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Evaluation of half-logs as habitat improvement structures for smallmouth bass (*Micropterus dolomieui*) and rock bass (*Ambloplites rupestris*).

presented by

Jill Ann Dufour

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William W. Taylor
Major professor

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EVALUATION OF HALF-LOGS AS HABITAT IMPROVEMENT STRUCTURES FOR SMALLMOUTH BASS (Micropterus dolomieui) AND ROCK BASS (Ambloplites rupestris).

By

Jill Ann Dufour

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ABSTRACT

EVALUATION OF HALF-LOGS AS HABITAT IMPROVEMENT STRUCTURES FOR SMALLMOUTH BASS (*Micropterus dolomieui*) and ROCK BASS (*Ambloplites rupestris*).

By

Jill A. Dufour

Installation of in-stream half-log structures has proven effective for increasing abundance of cold water species but has remained untested in warm water systems. To evaluate this, 3.0 x 0.3 m half-logs were installed at four stations in the Red Cedar River near Lansing, Michigan to test whether they would increase densities of smallmouth bass (*Micropterus dolomieui*) and/or rock bass (*Ambloplites rupestris*). Logs were installed in 40 meter test sites to provide a 20% increase in cover. Monthly sampling of sites installed in 1986 showed density increases of 24% for smallmouth bass and 99% for rock bass in test areas as compared to the control but neither change was significant at the .05 level. Abundances of both species were found to vary greatly from month to month with the highest estimates occurring in the months of July and August. Invertebrate species found in the gastrointestinal tracts of smallmouth and rock bass caught in the Red Cedar were also found colonizing the logs; supporting the hypothesis that in-stream structures might provide food items. Although density changes to date are insignificant, data trends

indicate that longer-term monitoring might show half-logs to be an effective technique for managers seeking to increase abundance of these warm water game species.

For you, Mom and Dad

ACKNOWLEDGEMENTS

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Many thanks are also owed to my parents and sister, who provided suggestions (How <u>do</u> you drill a hole through a one foot oak log?), field assistance (at the cost of a toe) and constant encouragement.

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INTRODUCTION

The goal of fisheries habitat management is to provide more favorable living conditions such that abundance and size of the fish are increased and the quality of the sport fishing experience is improved. Habitat manipulations can be used to increase the carrying capacity of the system; carrying capacity being defined as the amount of fish (or any other organism) that a stream has the resources to sustain over a given time (White and Brynildson 1967). "Habitat" is usually considered to be "the place where a population lives, both living and non-living" (Smith 1977). In recent years however, ecological theorists in fisheries (Kerr 1980) have begun to equate this interface between an organism and its environment with Hutchinson's (1957) concept of "niche", that is, an "n-dimensional hypervolume" arising from the combination of biotic and abiotic componentsnecessary for life. If any or all of the components are inadequate, fish survival, growth and reproduction may decrease or stop resulting in the loss of a self-sustaining fishery (White 1971). Conversely, if any component(s) is (are) enhanced through habitat management, then the quality of the fishery may be enhanced (i.e. more and/or bigger fish).

An important habitat component in running water systems is cover (White 1971). For the purposes of my study, cover has been defined as any structure which (a) re-directs current and/or (b) shades the substrate. It is considered crucial for the maintenance of stream-dwelling gamefish populations for a number of reasons. Cover provides protection from predators and forms pools and eddies which allow the fish a respite from fighting the current (Haines and Butler 1969). It also provides the wetable substrate which many aquatic invertebrates require for colonization (Hynes 1961, Angermeier and Karr 1984); many of which are favoured food for game species like bass and trout (George and Hadley 1979, Scott and Crossman 1979; respectively). Given these benefits, it has been hypothesized that the addition of cover might result in an increase in fish density; a desirable result for managers seeking to increase populations of game species.

Many of the structures commonly used in stream management efforts involving cover addition are constructed of, or incorporate, wood (White and Brynildson 1967). This can have significant implications for ecosystem production, since wood is the primary source of organic material in many streams (Andersen and Sedell 1979). Decomposition of such material involves colonization by organisms such as bacteria

(Triska et al. 1984), fungi (Shearer 1972) and invertebrates (Anderson et al. 1978, Benke et al. 1984). The quantity of woody material present in the stream, therefore, is positively correlated with production in these lower trophic levels (Anderson et al. 1978, Angermeier and Karr 1984) as well as with fish production (Coble 1975, Prince and Brouha (in preparation)). Hence, the addition of wood because of habitat management activities may not only serve to concentrate fish around a potential source of food and shelter, but may, in fact, increase ecosystem production.

Studies on a variety of habitat improvement methods which mimic the effects of naturally occurring woody debris have shown increased growth (Tarzwell 1930), survival (Gard 1961, Hunt 1971) and abundance (Boussu 1954; Saunders and Smith 1962, Burgess and Bider 1980) in coldwater salmonid populations. Hunt's (1978) study of the effects of adding in-stream structure (half-logs) on brown trout (*Salmo trutta*) demonstrated an average biomass increase of 188% and an increase in abundance of fish over 10 inches of 533%.

While structure addition has proven effective for increasing densities of cold water species like trout and salmon; it remains untested as a management technique for a number of important warm water sportfish fish. My hypothesis is that centrarchid populations will react to in-stream cover addition in a manner similar to salmonids due to a number of parallels in their respective habitat requirements. Both families of fish demonstrate strong behavioural associations with cover throughout their life histories. Salmonid and centrarchid juveniles are both negatively phototactic during their early ontogenies (Ritter and MacCrimmon 1973 and Haines and Butler 1969; respectively). The fry of both groups of fish actively seek out in-stream structure where they are less visible to potential predators and are sheltered from the current (MacCrimmon and Robbins 1981). There is no direct evidence of the influence of cover on mortality in the smallmouth and rock bass literature, but MacCrimmon (1954) has shown that survival of planted Atlantic salmon fry is higher in streams having more shelter.

The close association between centrarchid adults and structure is well documented (Hallam 1959, Brouha and von Geldern 1979, Prince and Maughan 1979), but why such congregations occur is not. One thing that is discussed extensively is its importance to centrarchid reproductive behaviour: both smallmouth and rock bass build their nests near the protection of logs and rocks (Cleary 1956, Pflieger 1966, Scott and Crossman 1979).

The purpose of my research has been to evaluate the effect of increasing cover, by adding half-logs, on the abundance of smallmouth bass (*Micropterus dolomieui*) and rock bass (*Ambloplites rupestris*). The hypothesis for the study was that densities of these species could be increased by adding in-stream cover in the form of half-logs; a desirable result for managers seeking to increase abundances of these two important warm water game species.

Study Area

The body of water used as a demonstration area for this project was the Red Cedar River, a fourth order warm water stream that flows through two Michigan counties (Ingham and Livingston) to its confluence with the Grand River in the City of Lansing (Figure 1). The river drains 472 square miles of predominantly agricultural land.

The four stations selected for the study were located between Okemos and Webberville (Figure 2). They represented a variety of warmwater riverine habitat types; varying in terms of substrate type, macrophyte density and available cover (a detailed summary of this information is presented in Table 1). The Dobie Road segments were predominantly composed of riffles (test and control segments were composed of 54% and 46% riffles, respectively). Occasional rocks were interspersed with submergent *Vallisneria americana* and *Sagittaria* sp..

The site at Sherwood Road had a substrate consisting primarily of silt and sand with patches of submergent macrophytes (*V. americana* and *Sagittaria* sp.). A number of submerged logs were present along its length, and gravel

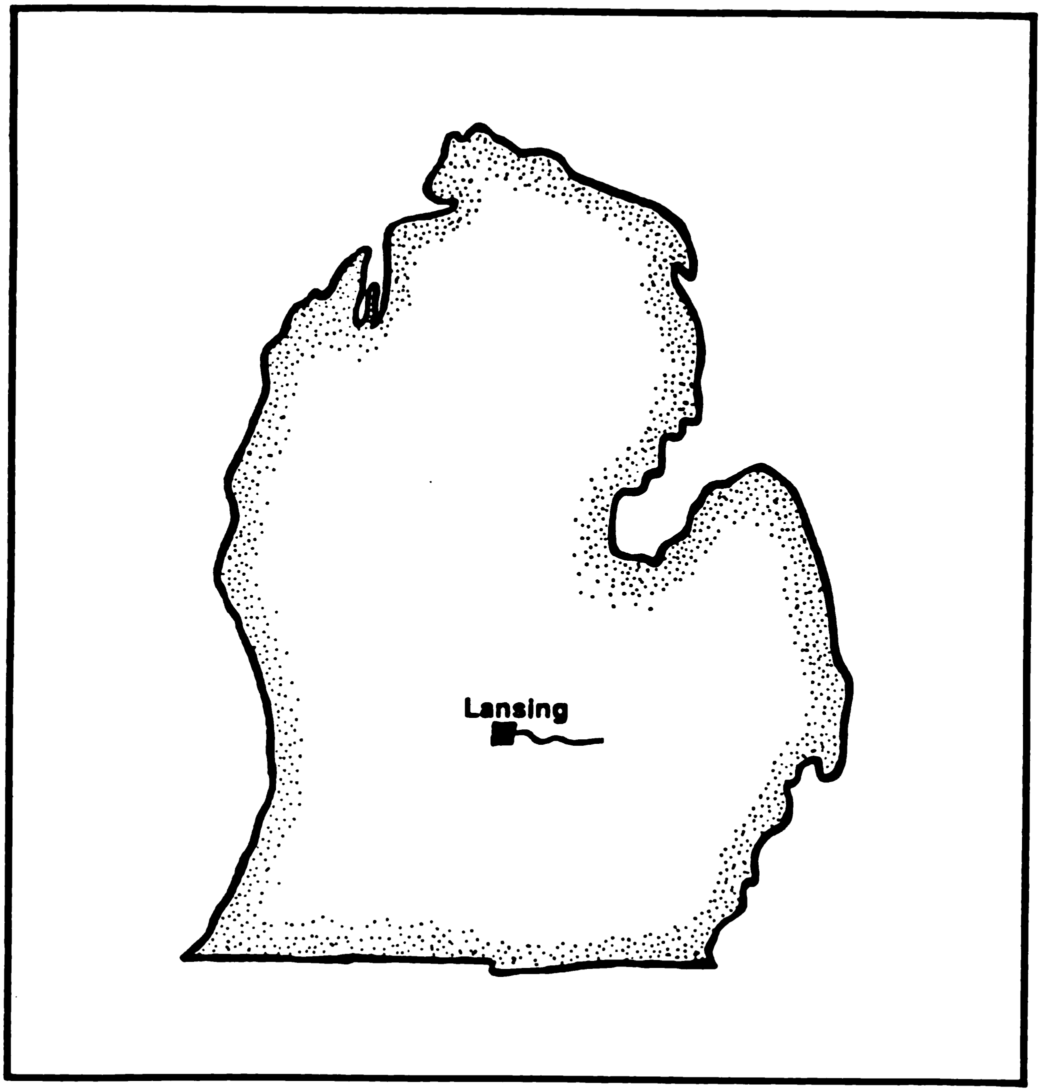

Figure 1. Map of the lower peninsula of Michigan showing the location of the Red Cedar River

