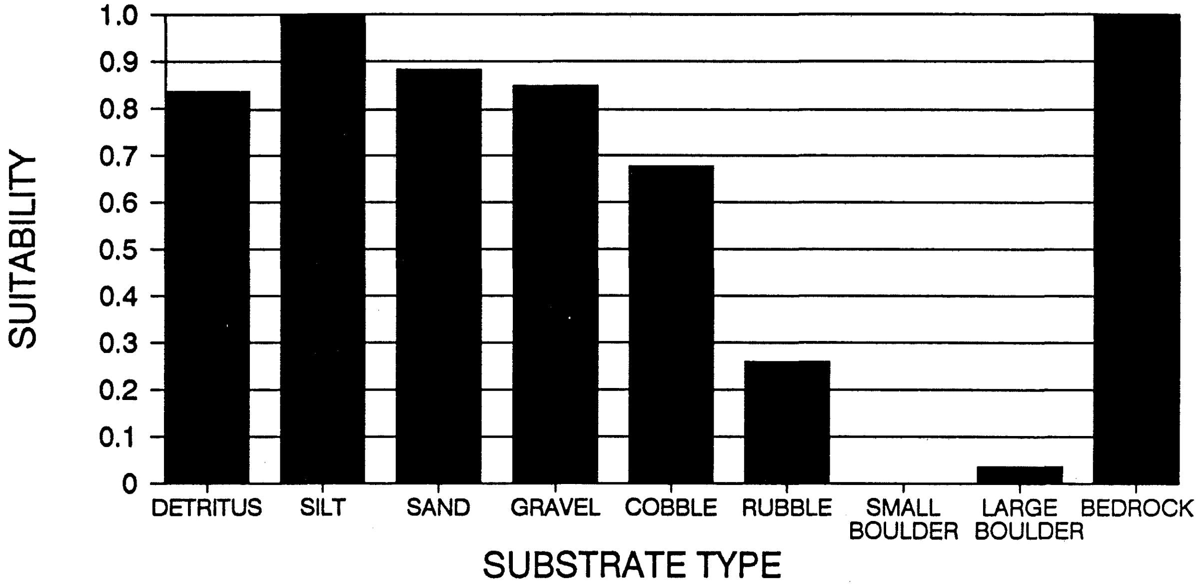


FIGURE 133. Dominant substrate preference of juvenile white sucker (75-300 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1274, number of samples=156).

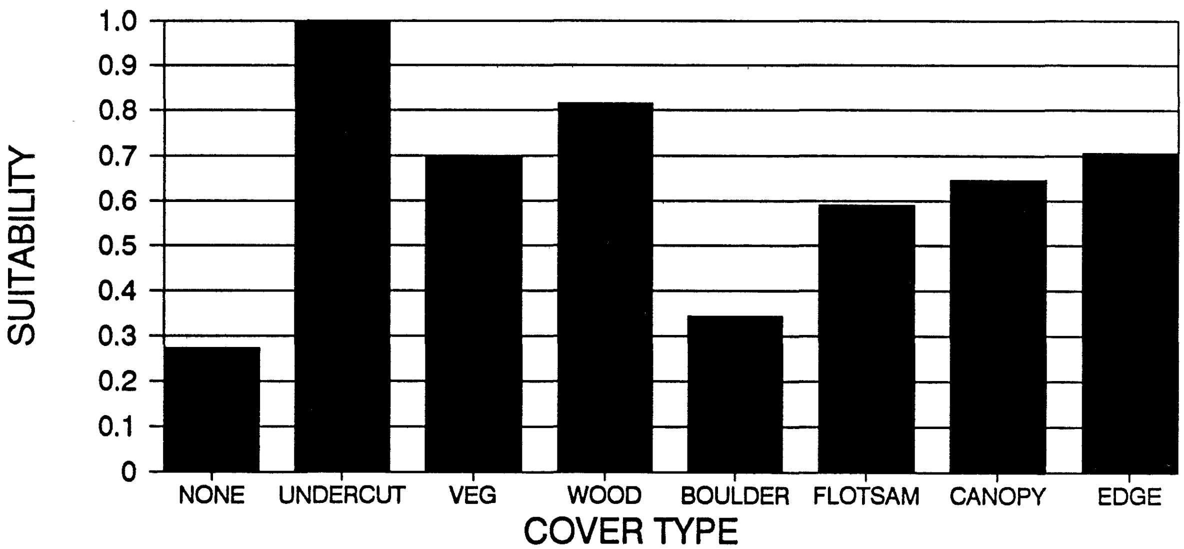


FIGURE 134. Cover preference of juvenile white sucker (75-300 mm) in the Zumbro, Snake, and Yellow Medicine rivers (number of individuals=1274, number of samples=156).

DISCUSSION

CURVE TRANSFERABILITY

Comparisons of habitat preference curves developed in this study with those from outside sources showed pronounced differences for some species life stages. For instance, velocity preference curves for smallmouth bass adults developed by Edwards et al. (1983) suggest 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 (Fig. 135). We found similar inconsistencies with curves for other smallmouth bass life stages (Figs. 136-140). Wiley et al. (1987) also found discrepancies in habitat preference values for many of the species life stages they compared.