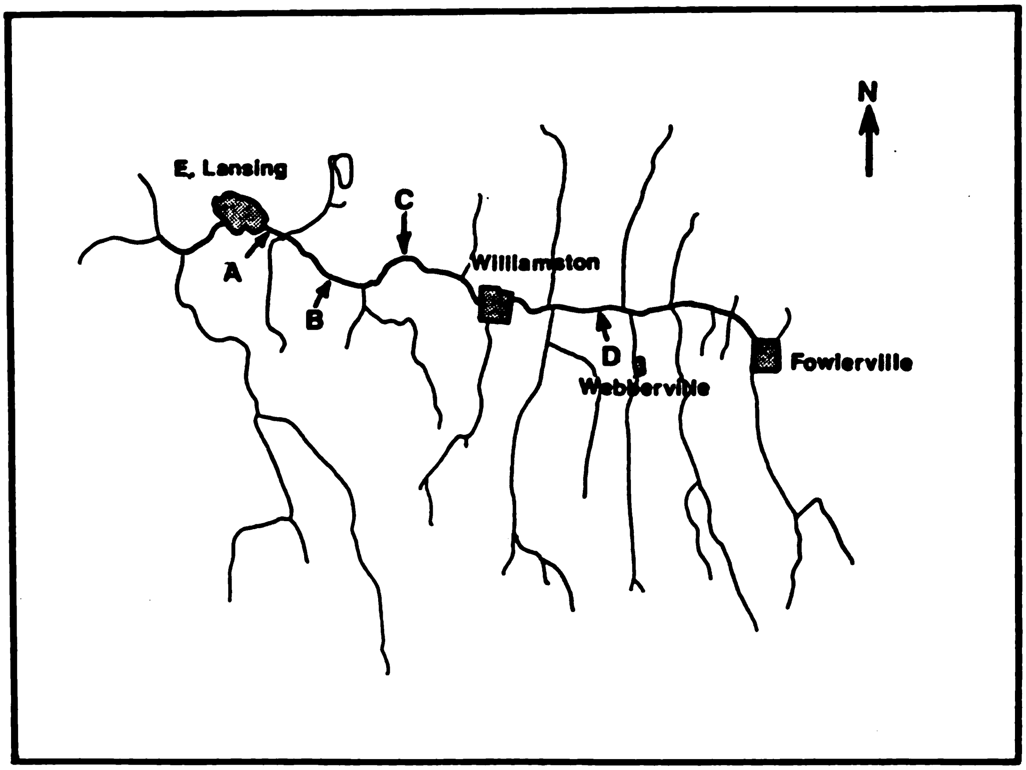

Figure 2. Map of the Red Cedar River and its tributaries showing the station locations: A = Dobie
B = Vanatta
C = Sherwood
D = M-52

Table 1. Summary of habitat data for eight study sites on the Red Cedar River, Michigan. Habitat category areas are expressed as percentages of total station surface area. Test sites (logs added) are denoted by "T" and control sites (no logs) are denoted by "C".

	SITES							
Habitat	Sherwood		Dobie		Vanatta		M-52	
Categories	T	C	T	C	T	C	T	C
Bank overhang						1.4	3.0	
Log-pool	3.8		12.1				5.7	
Emergent macrophytes	7.6	21.9			8.2	7.4	4.7	7.9
Gravel run	29.9					27.1		
Gravel bar	28.1		6.3					
Silt Glide	18.2				25.0		23.5	
Submergent macrophytes	9.4	30.0	13.0	41.1				
Woody debris	3.1	11.4	14.1	12.4	17.4	27.4	16.3	20.9
Rocks (>5")								12.3
Sand		36.7			49.4	36.6	46.9	58.5
Riffle			54.4	46.4				
Total Area (m^2)	713	904	808	952	801	875	877	506

runs, riffles and a weir provided additional habitat diversity.

The Vanatta Road station, located slightly upstream of the Vanatta bridge, is characterized by a muck/silt substrate and a preponderance of woody material (17% and 24% of the test and control sites, respectively).

The last station was located near Webberville where highway M-52 crosses the Red Cedar. It was a diverse site in terms of the richness of habitat types present. Gravel runs and riffles alternated with silty eddies and submerged woody debris.

Each of the four stations was divided into three sampling subunits: a 40 m experimental site to which half-logs were added, a 40 m site having no half-logs, and a separation zone between the two of at least 100 m to ensure that there was no mixing between the segments (Figure 3). The length of this separation zone was based on telemetry data from smallmouth bass movement studies in Ozark streams which indicated that smallmouth do not move (Rabeni, personal communication).

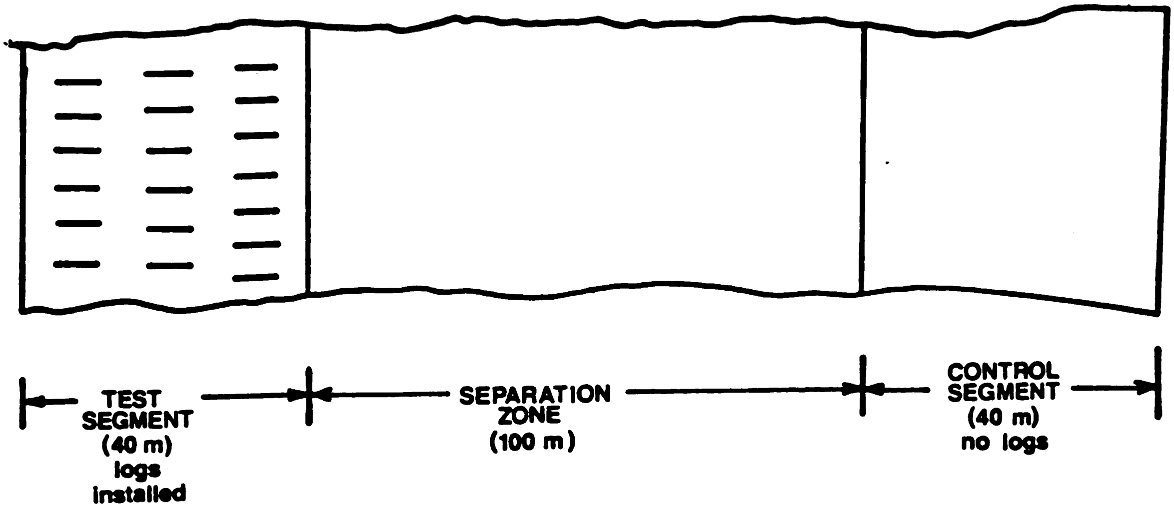

Figure 3. Schematic showing placement of test segment (logs added), control segment (no logs) and separation zone (minimum 100 m) at each of the four stations.

METHOD

Site mapping and log installation at the four sites were carried out in two phases. The Dobie and Sherwood road stations were installed in July, 1986, and the Vanatta and M-52 stations in April 1987. Station placement along the river was determined by three criteria:

(a) Easy access to a road to facilitate log transport,

(b) Water shallow enough to be waded and shocked from April to October, and

(c) A homogeneous distribution of habitat types within each station so that similar test and control sites could be chosen.

Site Mapping

A visual survey of approximately one quarter mile of river at each station was done to choose the 40 m test and control segments. Existing habitat was first categorized (bank overhang, log-pool complex, emergent macrophytes, gravel run, gravel bar, silt glide, submergent macrophytes, woody debris, rocks, sand and riffle) and then measured with a tape measure (see Table 1). Of these categories; bank overhang, log-pool complex, emergent macrophytes, submergent macrophytes, woody debris, rocks and riffles were considered to be "cover" according to our definition (Table 2). Decisions regarding habitat categorization were made by one individual to ensure consistency given the subjective nature of such classifications. A convention was established and implemented which designated that a 1.0 m perimeter zone surrounding a habitat feature was associated with that structure. For example, if a riffle zone were being measured, a strip 1.0 m wide would be added around the entire perimeter and included as part of the area of that riffle zone. If this riffle zone were immediately adjacent to a macrophyte bed, there would be a one meter overlap zone between the two. One meter on the edge of the macrophytes would be considered riffle habitat and one meter of the riffle would be considered macrophyte habitat. This convention was established based on the hypothesis that a fish did not need to be immediately underneath or above a structure in order to be associated with it. By this definition, a fish within 1.0 m of a macrophyte bed was present because of the existence of the macrophytes.

Scale habitat maps were produced from these field measurements and the areas of the various habitat categories determined by digitizing the maps using a GTCO digitizing pad interfaced with an IBM microcomputer (Table 1).

Table 2. Total cover in test and control segments for all stations on the Red Cedar River, Michigan. Area estimates are expressed as percentages of stream segment surface area.

	% Surface Area	
	TEST	CONTROL
STATION		
Sherwood	3.4	7.0
Dobie	11.6	10.5
Vanatta	3.2	4.1
M-52	3.4	8.1

Log Construction and Installation

The half-logs used in this project were constructed from center-split maple and oak logs (White 1971), 0.3 m in diameter and approximately 3.0 m in length (Figure 4). They were installed with 7 foot lengths of steel rerod and held 0.2 m above the bottom using blocks of wolmanized wood secured to the flat side with Ardox nails. The height of the spacers was chosen to accommodate the height of an adult fish (Scott and Crossman 1979). Cover was increased by 20% at all test sites by installing the logs along equidistant transects running from bank to bank (Figure 3). Individual logs were placed parallel to the current to provide less resistance to water and ice movement.

Fish Population Sampling

Treatment and control sites were sampled using a 250 Volt D.C. electroshocker on an approximately monthly schedule from April through October of each year. Preliminary shocking of the Dobie and Sherwood stations (i.e. before half-log installation) was carried out July 14-15, 1986. Preliminary shocking of the Vanatta and M-52 stations was done from April 30 to May 1, 1987. The remainder of sampling dates can be found listed in Table 5.

Captured smallmouth and rock bass were counted, measured and weighed using a Portagram digital balance. Scalesamples were taken and a site-specific fin clip applied before the

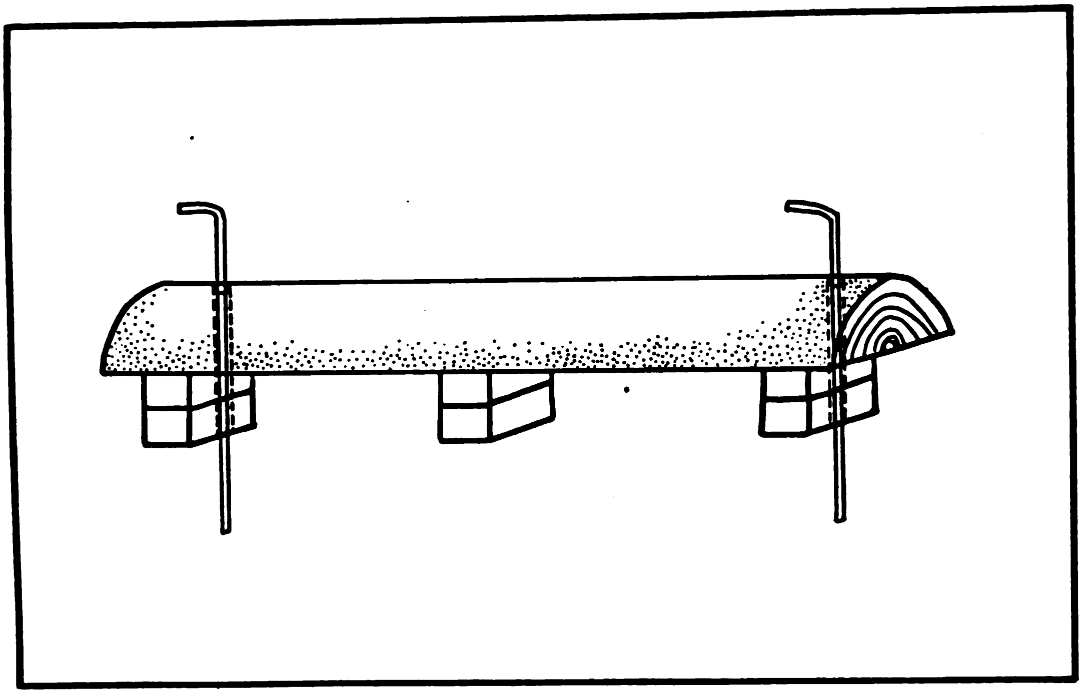

Figure 4. Line drawing showing the parts of a typical half-log habitat structure.

fish were released at the downstream edge of the segment from which they were captured. Centrarchids home by olfaction (Gerking 1959) and downstream placement facilitates the homogeneous return to the resident unmarked population which is required for use of Chapman's modification of the Petersen mark-recapture population estimator (Ricker 1975):

$$N = \frac{(M+1)\ (C+1)}{(R+1)}$$

Where: N = estimated number of fish in population
M = the number of fish marked and released into the population
C = the number of fish examined for marks.
R = the number of marked fish recaptured

A 24 hour recovery period was maintained between mark and recapture runs. Fish densities were determined by dividing the calculated abundance estimates by the surface area of the stream segments. Test and control densities were then compared using the paired t-test statistic (Huntsberger and Billingsley 1981):

$$t = \frac{X_1 - X_2}{s_d}$$

Where: X_1 = test site density
X_2 = control site density
s_d = standard error

which tests the null hypothesis that there is no difference between the sample means. Inherent to this test is the assumption that variances between the test and control populations were equal in the absence of treatment effects. Since the study was not of long enough duration to allow sufficient monitoring of annual population fluctuations before addition of the half-logs, homoscedasticity is assumed on the basis of equal cover areas between the test and control sites. In view of my choice of a paired design, some justification of the decision to lump vegetative and non-vegetative categories under the heading "cover" is in order. The fact that cover is essential to centrarchid biology is well-documented in the literature. The type of cover necessary to these fish, however, appears to be a source of controversy. Requirements seem to be dependent on life history stage and water temperature but there is a fair amount of disagreement on the influence of these two factors. George and Hadley (1979) indicated that young of the year smallmouth preferred rocky substrates whereas rock bass held in heavily vegetated areas. Dowling's work (1987), in contrast, indicated that young of the year fish of both species preferred submergent vegetation. Both of these young of the year studies ignore woody debris (George and Hadley 1979) or dismiss it as being insignificant (Dowling 1987). The latter is strongly contradicted by my own personal observations of large quantities of both study species holding beneath my half logs or in root wads. Adults of both species spawn over gravel (George and Hadley 1979), preferably where there is some type of simple cover (i.e. a rock or log). In the case of adult smallmouth bass, Todd and Rabeni (1989, in press) have found that Ozark fish will hold in boulders during cooler seasons of the year and move to log jams and root wads during the summer months. In view of all of this conflicting information regarding microhabitat requirements, and taking into consideration my own personal observations during fish sampling, it was concluded that the categories which I considered to be "cover" were treated equally by the study species. In other words, as long as a particular piece of structure provided relief from the current and protection from incident sunlight, we found fish associated with it.

I felt, after examination of the cover data in Table 2, that the test and control sites were similar enough in terms of their respective cover areas to justify a paired-t design. The largest differences were observed at the Sherwood and M-52 stations, but these didn't even exceed 5%.

Benthos Sampling

A peripheral study to identify similarities between the taxonomic composition of invertebrates present on the logs and those in the gastrointestinal tract of rock bass and smallmouth bass was done in July, 1988. The objective of this study was to see if the logs might provide food items utilized by smallmouth and rock bass in the Red Cedar River.

The field routine for benthos sampling at each test site began by counting the number of logs which were totally submerged and assigning each a number. One third of these logs were then chosen at random for benthos sampling. A 2.0 m x 3.0 m drift net was constructed using 1.5" P.V.C. pipe for the frame and 0.75 mm fiberglass window screen for the net. The net was held by one crew member so that its base was against the substrate and in contact with the downstream spacer block of the half-log being sampled. The other person scrubbed all surfaces vigorously with a long-handled hard bristle brush. All material collected in this manner was preserved immediately in a 15% solution of formaldehyde and later identified.

Gut samples were taken from smallmouth and rock bass within 2000 m of the test and control segments using the same 250 Volt D.C. boat-shocker used for the population estimates. These fish were kept on ice in a cooler and transported back to the lab where they were measured and weighed. The gastrointestinal tract from each fish was preserved in 15% formaldehyde and the invertebrate contents identified.

RESULTS

General Observations on Fish Densities

Direct density comparisons with a previous study by Dowling (1987) were precluded by (a) lack of information regarding stream surface area during his sampling periods and (b) temporal changes in the habitat quality of sampling sites common to our respective studies. The former prevented me from making determinations of fish densities and the latter, shown to be highly variable by Dowling (1987), has direct bearing on carrying capacity; a factor which would make density comparisons invalid.

Densities in the Red Cedar River are high relative to other Midwestern streams (Tables 3 and 4; respectively). Estimates of smallmouth densities ranged from 0 to 8740 fish/ha in my test sites, and from 0 to 17400 fish/ha in the control sites. Rock bass densities ranged from 0 to 8050 fish/ha in the test sites and from 20 to 2770 fish/ha in the control sites. Rock bass mean densities in the test segments (i.e. average fish density for the duration of the study after log installation) exceeded control densities only at the two sites established in 1986. Smallmouth bass mean test densities exceeded control densities at the Dobie

Table 3. Mean fish densities and associated standard deviations observed at four stations on the Red Cedar River, Michigan. "T" denotes test sites (to which half-logs have been added) and "C" denotes control sites (no logs).

Rock Bass Densities (fish/ha)

	DOBIE		VANATTA		SHERWOOD		M-52	
	T	C	T	C	T	C	T	C
Mean	1340	180	304	577	1270	1095	310	717
S.D.	2310	170	226	457	626	768	208	464
n	11	11	9	9	11	11	9	9

Smallmouth Bass Densities (fish/ha)

	DOBIE		VANATTA		SHERWOOD		M-52	
	T	C	T	C	T	C	T	C
Mean	1038	766	1465	2223	774	1343	14	6
S.D.	1677	120	2799	5699	1330	2407	25	13
n	11	11	9	9	11	11	9	9

Table 4. Densities (fish/ha) of selected midwestern smallmouth bass and rock bass populations.

SMALLMOUTH BASS		
Stream	Density (fish/ha)	Study
Bear Creek, MN	453 - 2,330	Palomis (1988)
Maquoketa River, IA	67 - 542	Paragamian (1986)
Livingston Branch, WI	------	Brynildson and Truog (1965)
Speed River, Ontario	190	Mahon et al. (1979)
Red Cedar and Plover Rivers, WI	45 - 164	Paragamian and Coble (1975)
Jacks Fork and Current Rivers, MO	39 - 210	Covington et al. (1983)
North Fork Little Miami R., OH	29	Brown (1960)
Des Moines., IA	1 - 2	Reynolds (1965)

ROCK BASS		
Stream	Density (fish/ha)	Study
Bear Creek, MN	127 - 192	Palomis (1988)
Speed River, Ontario	158	Mahon et al. (1979)
Courtois Creek, MO	4.5	Fajen (1975)
Jacks Fork and Current Rivers, MO	168 - 770	Covington et al. (1983)

Road (installed in 1986) and M-52 (installed in 1987) stations.

The extremely high standard deviations associated with these means prompted examination of the data on a monthly basis. Paired-t comparisons of mean smallmouth bass test and control densities for all stations combined (Table 5) show only one sampling period (October 1988) in which the half-logs appear to have significantly increased densities at the .05 level. Test densities in two other sampling periods, June 1987 and August 1988, significantly exceed control densities at $P<.15$ ($P=.1152$ and $P=.1283$; respectively). Four of the calculated t statistics were negative values, indicating that fish densities were greater in the control segments. No overall mean increase was observed in test density when all stations were averaged together.

Paired t comparisons of mean rock bass test and control densities for all stations combined (Table 6) demonstrated no differences significant at the .05 level. One sampling period, October 1988, was significant at $P<0.2$ and only one calculated t statistic, June 1988, was a negative value indicative of a higher mean density in the control segments. Overall rock bass densities in the test segments exceeded those in the control by 24 ($\pm$ 45) fish/1000$\cdot m^2$ ($\pm$ 95% C.I.) but in view of the above analysis the increase was not considered to be statistically significant.

Table 5. Paired t-test comparisons of smallmouth bass densities observed in test and control segments or four stations on the Red Cedar River, Michigan. Calculated t statistics reflect differences between mean fish densities in test and control segments for all stations combined after the addition of half-logs.

Month	n	Mean** Diff.	Standard Error	t	Probability*
JUN/87	4	.0065	.0043	1.5011	.1152
JUL/87	4	-.0060	.0107	- .5591	.3076
SEP/87	4	.0173	.0155	-1.1153	.1730
OCT/87	4	-.0120	.0099	-1.2081	-.1568
APR/88	4	.0070	.0198	.3531	.3737
JUN/88	4	.0028	.0050	.5457	.3116
JUL/88	4	-.3570	.2504	-1.4256	.1246
AUG/88	4	.0630	.0451	1.3982	.1283
OCT/88	4	.0288	.0218	2.2511	.0549

* Probability that the difference between test and control mean densities is equal to 0.