Discrepancies between other habitat suitability curves and the preference curves developed in this study relate to techniques of developing curves, to geographic differences, to range of habitats sampled, and to interaction effects of variables and biotic interactions. 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. For instance, depth and velocity curves for smallmouth bass developed by Edwards et al. (1983) were substantially different from those we developed (Figs. 137-140). These subjective techniques may lead to different conclusions than those derived from empirical data. For instance, 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. 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. Adult banded darter in the Zumbro and Yellow Medicine rivers preferred fast riffles whenever available but were found in slow riffles during low flows in the Yellow Medicine river when faster water was not present. Biases due to interaction between variables, like depth and velocity would also be most evident in streams lacking adequate habitat variation. 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

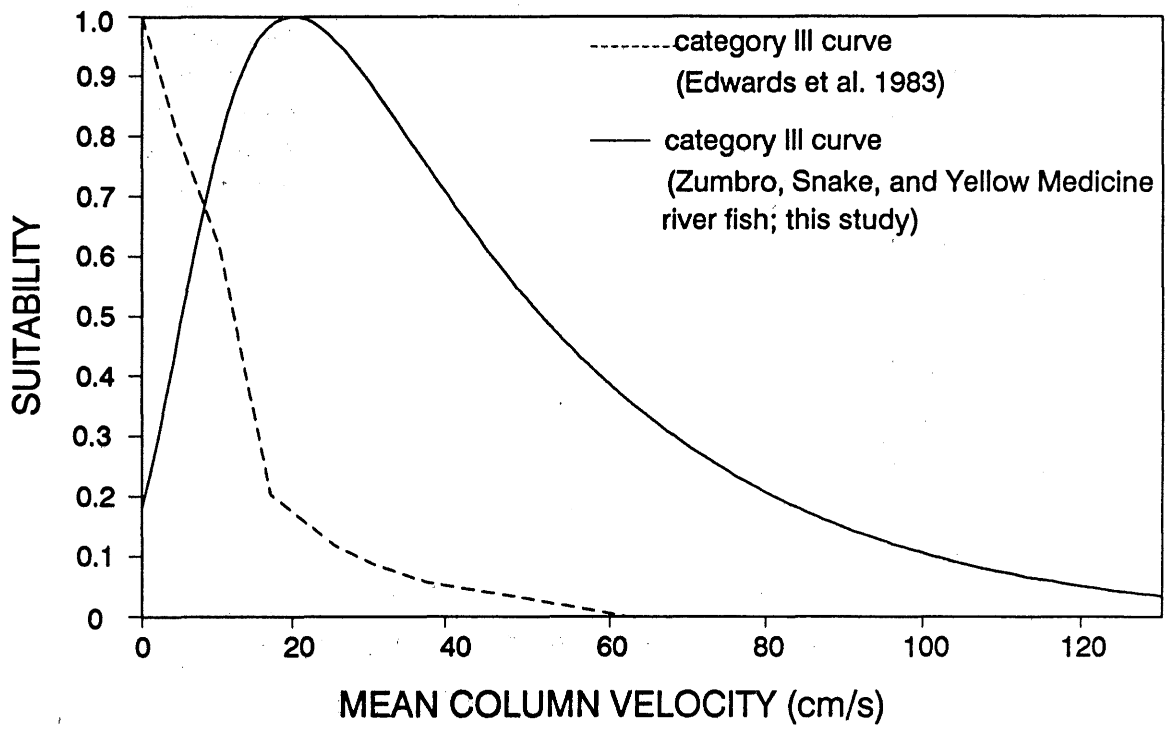


Figure 135. Comparison of category III velocity suitability curves for adult smallmouth bass.

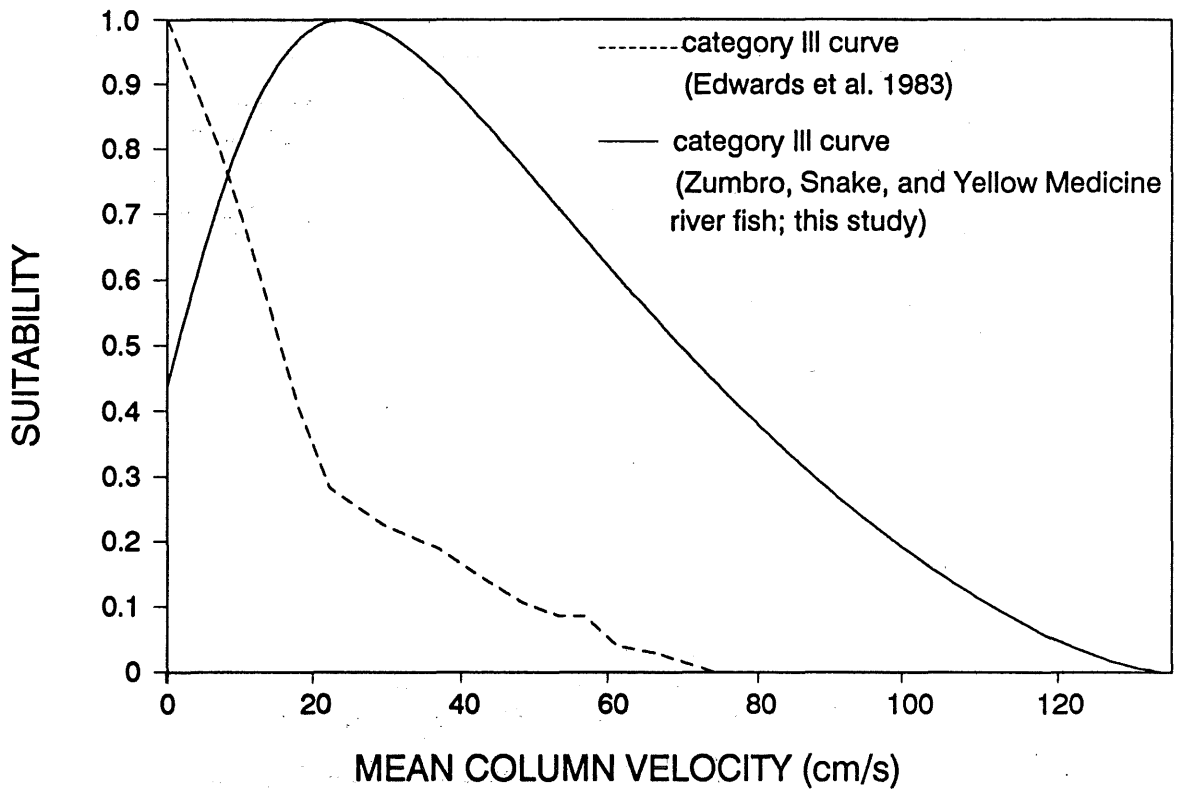


Figure 136. Comparison of category III velocity suitability curves for juvenile smallmouth bass

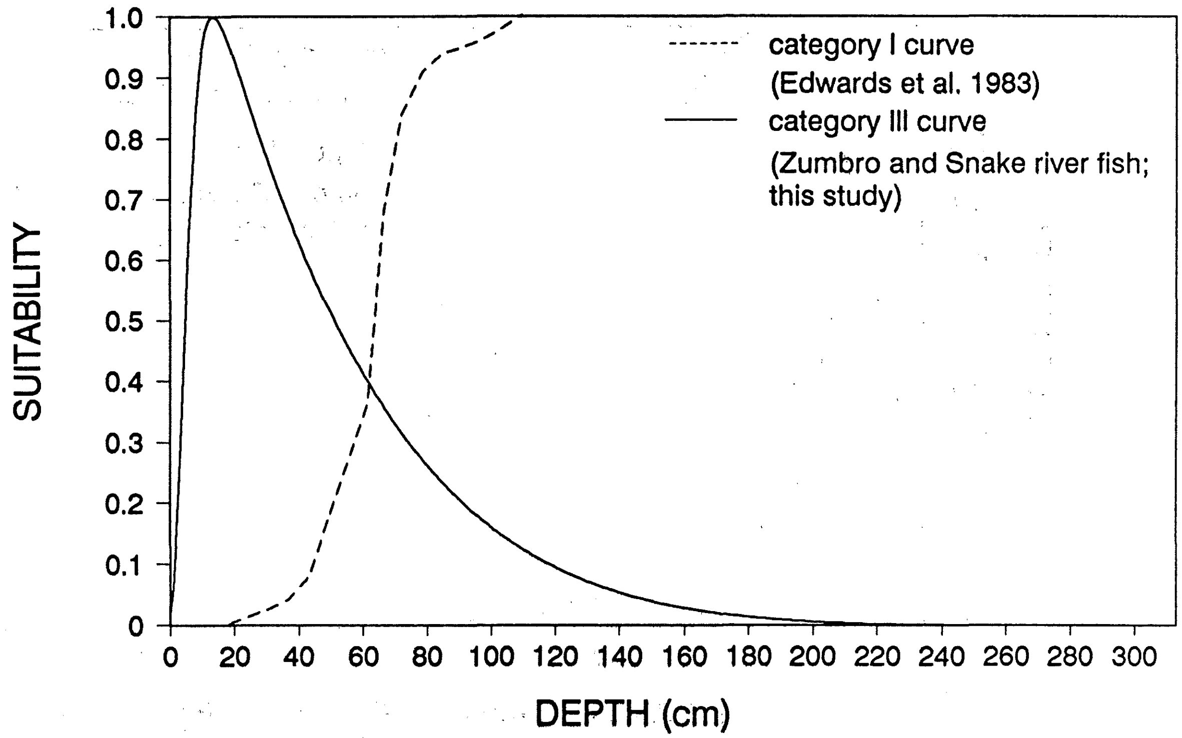


Figure 137. Comparison of category I and III depth suitability curves for smallmouth bass fry.