** Mean difference between test and control densities: test-control (fish/m^2).

Table 6. Paired t-test comparisons of rock bass densities observed in test and control segments for four stations on the Red Cedar River, Michigan. Calculated t statistics reflect differences between mean fish densities in test and control segments for all stations combined after the addition of half logs.

Month	n	Mean** Diff.	Standard Error	t	Probability*
JUN/87	4	.0090	.0273	.3298	.3816
JUL/87	4	.0085	.0235	.3623	.3706
SEP/87	4	.0323	.0585	.5509	.3100
OCT/87	4	.0003	.0079	.0317	.4884
APR/88	4	.0148	.0223	.6628	.2774
JUN/88	4	-.0548	.0294	-1.8642	.0796
JUL/88	4	.0110	.0280	.3932	.3602
AUG/88	4	.1600	.2045	.7823	.2455
OCT/88	4	.0143	.0143	1.0018	.1952

* Probability that the difference between test and control mean densities is equal to zero.

**Mean difference between test and control densities: test - control (fish/m^2).

Density Trends over Time

When rock bass data from sites installed in 1986 and 1987 were analyzed separately, test densities in the 1986 sites exceeded control densities by an average of 73 ($\pm$ 82) fish/1000 m^2 (Figure 5). Test sites established in 1987 showed no increase (-31 $\pm$ 14 fish/1000 m^2); a phenomenon indicative of either (a) a lag time between installation of the logs and colonization by the fish or (b) station-specific differences.

Paired-t analysis of monthly densities of rock bass for stations installed in 1986 revealed that test densities exceeded control in the June 1987 and July 1987 sampling periods ($P<.05$) (Table 7). The July 1988 and October 1988 comparisons were significant at $P\leq 0.2$. Paired-t comparisons of test and control rock bass densities for stations installed in 1987, in contrast, did not show a single instance where density had been increased by adding half-logs (Table 8).

When smallmouth bass data from stations installed in 1986 and 1987 were analyzed similarly, test densities were found to be, on average, 26 ($\pm$ 29) fish/1000 m^2 greater than the control (Figure 6). Stations established in 1987 exhibited a slight decrease in test densities (-7 $\pm$ 53 fish/1000 m^2); once again indicating either a lag time or site-specific differences.

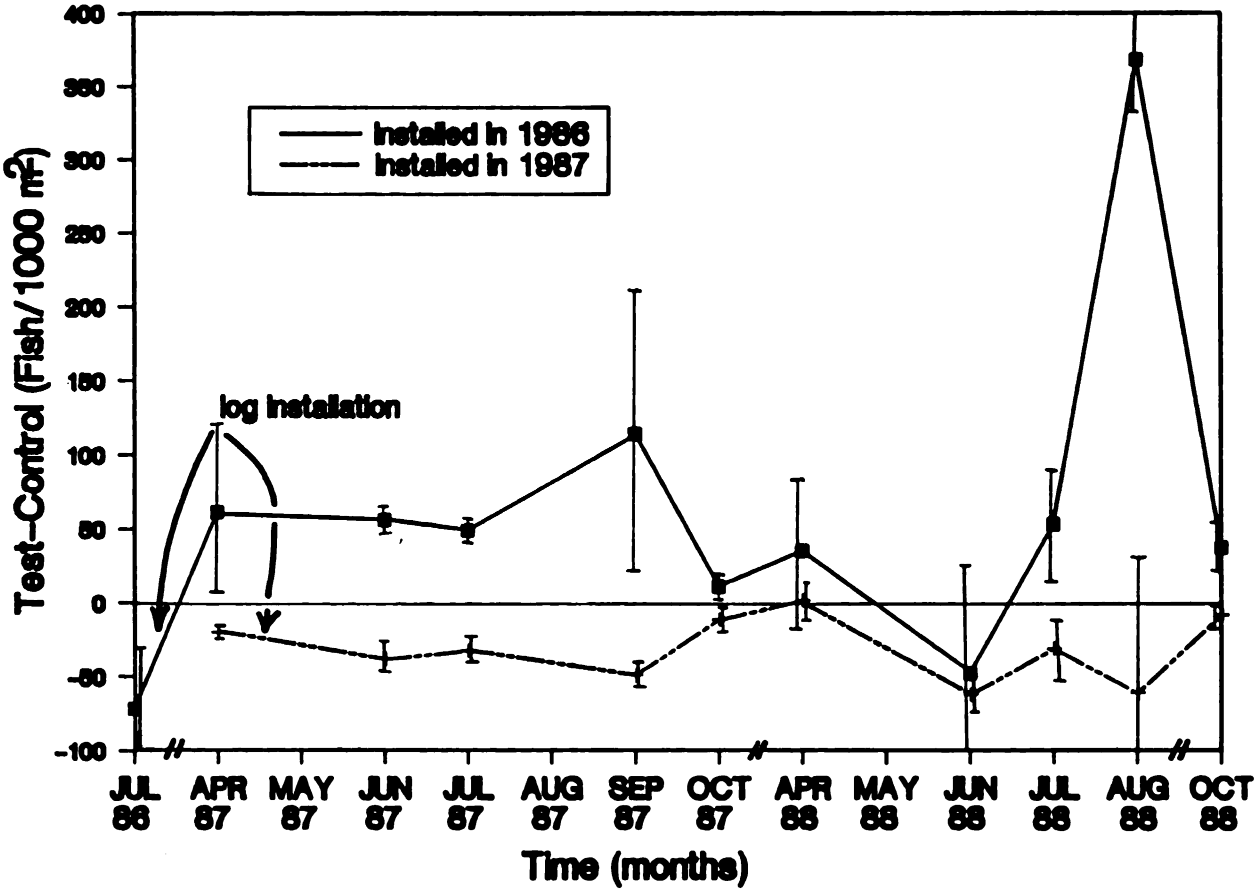

Figure 5. Mean differences between test and control densities plotted over time for rock bass (Ambloplites rupestris) (± standard error).

Table 7. Paired t-test comparisons of rock bass densities observed in test and control segments of two stations installed in 1986 (Sherwood and Dobie) on the Red Cedar River, Michigan. Calculated t statistics reflect differences between mean fish densities in test and control segments for both stations combined. July 1986 data were taken before half-log installation. All other data were taken after logs were in place.

Month	n	Mean** Diff.	Standard Error	t	Probability*
JUL/86	2	-.0040	.0450	-.0889	.4718
NOV/86	2	-.0005	.0015	.3333	.3976
APR/87	2	.0610	.0620	.9839	.2526
JUN/87	2	.0560	.0010	56.00	.0060
JUL/87	2	.0485	.0055	8.8182	.0359
SEP/87	2	.1135	.0855	1.3275	.2055
OCT/87	2	.0110	.0100	1.1000	.2349
APR/88	2	.0345	.0455	.7582	.2935
JUN/88	2	-.0475	.0705	-.6738	.3113
JUL/88	2	.0530	.0320	1.6563	.1729
AUG/88	2	.3675	.4015	.9153	.2641
OCT/88	2	.0365	.0155	2.3548	.1278

* Probability that the difference between test and control mean densities is equal to 0.

** Mean difference between test and control densities: test-control (fish/m^2).

Table 8. Paired t-test comparisons of rock bass densities observed in test and control segments of two stations installed in 1987 (M-52 and Vanatta) on the Red Cedar River, Michigan. Calculated t-statistics reflect differences between mean fish densities in test and control segments for both stations combined. April 1987 data were taken before half-log installation. All other data were taken after the logs were in place.

Month	n	Mean** Diff.	Standard Error	t	Probability*
APR/87	2	-.0020	.001	-20.0	.0159
JUN/87	2	-.0380	.0070	-5.4286	.0580
JUL/87	2	-.0315	.0085	-3.7059	.0839
SEP/87	2	-.0490	.0070	-7.0000	.0452
OCT/87	2	-.0105	.0065	-1.6154	.1764
APR/88	2	-.0050	.0110	- .4545	.3642
JUN/88	2	-.0620	.0100	-6.2000	.0509
JUL/88	2	-.0310	.0120	-2.5833	.1176
AUG/88	2	-.0475	.0605	- .7851	.2881
OCT/88	2	-.0075	.0005	-16.556	.0192

* Probability that the difference between test and control mean densities is equal to 0.

** Mean difference between test and control densities: test-control (fish/m^2).

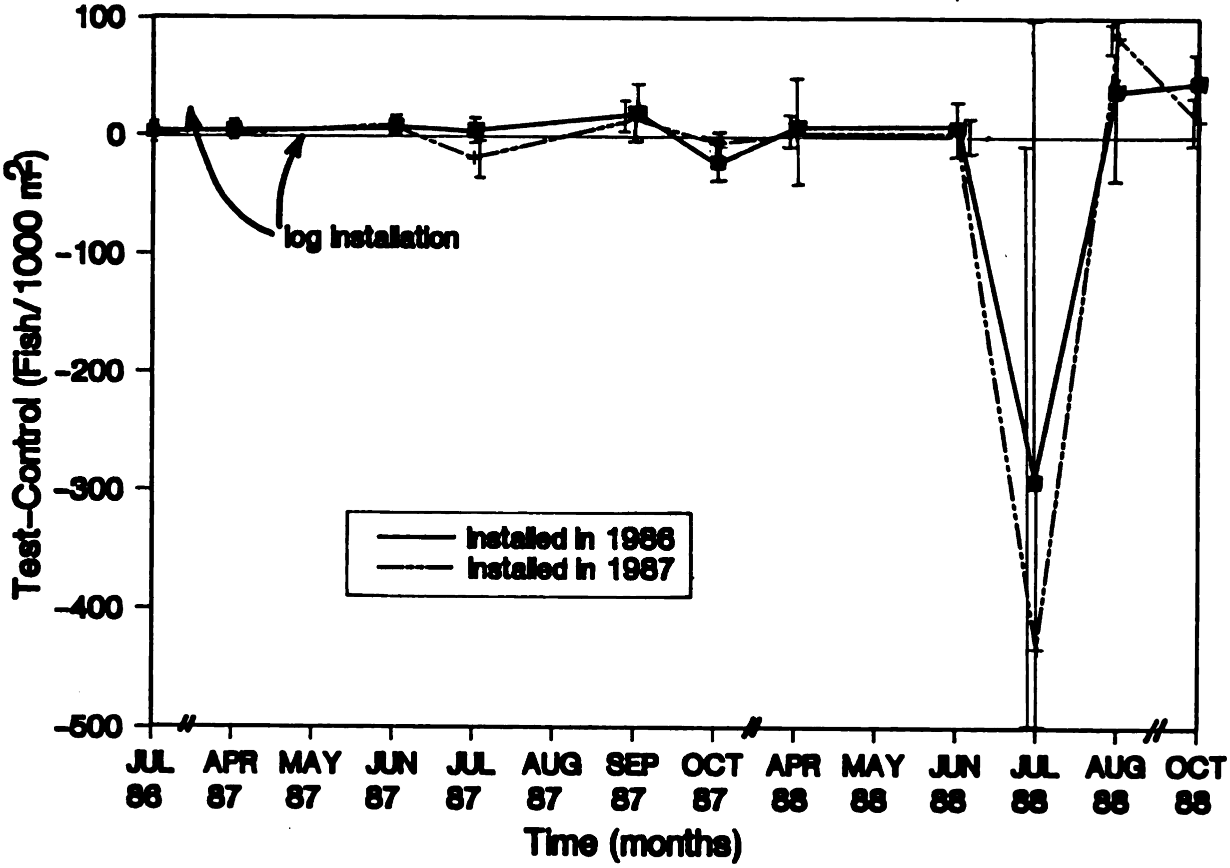

Figure 6. Mean differences between test and control desnities plotted over time for smallmouth bass (*Micropterus dolumieui*) (± standard error).