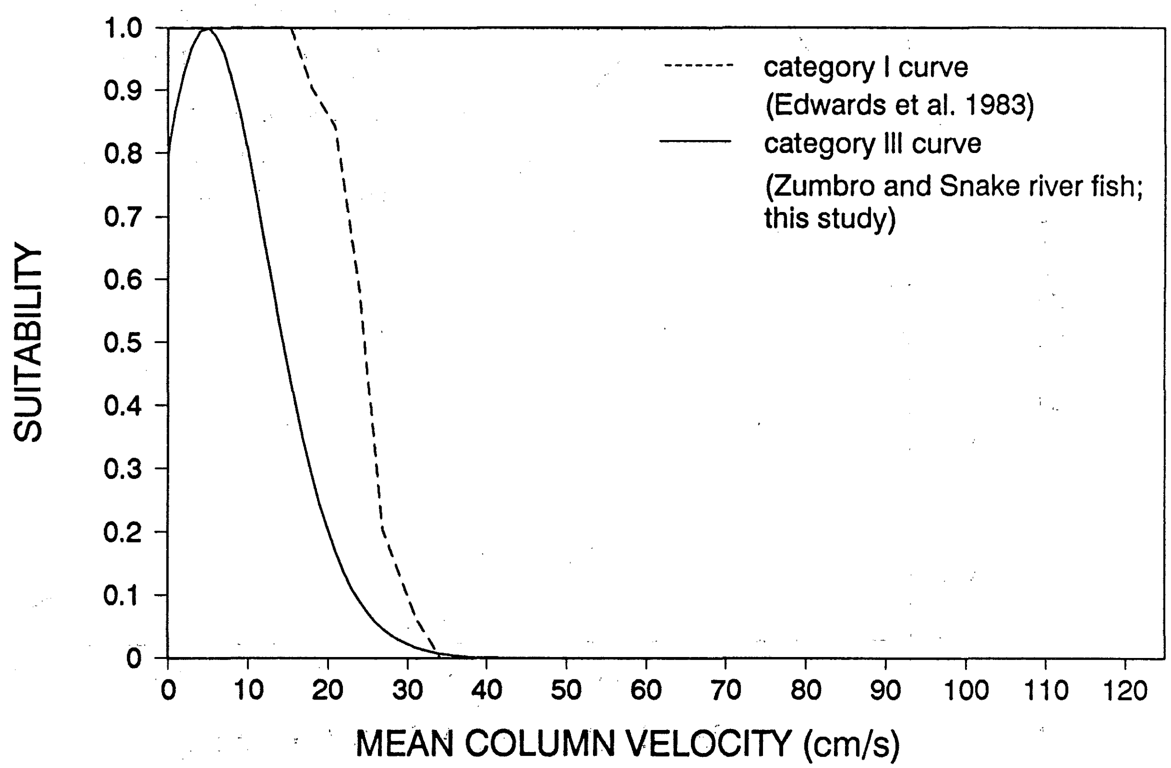


Figure 138. Comparison of category I and III velocity suitability curves for smallmouth bass fry.

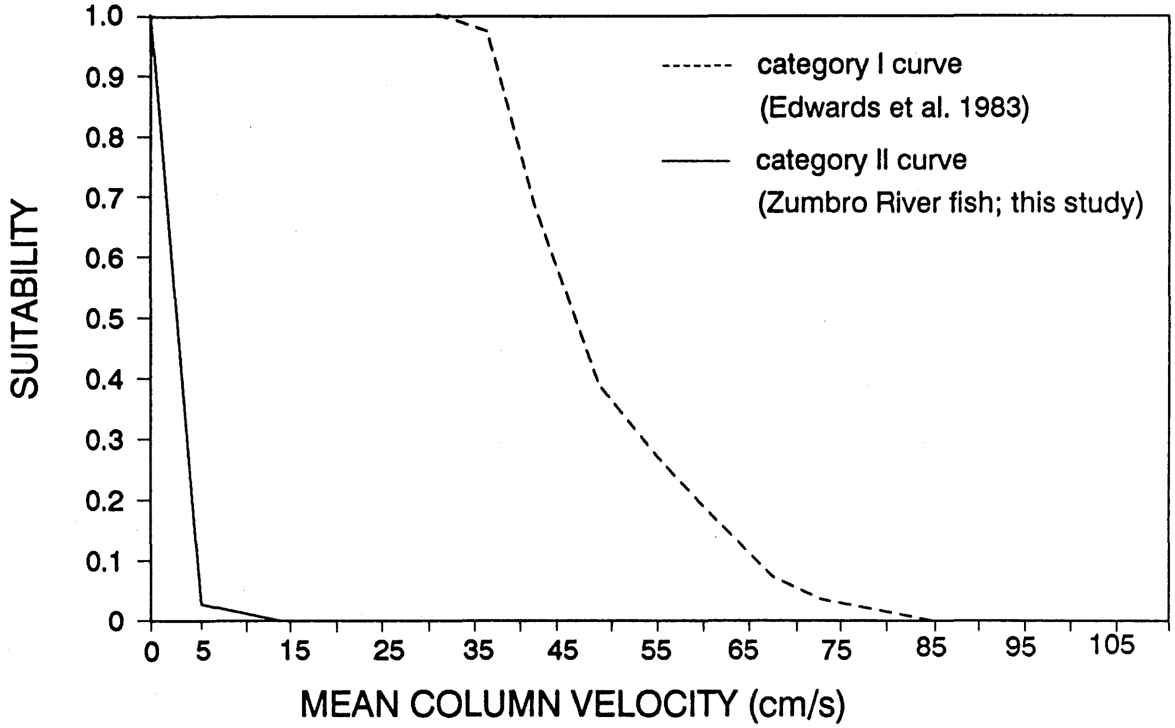


Figure 139. Comparison of category I and III velocity suitability curves for spawning smallmouth bass.

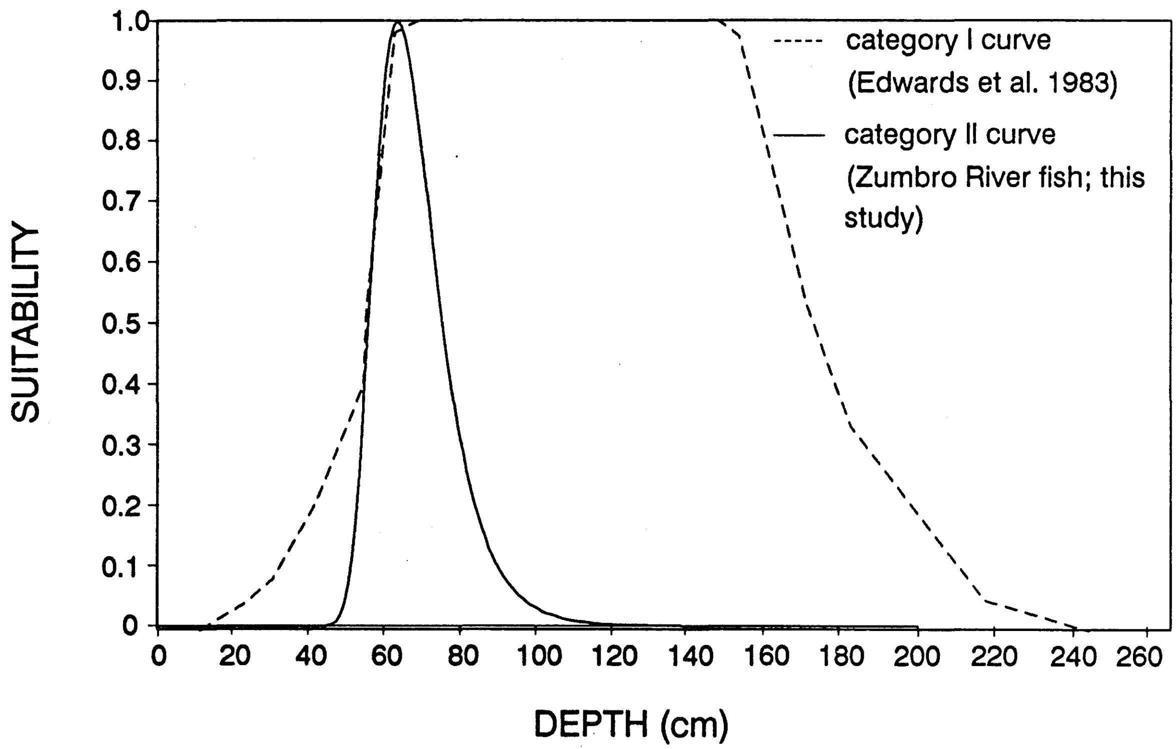


Figure 140. Comparison of category I and III depth suitability curves for spawning smallmouth bass.

biased because of the lack of adequate velocity in deep areas. Development of multivariate criteria, is cost prohibitive due to the large number of observations which would be necessary. The three study streams used here contained a wide range of habitat types, velocities, depths, substrates, and cover types, thus allowing us to minimize these biases in development of category III (preference) curves.

Biotic interactions also cause differences in habitat preference curves. Werner and Mittelbach (1981) and Schlosser (1987) have shown predation and competition can cause changes in habitat use by fishes. Consequently, regional differences in species assemblages and predator-prey relationships may also explain differences in habitat suitability curves. For instance, juvenile smallmouth bass preferred raceways and slow riffles in the Snake river where they fed largely on mayflies, caddisflies, and other riffle-oriented invertebrates; Zumbro River bass preferred medium pools and fed largely on crayfish and fishes. Insects are smaller and have a lower caloric content than do fish or crayfish and may require the predator to spend a greater proportion of their time feeding to obtain the same food value. For these reasons, it is preferable that curves used in IFIM studies be developed in streams similar to those being assessed, and that species selected for IFIM simulations be appropriate for the river section being assessed. As noted previously, we further reduced these biases by fitting preference functions only to data from streams when velocity or depth ranges did not appear to restrict distributions.

Another factor limiting the value of curve comparisons is the lack of adequate documentation of available curves. The most extensive library of suitability criteria is kept by the U.S. Fish and Wildlife Service in Fort Collins, Colorado. Unfortunately, explicit methods and length breaks of life stages are largely unavailable for many of the curves. 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.

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. Unweighted (presence or absence) curves have been the convention in most microhabitat studies. This is probably because researchers can only record a limited number of individuals at a time when making observations by snorkeling or SCUBA.

Both unweighted and weighted data were used in habitat preference calculations in this study. Unweighted curves were preferred when the species life stage was known to school. Weighted curves were used for species life stages which were consistently concentrated in the same 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. Use of weighted curves in this instance would be most appropriate. In most instances, weighted and unweighted curves gave very similar results when both were calculated for a species-life stage.

MEAN COLUMN VERSUS NOSE VELOCITY

All velocity criteria presented here have been mean column. Velocity criteria have also been presented using nose velocity. Use of nose velocities for riffle fishes in PHABSIM may be deceptive since most riffle species orient their snouts near the stream bottom where velocities are low. Riffle-loving fishes were rarely found in habitat types with low mean column velocities such as backwaters and pools even though bottom velocities in these areas were similar to those in riffles. Since bottom velocities in riffles and backwaters are similar (near zero; Morisawa 1968), nose velocity may have little value as a predictive variable. Therefore, it is our opinion that mean column velocity more reliably describes habitat used by fish in warmwater streams.