Paired-t analysis of smallmouth bass data from the individual sampling periods for the two stations installed in 1986, Sherwood and Dobie, show no significant differences at the .05 level (Table 9) and P-values ranged from 0.1198 (October, 1988) to 0.4220 (April, 1988). The 1987 stations, similarly, showed no significant differences between test and control densities at the .05 level (Table 10).

Qualitative Observations on Density Trends

Examination of the smallmouth bass data over time for the individual stations shows that the highest test site density was observed at the Vanatta station in July of 1988 (Figure 7). This was followed in descending order by Dobie Rd. (Figure 8), Sherwood (Figure 9) and M-52 (Figure 10). All of these, except for Sherwood, occurred in either June or July. The plots of the control densities follow a similar trend, with the highest densities observed in the summer of 1988.

When rock bass density plots for the individual stations are examined (Figures 11, 12, 13, 14), most show an increase in the summer of 1988 similar to that observed in the smallmouth bass populations. Dobie station (Figure 11) shows a definite trend toward higher fish densities in the test segment towards the end of the study. This consistent

Table 9. Paired t-test comparisons of smallmouth bass densities observed in test and control segments of two stations installed in 1986 (Sherwood and Dobie) in the Red Cedar River, Michigan. Calculated t statistics reflect differences between mean fish densities for the two stations combined. July 1986 data were taken before half-log installation. All other data were taken while logs were in place.

Month	n	Mean** Diff.	Standard Error	t	Probability*
JUL/86	2	.0025	.0045	.5556	.3386
NOV/86	2	-.0040	.0030	-1.3333	.2048
APR/87	2	.0030	.0030	1.0000	.2500
JUN/87	2	.0055	.0045	1.2222	.2183
JUL/87	2	.0065	.0085	.7647	.2922
SEP/87	2	.0210	.0350	.6000	.3280
OCT/87	2	-.0180	.0220	-.8182	.2817
APR/88	2	.0120	.0480	.2500	.4220
JUN/88	2	.0045	.0105	.4286	.3711
JUL/88	2	-.2810	.4210	-.6675	.3127
AUG/88	2	.0420	.0700	.6000	.3280
OCT/88	2	.0447	.0177	2.5297	.1198

* Probability that the difference between test and control mean densities is equal to 0.

** Mean difference between test and control densities: test-control (fish/m^2).

Table 10. Paired t-test comparisons of smallmouth bass densities observed in test and control segments for two stations installed in 1987 (Vanatta and M-52) on the Red Cedar River, Michigan. Calculated t statistics reflect differences between mean fish densities of test and control segments for both stations combined. April 1987 data were taken before half-log installation. All other data were taken after the logs were in place.

Month	n	Mean** Diff.	Standard Error	t	Probability*
APR/87	2	.0030	.0010	3.000	.1024
JUN/87	2	.0075	.0095	.7895	.2873
JUL/87	2	-.0185	.0175	-1.0571	.2412
SEP/87	2	.0135	.0135	1.000	.2500
OCT/87	2	-.0060	.0060	-1.000	.2500
APR/88	2	.0020	.0020	1.000	.2500
JUN/88	2	.001	.0060	.1667	.4474
JUL/88	2	-.4330	.4330	-1.000	.2500
AUG/88	2	.0840	.0800	1.050	.2422
OCT/88	2	.0128	.0128	1.000	.2500

* Probability that the difference between test and control mean densities is equal to 0.

** Mean difference between test and control densities: test-control (fish/m^2).

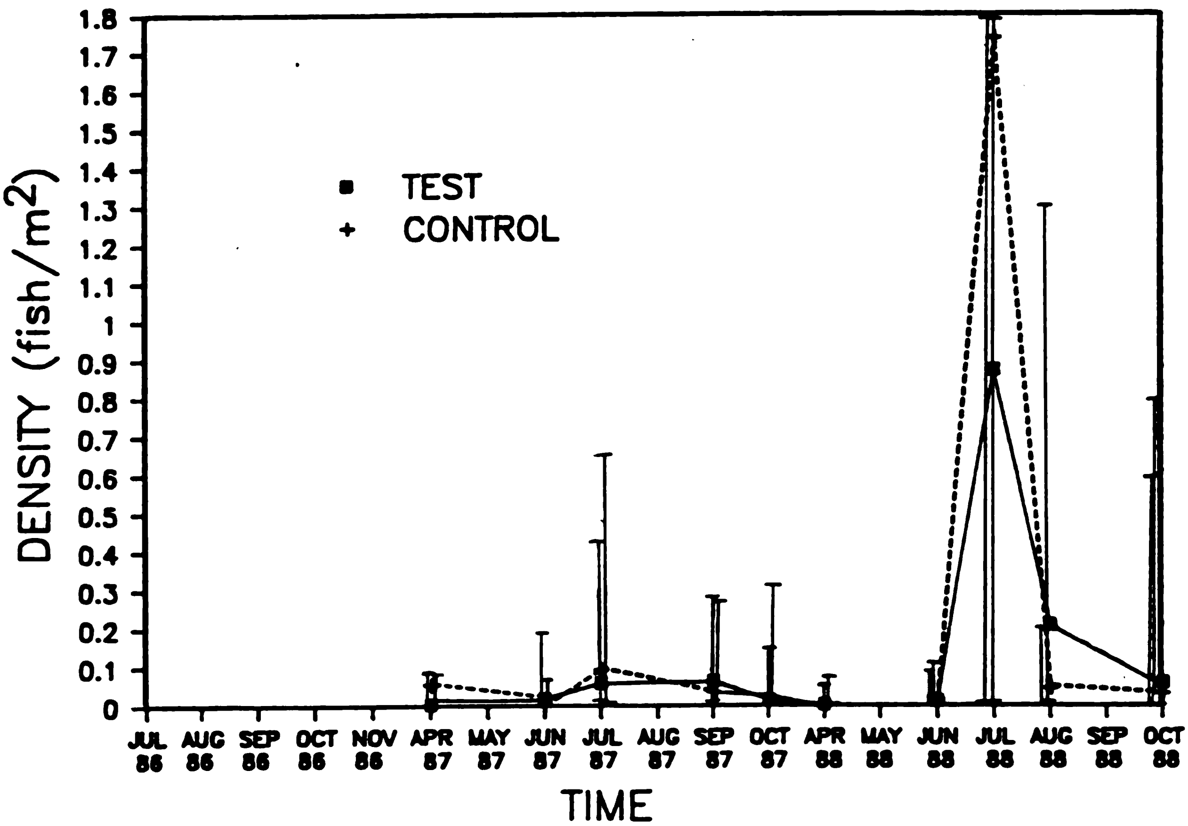

Figure 7. Smallmouth bass (*Micropterus dolomieui*) densities at Vanatta station plotted over time (± standard deviation).

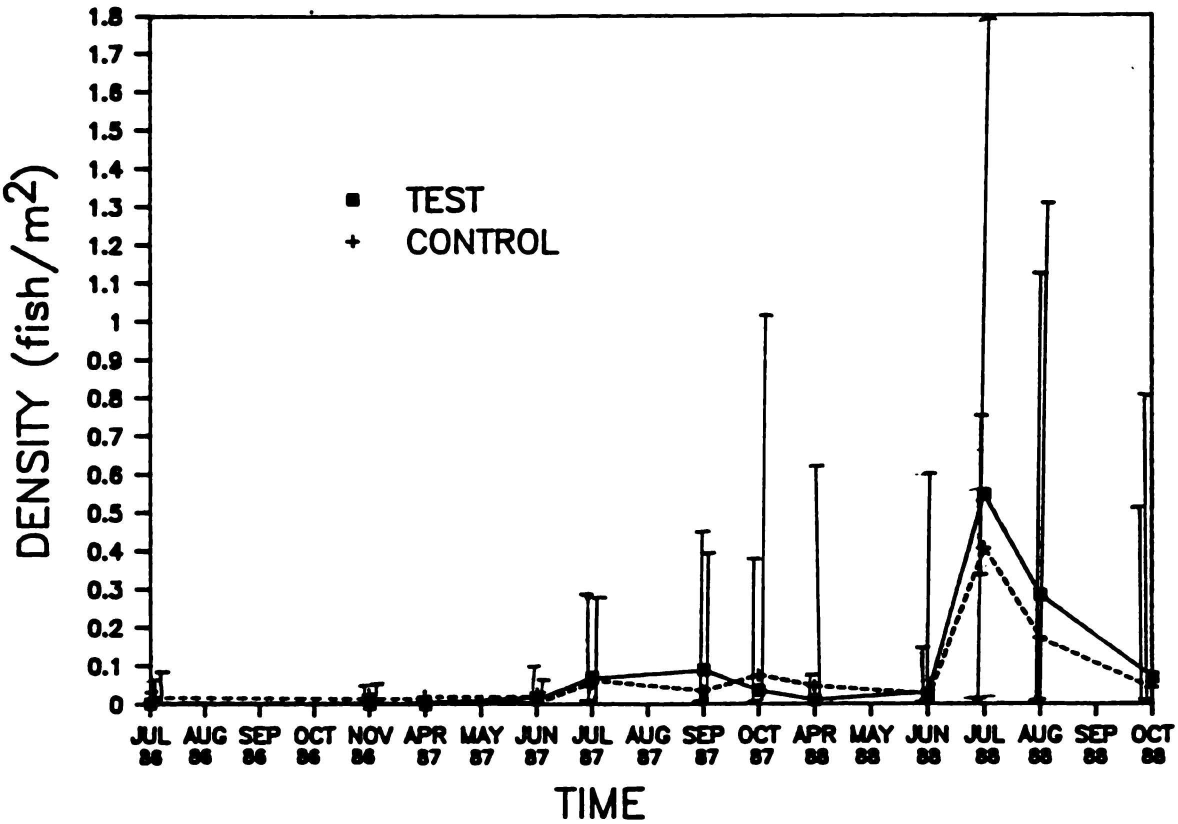

Figure 8. Smallmouth bass (*Micropterus dolomieui*) densities at Dobie station plotted over time (± standard deviation).

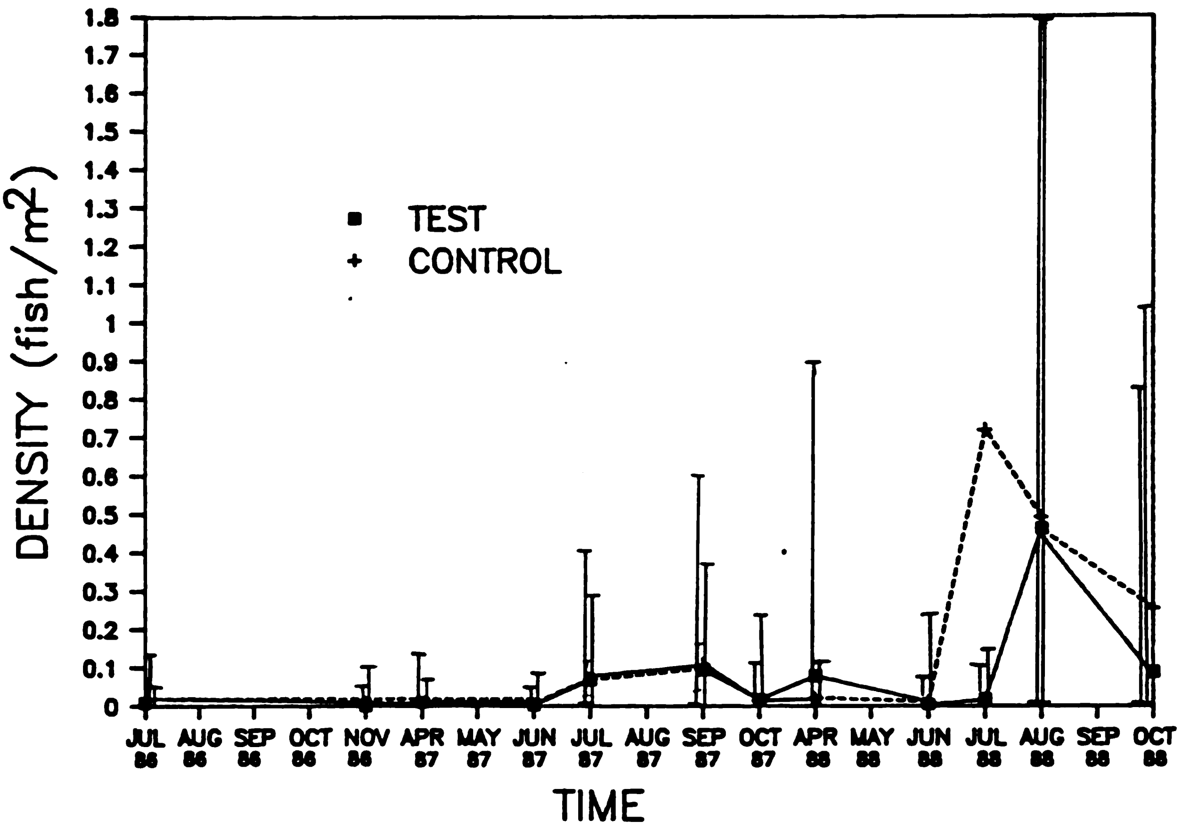

Figure 9. Smallmouth bass (Micropterus dolomieui) densities at Sherwood station plotted over time (± standard deviation).

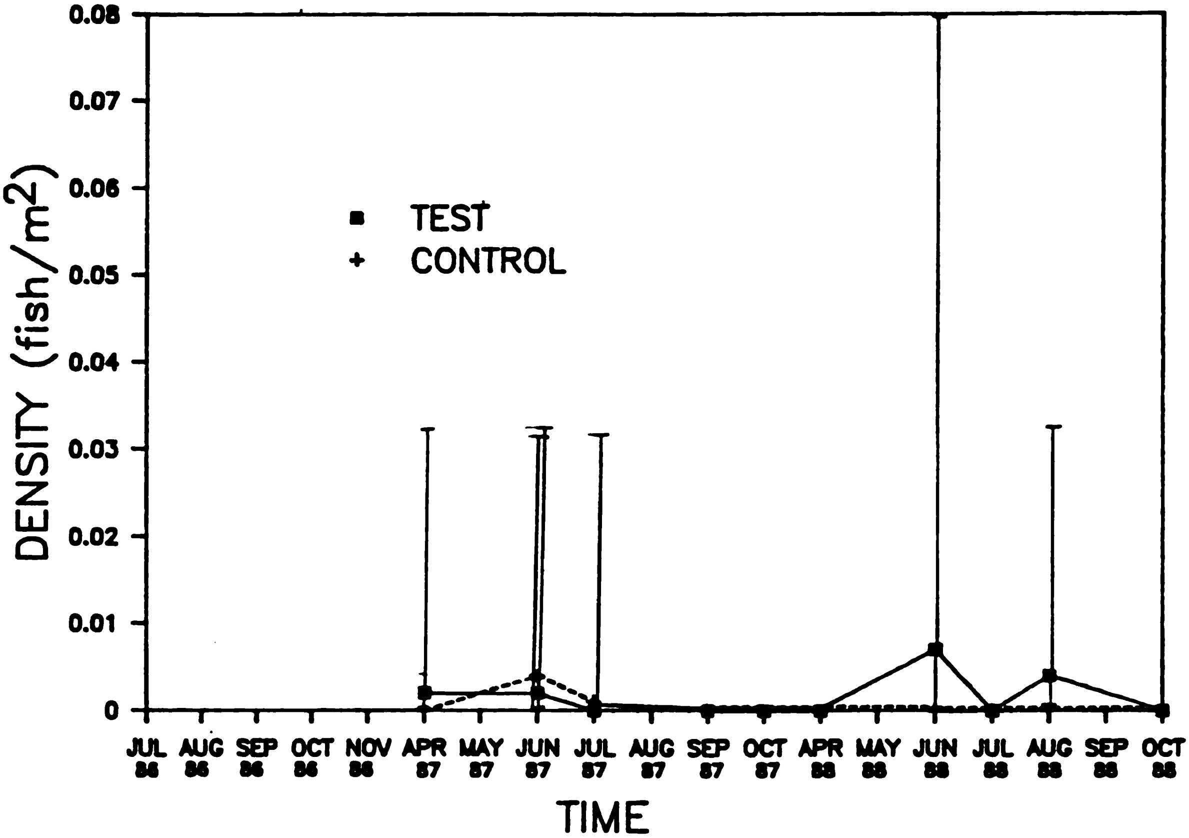

Figure 10. Smallmouth bass (<u>Micropterus</u> <u>dolomieui</u>) densities at M-52 station plotted over time (± standard deviation).

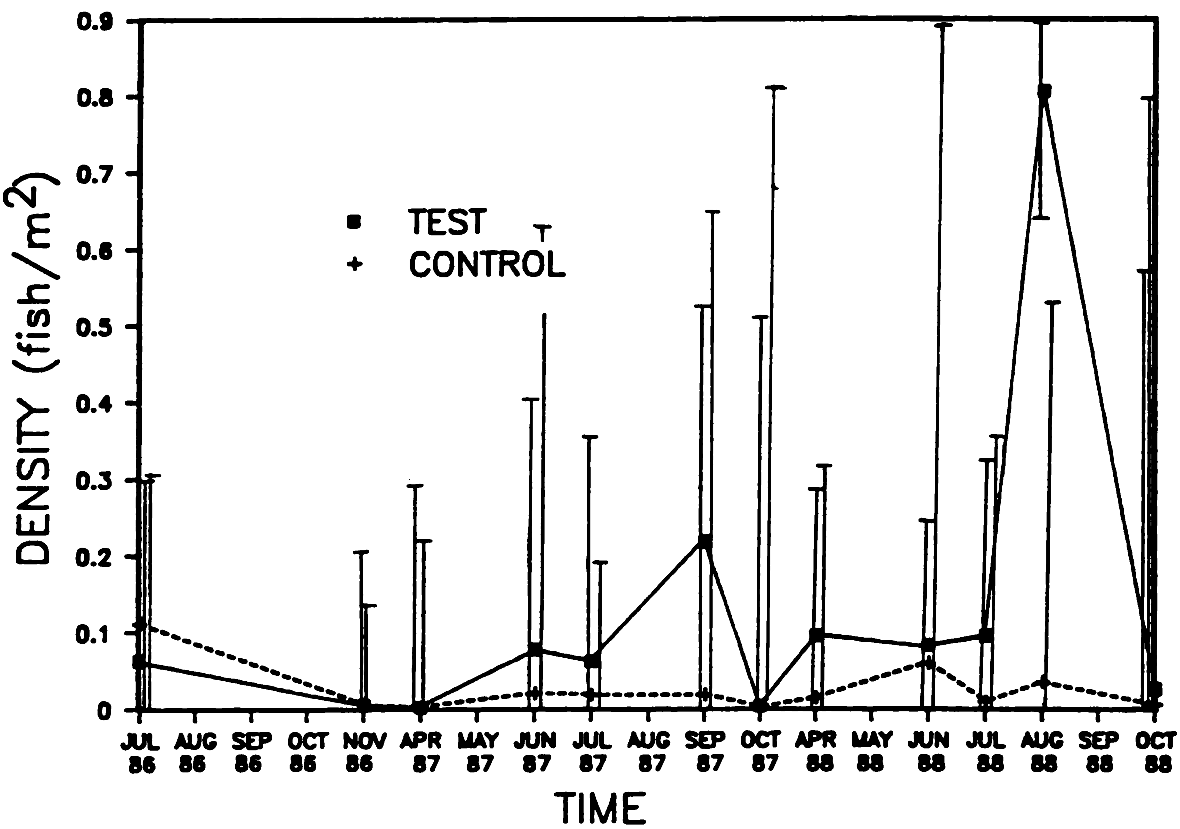

Figure 11. Rock bass (*Ambloplites rupestris*) densities at Dobie station plotted over time (± standard deviation).