LIMITATIONS OF COVER

Cover does not seem to be important for some species-life stages (those with a preference value of one for no cover). In these instances, it may be advisable to exclude cover from IFIM analyses unless actual avoidance of cover is suspected. Apparent avoidance of cover may be an artifact of the distribution of cover in the channel where the preference data were collected rather than true avoidance. For instance, spawning walleyes use areas with no cover more frequently than areas with cover in the Mississippi River. It is not likely that they were avoiding cover, there simply was very little cover present in the gravel bottomed riffles where they were spawning. Consequently, use of cover was not presented for spawning walleyes. This does not pose any problems if the preference curves are developed in the stream or a similar stream for which the IFIM analyses are being conducted. If, however, the study stream has a much different distribution of cover than the stream where the curves were developed, the analysis could be distorted.

Edge (current break) was included as a cover type because it appeared to be an important attribute for some species-life stages. Edge was the preferred cover type for adult smallmouth bass and channel modifications which create edge may be valuable habitat enhancement methods.

HABITAT ENHANCEMENT

Microhabitat suitability information presented here should be useful as a guideline for habitat enhancement projects. Various habitat structures have been widely used in coldwater (trout) streams and are now being considered for use in warm and cool water streams as well. A primary question should be considered before such projects are undertaken: Is habitat limiting and, if so, what kind of habitat? This is a very complex and difficult question to answer *a priori* for a warmwater stream. If we wish to increase the number and size of adult bass do we need to improve spawning habitat, nursery habitat, juvenile habitat, adult resting habitat, or do we need to improve the habitat of their prey? Thorough population information will provide the answers to some of these questions, but we may need to understand the structure and dynamics of the community to accurately predict the full effects of the proposed habitat modifications.

The type of habitat structure used is also important since it must provide a preferred cover type for the species-life stage of interest. For instance, adult smallmouth bass did not show a strong preference for any of the cover types assessed in this study with the exception of current break (edge). In order to improve adult habitat, structures which create eddies and sharp riffle-pool interfaces may be most appropriate. In contrast, juvenile smallmouth bass show a strong preference for boulders. The use of boulders to create channel constrictions in run areas may be an effective way of providing habitat for both adults and juveniles.

Any habitat enhancements which are conducted should be well documented. Fish populations and communities should be assessed before and after installation so that any positive or negative effects can be noted. In addition, control sites should be established to monitor changes which may be due to extraneous variables.

A COMMUNITY ORIENTED APPROACH FOR IFIM STUDIES

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 coldwater streams with low species diversities, it is not adequate for warmwater streams. The energetics of warmwater streams are very complex and an over-simplified approach (single or few target species) 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 (Fig. 26) and 75% of those prey items consumed had the highest densities in riffles. 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 summarize 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 differ for each of the guild representatives so interpretation of the habitat simulation will require a good understanding of the stream's community dynamics and the management objectives the stream.

It is very difficult to determine the amount of habitat (WUA) required by one species life stage relative to another. For instance, do adult smallmouth bass need more habitat area than young-of-the-year to maintain a healthy population? In some situations, where good population data are available, there may be indications that spawning or nursery habitat is limited. Under these circumstances, one species-life stage may be emphasized or when detailed population, recruitment, and reproduction data are available, various optimization techniques specific to a single species may be used. Frequently, however, this type of data is lacking or there are multiple species of interest. In the absence of specific management objectives we recommend following the interpretive approach outlined in Loar and Sale (1981), Bovee (1982), Sale et al. (1982) and Leonard et al. (1986); 1) normalize all WUA versus discharge relationships so that the optimal discharge for that species-life stage has a value of one and 2) determine the life stage with the lowest normalized WUA at each discharge and use these values as the indicators of optimal discharge. By using this method, no assumptions are made about how much one life stage requires relative to another. Instead, the species-life stages whose habitat is most restricted at a given flow are those on which recommendations are based.

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 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 rivers of similar order and gradient, but may not be appropriate on streams such as the Minnesota River, which are morphologically dissimilar to the our study streams. 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 were 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.

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. This study moves towards filling this knowledge void. Every effort should be made to continue this program for the protection of Minnesota's stream resources.

CONCLUSIONS

The Instream Flow Incremental Methodology is a valuable tool for assessing the effects of regulation and withdrawal on stream fishery resources. Selection of appropriate target species is an important step in the application of IFIM. Game species are frequently the sole focus of instream flow investigations. Due to the complexity of warmwater streams, selection of only game species for flow assessments may be inadequate. Game fishes are usually predators and depend on other fishes and invertebrates for their survival. The interdependency of aquatic organisms warrants the investigation of flow effects on the entire stream community.

The habitat guild approach allows the selection of representative indicator species so that flow effects on the different biotic components of the stream community can be assessed. Six guilds were identified (shallow pool, medium pool, deep pool, raceway, slow riffle, and fast riffle) and we recommend that representatives from each of these guilds be included in stream flow assessments. By plotting weighted useable area against discharge for each of these representatives, guilds sensitive to proposed changes in flow regime can be identified. Protection of these sensitive elements should help to preserve the integrity of the stream ecosystem.

Other components of the stream ecosystem should be considered in future studies and assessments. Stream fishes may be food-limited under some conditions (Irvine et al. 1986) and invertebrate production may be a key element in defining fish biomass and size structure. Habitat preference criteria for invertebrates are needed to properly examine the effects of altered flow regimes on stream ecosystems. Protection of fish habitat cannot be expected to yield predictable results if an unprotected component of the ecosystem limits production.