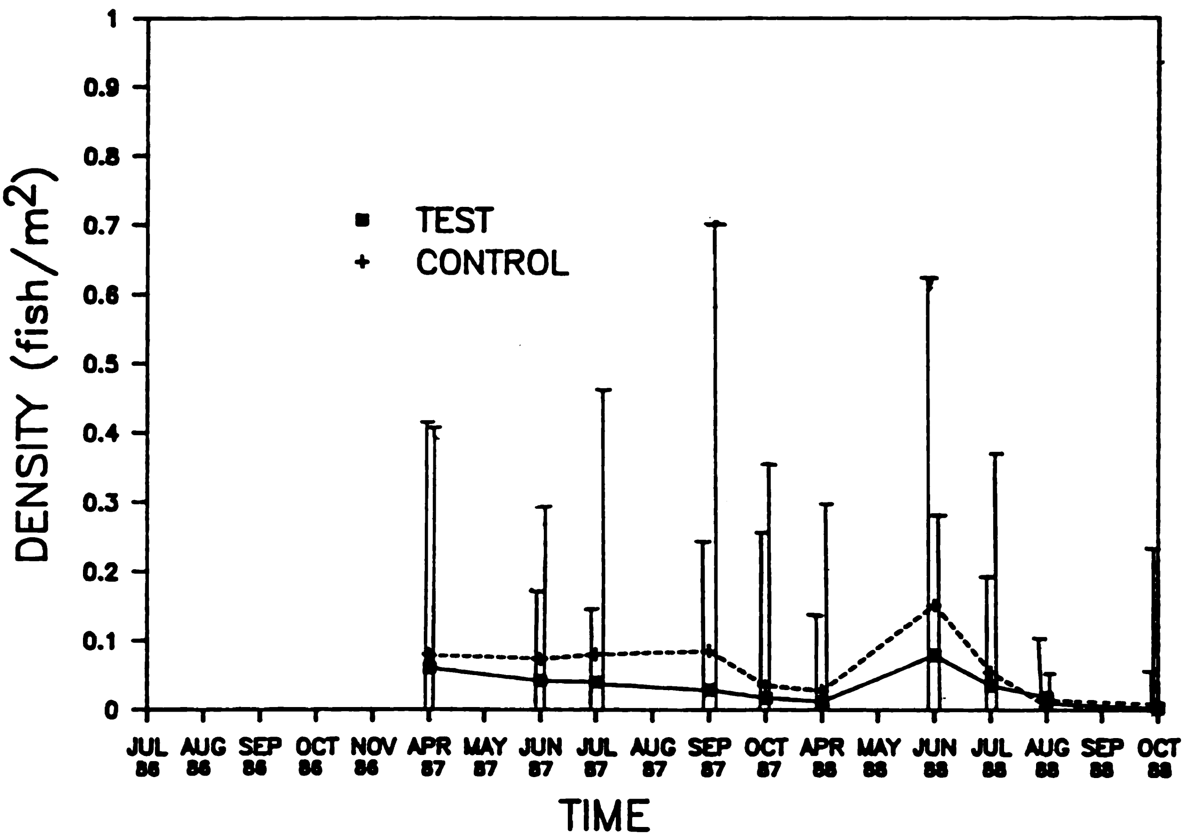

Figure 12. Rock bass (Ambloplites rupestris) densities at Vanatta station plotted over time (± standard deviation).

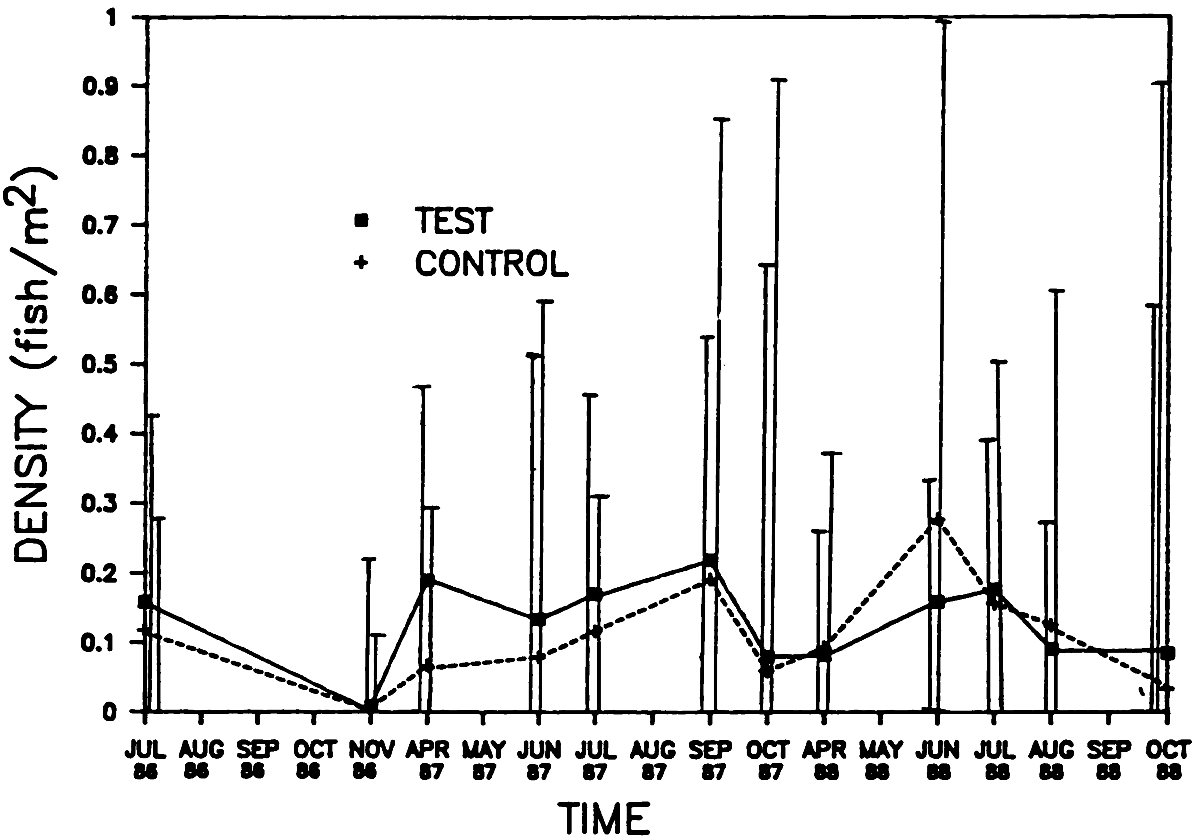

Figure 13. Rock bass (Ambloplites rupestris) densities at Sherwood station plotted over time (± standard deviation).

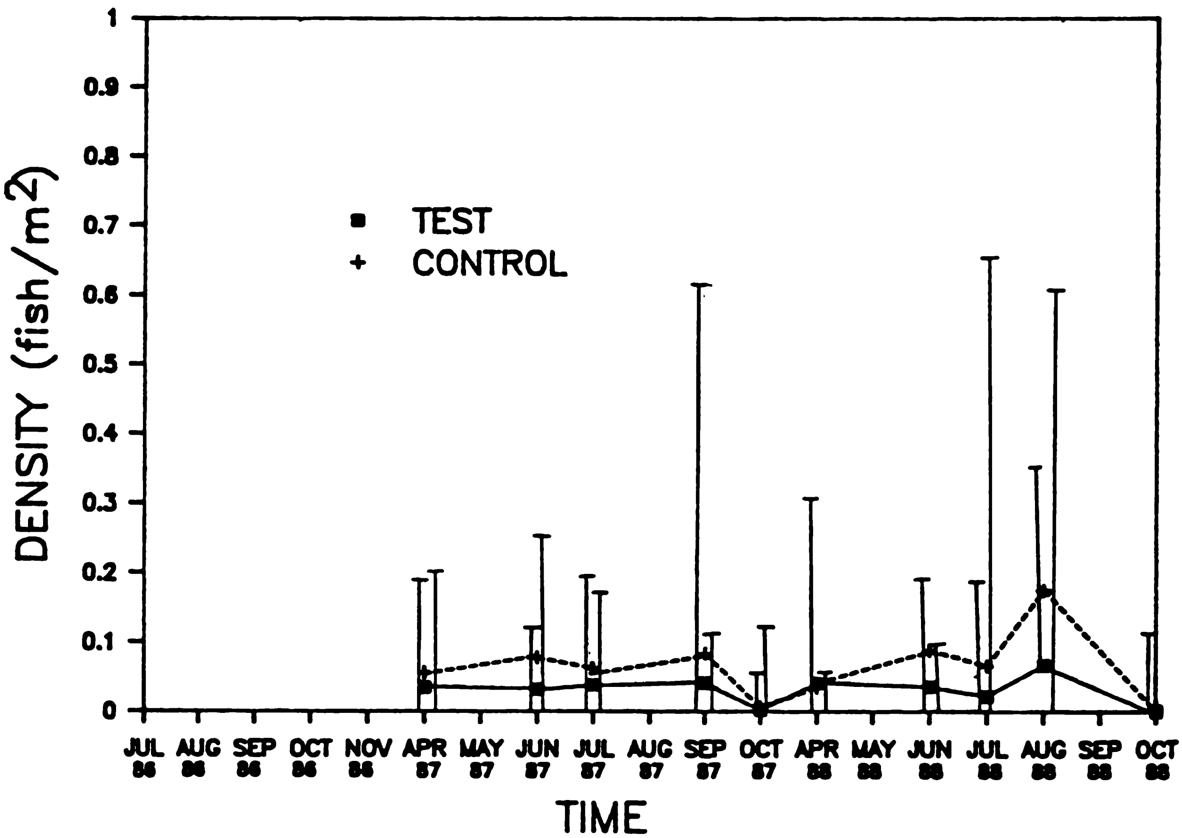

Figure 14. Rock bass (<u>Ambloplites rupestris</u>) densities at the M-52 station plotted over time (± standard deviation).

increase differs significantly enough from the control to suggest a lag period after installation.

General Fish Movement

Population densities varied greatly from month to month, with the highest densities occurring in June, July and August and the lowest densities occurring in early spring and late fall. A plot of the relationship between water temperature and fish density was constructed (Figure 15) which indicates that the low densities occurred when water temperatures in the Red Cedar approached 5°C.

In the last field season, record was kept of the number of fish in each sample that had been captured at a previous time (NOT from the previous day's marking). Of the 462 rock bass that were captured, 90 (20%) had previously been clipped for the segment in which they were shocked. Of the 456 smallmouth bass that were captured, 15 (3.3%) had previously been clipped for the segment they were captured in. The remaining fish in both of these groups were almost all young of the year. Although not explicit proof of any hypothesis regarding movement, this does give an indication of the sedentary nature of rock bass and smallmouth. Certain easily recognized individual rock bass and smallmouth were observed to remain under a single log or submerged tree trunk for the duration of a field season (1988).