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APPENDIX I:

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

PETROMYZONTIDAE/LAMPREYS
- Chestnut lamprey.........*Ichthyomyzon castaneus*

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

UMBRIDAE/MUDMINNOW
- Central Mudminnow.......*Umbra limi*

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

CYPRINIDAE/CARPS and MINNOWS
- Central Stoneroller......*Campostoma anomalum*
- Largescale Stoneroller...*Campostoma oligolipis*
- Carp.....................*Cyprinus carpio*
- Hornyhead Chub...........*Nocomis biguttatus*
- Golden Shiner............*Notemigonus crysoleucas*
- Emerald Shiner...........*Notropis atherinoides*
- River Shiner.............*Notropis blennius*
- Common Shiner............*Notropis cornutus*
- Blackchin Shiner.........*Notropis heterodon*
- Blacknose Shiner.........*Notropis heterolepis*
- Spottail Shiner..........*Notropis hudsonius*
- Spotfin Shiner...........*Notropis spilopterus*
- Sand Shiner..............*Notropis stramineus*
- Mimic Shiner.............*Notropis volucellus*
- Suckermouth Minnow.......*Phenacobius mirabilis*
- Bluntnose Minnow.........*Pimephales notatus*
- Fathead Minnow...........*Pimephales promelas*
- Blacknose Dace...........*Rhinichthys atratulus*
- Longnose Dace............*Rhinichthys cataractae*
- Redside Dace.............*Clinostomus elongatus*
- Creek Chub...............*Semotilus atromaculatus*

CATOSTOMIDAE/SUCKERS
- River Carpsucker.........*Carpiodes carpio*
- Quillback Carpsucker.....*Carpoides cyprinus*
- White Sucker.............*Catostomus commersoni*
- Spotted Sucker...........*Minytrema melanops*
- Northern Hog Sucker......*Hypentelium nigricans*
- Smallmouth Buffalo.......*Ictiobus bubalus*
- Silver Redhorse..........*Moxostoma anisurum*
- River Redhorse...........*Moxostoma carinatum*
- Golden Redhorse..........*Moxostoma erythrurum*
- Shorthead Redhorse.......*Moxostoma macrolepidotum*
- Greater Redhorse.........*Moxostoma valenciennesi*

ICTALURIDAE/CATFISHES

Black Bullhead...........*Ictalurus melas*
Yellow Bullhead..........*Ictalurus natalis*
Channel Catfish..........*Ictalurus punctatus*
Stonecat.................*Noturus flavus*

GADIDAE/CODFISHES
Burbot...................*Lota lota*

ATHERINIDAE/SILVERSIDES
Brook Silverside.........*Labidesthes sicculus*

PERCICHTHYIDAE/TEMPERATE BASSES
White Bass...............*Morone chrysops*

CENTRARCHIDAE/SUNFISHES
Rock Bass................*Ambloplites rupestris*
Green Sunfish............*Lepomis cyanellus*
Orangespotted Sunfish....*Lepomis humilis*
Bluegill Sunfish.........*Lepomis macrochirus*
Smallmouth Bass..........*Micropterus dolomieui*
Largemouth Bass..........*Micropterus salmoides*
White Crappie............*Pomoxis annularis*
Black Crappie............*Pomoxis nigromaculatus*

PERCIDAE/PERCHES
Rainbow Darter...........*Etheostoma caeruleum*
Fantail Darter...........*Etheostoma flaballare*
Johnny Darter............*Etheostoma nigrum*
Banded Darter............*Etheostoma zonale*
Yellow Perch.............*Perca flavescens*
Log Perch................*Percina caprodes*
Gilt Darter..............*Percina evides*
Blackside Darter.........*Percina maculata*
Slenderhead Darter.......*Percina phoxocephala*
Sauger...................*Stizostedion canadense*
Walleye..................*Stizostedion vitreum*

SCIAENIDAE/DRUMS
Freshwater Drum..........*Aplodinotus grunniens*

APPENDIX II

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

ABBREVIATION AND COMMON NAME	Y-O-Y	JUV	ADT
CYPRINIDAE/CARPS AND MINNOWS			
Carp		200	300
Central Stoneroller		65	79
Largescale Stoneroller		65	80
Blackchin Shiner			40
Blacknose Shiner		40	80
Bluntnose Minnow			50
Common Shiner		50	81
Creek Chub		65	81
Emerald Shiner			41
Fathead Minnow			40
Golden Shiner			64
Hornyhead Chub		50	100
Mimic Shiner			40
River Shiner			60
Sand Shiner			40
Spotfin Shiner			41
Spottail Shiner			67
Suckermouth Minnow		40	80
Blacknose Dace			40
Longnose Dace			50
Redside Dace		40	60
CATOSTOMIDAE/SUCKERS			
Quillback Carpsucker		150	350
River Carpsucker		170	370
Northern Hog Sucker		70	151
Smallmouth Buffalo		250	350
Spotted Sucker		60	250
White Sucker		75	301
Golden Redhorse		100	251
Greater Redhorse		50	430
River Redhorse		50	350
Shorthead Redhorse		100	250
Silver Redhorse		100	250

ABBREVIATION AND COMMON NAME	YOY	JUV	ADT
ICTALURIDAE/CATFISHES			
Black Bullhead		70	150
Yellow Bullhead		70	150
Channel Catfish		80	310
Stonecat		50	100
GADIDAE/CODFISHES			
Burbot			250
ATHERINIDAE/SILVERFISHES			
Brook Silverside			60
PERCICHTHYIDAE/TEMPERATE BASSES			
White Bass		150	300
CENTRARCHIDAE/SUNFISHES			
Bluegill Sunfish		35	100
Green Sunfish			50
Orangespotted Sunfish		30	50
Rock Bass		50	70
Smallmouth Bass	60	100	189
Largemouth Bass		100	250
Black Crappie		90	150
White Crappie		90	150
PETROMYZONTIDAE/LAMPREYS			
Chestnut Lamprey		70	130
CLUPEIDAE/HERRINGS			
Gizzard Shad			150
UMBRIDAE/MUDMINNOW			
Central Mudminnow			50
SCIAENIDAE/DRUMS			
Freshwater Drum		125	300
ESOCIDAE/PIKES			
Northern Pike			250
PERCIDAE/PERCHES			
Banded Darter			38
Blackside Darter			70
Fantail Darter			40
Gilt Darter			70
Johnny Darter			56
Rainbow Darter			40
Slenderhead Darter			40

ABBREVIATION AND COMMON NAME	YOY	JUV	ADT
Log Perch			61
Yellow Perch		70	150
Sauger		150	250
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
Banded Darter, *Etheostoma zonale*				
adult				
velocity	194	88.3	62.3	0.183
depth	355	23.6	10.8	41.1
young-of-the-year				
velocity	744	58.7	117	0.814
depth	355	19.2	15.1	48.5
Bluntnose Minnow, *Pimephales notatus*				
adult				
velocity	489	25.4	319	0.477
depth	500	25.4	9.92	60.8
Central Stoneroller, *Campostoma anomalum*				
adult				
velocity	195	79.2	61.9	0.269
depth	499	25.3	22.0	38.7
juvenile				
velocity	143	55.7	61.8	0.575
depth	355	20.0	20.5	37.2
young-of-the-year				
velocity	146	55.7	65.0	0.565
depth	355	11.5	21.2	82.4
Channel Catfish, *Ictalurus punctatus*				
juveniles				
velocity	90	13.1	29.9	0.487
depth	288	87.8	92.9	0.676
Emerald Shiner, *Notropis atherinoides*				
adult				
velocity	135	19.8	1.08	2.25
depth	9370000	7.14	188000	7640000

SPECIES CURVE	B	A	C	D
Emerald Shiner, *Notropis atherinoides* (cont.)				
young-of-the-year				
velocity	406	0	12.45	18.21
depth	398	11.6	19.1	61.8
Log Perch, *Percina caprodes*				
adult				
velocity	356	42.3	4.92	23.5
depth				
Longnose Dace, *Rhinichthys cataractae*				
adult				
velocity	180	98.9	101	0.063
depth	355	9.04	9.08	163
young-of-the-year				
velocity	2410000	13.3	33700	225000
depth	355	5.53	12.6	1000
Northern Hog Sucker, *Hypentelium nigricans*				
adult				
velocity	177	90.7	112	0.059
depth	500	65.6	18.8	12.3
juvenile				
velocity	178	85.2	109	0.110
depth	355	6.30	8.38	1160
Sand Shiner, *Notropis stramineus*				
adult				
velocity	165	53.6	76.1	0.34
depth	235	14.5	20.0	25.0
young-of-the-year				
velocity	365	0.000	12.5	150
depth	388	8.36	12.9	171
Shorthead Redhorse, *Moxostoma macrolepidotum*				
adult				
velocity	845	64.7	25.8	10.2
depth	500	92.9	168	1.77
juvenile				
velocity	135	18.9	2.56	13.7
depth	356	64.2	14.2	7.89
young-of-the-year				
velocity	135	33.6	1.93	13.7
depth	355	12.7	5.26	129

SPECIES CURVE	B	A	C	D
Shorthead Redhorse, *Moxostoma macrolepidotum*				
spawning				
velocity	154	112	0.239	2.88
depth	135	99.3	2.42	1.02
Slenderhead Darter, *Percina phoxocephala*				
adult				
velocity	40300000	50.2	1600000	821000
depth	371	28.7	8.93	32.6
spawning				
velocity	200	55.3	3.06	8.63
depth	355	32.3	185	8.06
Smallmouth Bass, *Micropterus dolomieui*				
fry				
velocity	125	4.81	26.8	9.58
depth	350	13.5	6.34	109
fingerling				
velocity	130	33.8	0.755	6.71
depth	350	30.0	1.97	52.2
juvenile				
velocity	135	23.8	1.59	11.4
depth	502	54.8	6.57	30.4
adult				
velocity	370	19.3	9.42	46.2
depth	391	124	95.9	0.484
spawning				
velocity	no curve			
depth	26400000	63.0	3200000	3520000
Walleye, *Stizostedion vitreum vitreum*				
spawning				
velocity	429	57.0	24.1	20.4
depth	355	62.0	23.1	15.6
White Sucker, *Catostomus commersoni*				
juvenile				
velocity	135	29.9	1.29	1.54
depth	598	17.3	9.67	138
young-of-the-year				
velocity	135	17.3	18.8	0.251
depth	355	6.87	12.9	230

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