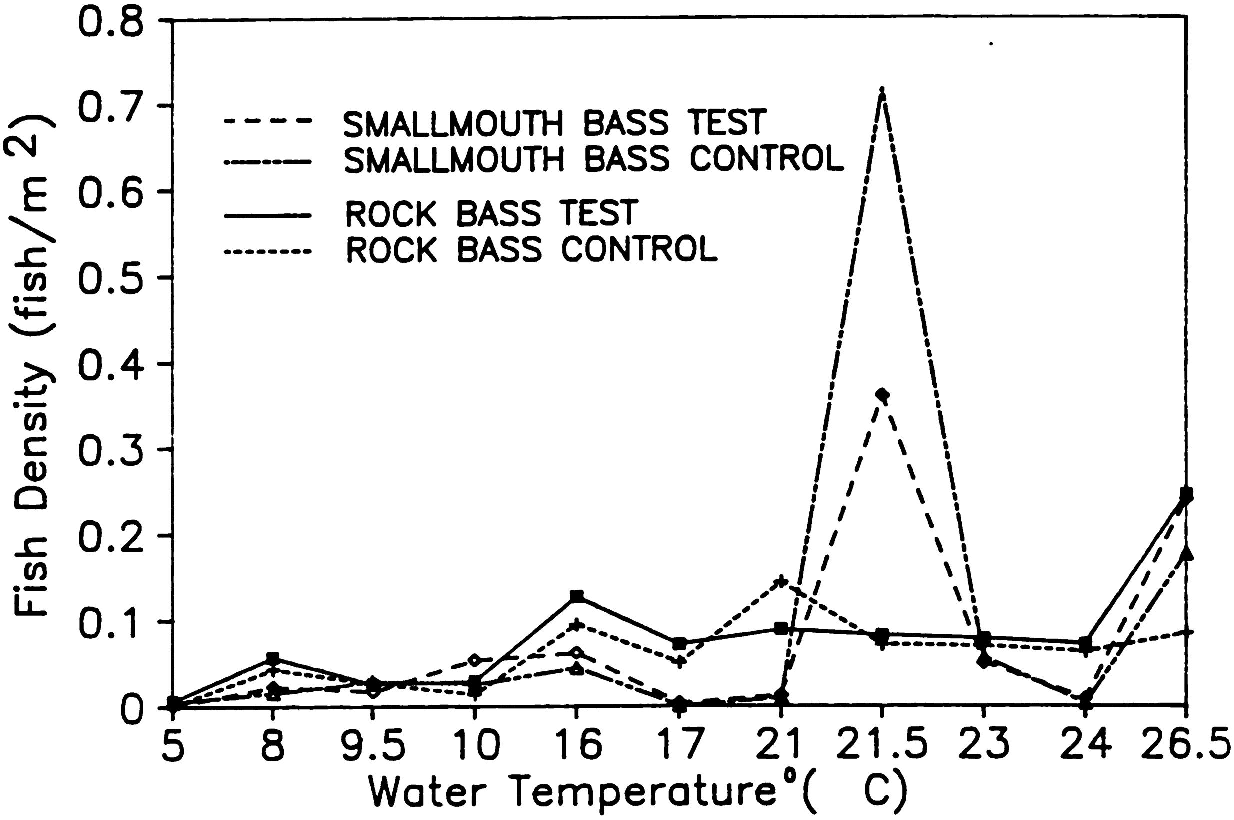

Figure 15. Rock bass and smallmouth bass mean densities observed at various water temperatures in the Red Cedar River, Michigan.

Movement between Test and Control Sites

Careful note was taken of any fish which moved between the test and control segments at each station. As of October 1988, only 7 fish were found to have moved between segments, a total less than 1%. Of these seven, four were rock bass between the lengths of 13.2 and 16.3 cm and the remaining three were smallmouth bass between the lengths of 13.1 cm and 34.2 cm. Six of these fish were captured in July 1988 and it is probable that their movement was prompted by the extremely low water levels during this time (Figure 16). The other two, one rock bass and one smallmouth, were captured during similar drought conditions in June 1988.

Log Decomposition and Siltation Effects

One of the most important factors to be considered in habitat work of this kind is the life expectancy of the structure being installed. Decomposition of in-stream structures and siltation have proven to be a problem in a number of trout stream rehabilitation projects. No noticeable decomposition of the logs used in my experiment appeared to have taken place; even those which had been in place for three years. Siltation was minimal: only six of the ninety-seven logs installed were silted over at the end of the study leaving 96% of the logs effective as in-stream structure.

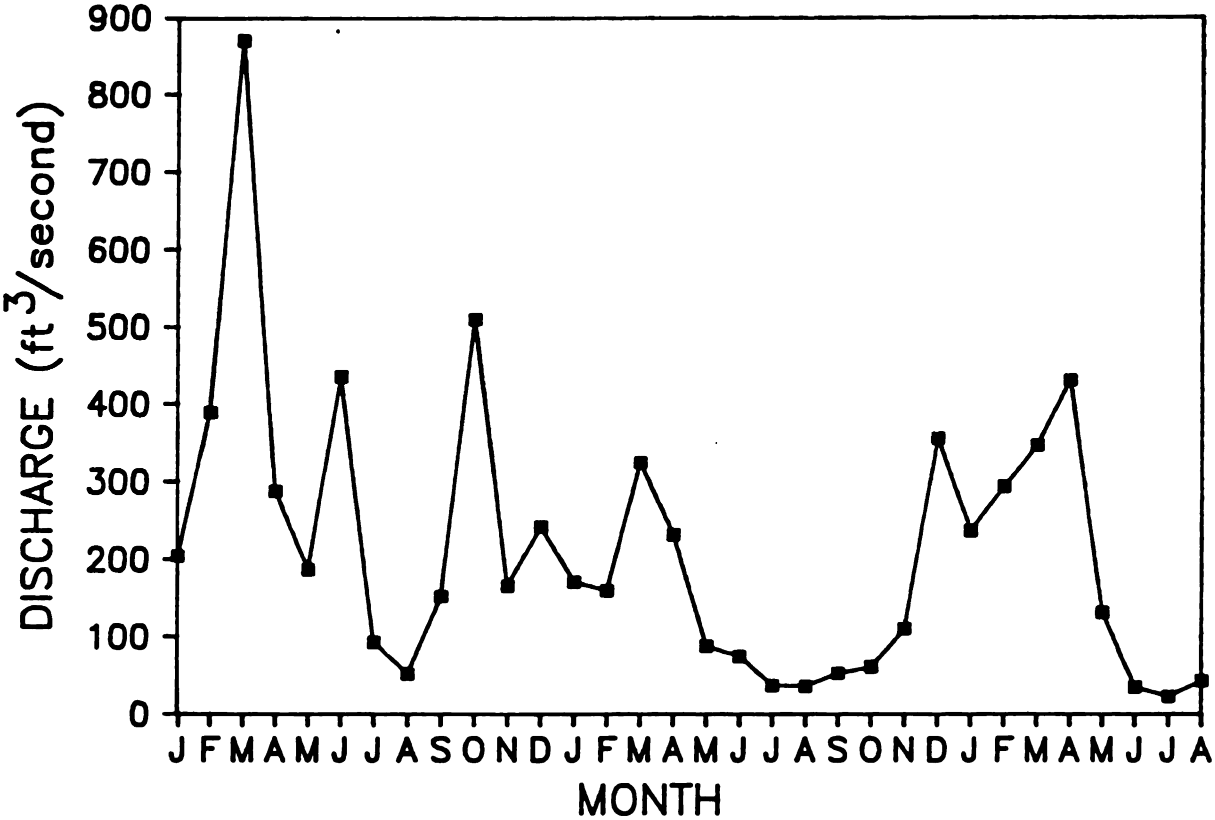

Figure 16. Mean monthly discharge rates for the Red Cedar River from 1986 to 1988 (U.S.G.S. unpublished data).

<u>Fish Size in Test and Control Sites</u>

Mean lengths at age for scales taken from a subsample of the fish captured by electroshocking are presented in Table 11. There is little difference between test and control fish size with the exception of age classes for which there were very few fish sampled. Statistical examination of this data was not pursued since fish were not marked as individuals. Without such identification there was no assurance that differential growth resulted from residence in a particular stream segment (since there was no explicit determination of movement to and from the test sites).

<u>Benthos Analysis</u>

The mean length of rock bass sacrificed for gut content analysis was 150 mm, with sizes ranging from 63 mm to 167 mm. Smallmouth bass averaged 100 mm in length and ranged in size from 45 to 304 mm. The invertebrate taxa present in the gut contents of smallmouth bass and rock bass overlapped almost completely with species found in association with the half-logs (Figure 17) with two exceptions. A large number of amphipods (<u>Hyalella</u> <u>azteca</u>) were found in association with the half-logs but are completely absent from the gut contents of both smallmouth and rock bass. Secondly, crayfish were frequently found in the guts of both species of fish but were not found colonizing the logs. Both smallmouth and rock bass seemed to select Ephemeroptera and

Table 11. Mean lengths at age (mm) for rock bass and smallmouth bass captured by electroshocking from the Red Cedar River, Michigan. Standard deviations are in parentheses.

AGE	RB-test	RB-control	SMB-test	SMB-control
0	9.1 (3.2)	21.8 (4.6)	5.0 (2.3)	37.2 (13.2)
I	35.3 (8.5)	50.9 (7.0)	65.2 (15.8)	84.5 (17.3)
II	65.2 (12.2)	88.6 (13.8)	120.9 (26.8)	153.9 (31.9)
III	111.8 (19.2)	124.4 (14.7)	170.7 (13.3)	199.0 (42.7)
IV	140.5 (12.1)	153.4 (18.1)	202.5 (39.9)	258.1 (44.5)
VI	149.1 (9.4)	160.7 (22.3)	323.1 (0.0)	301.6 (24.5)
VII	-	198.8 (0.0)	338.3 (0.0)	332.3 (20.3)

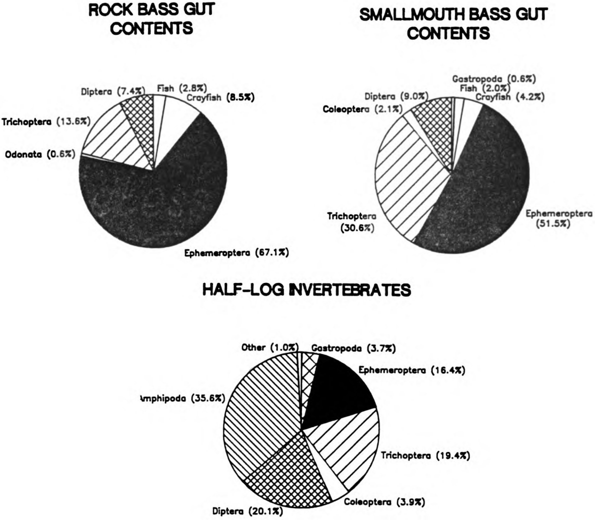

Figure 17. Numerical invertebrate composition of rock bass and smallmouth bass gastrointestinal contents in the Red Cedar River, Michigan.

Trichoptera, two groups composing a numerically large percentage (Figure 17) of the half-log invertebrate community.

DISCUSSION

Most of the statistical findings do not suggest that abundance of the study species at my stations was affected by the presence of half-logs. Isolated significant differences between test and control densities, as well as qualitative observations of trends in the density plots, indicate that this lack of significance may be due to the short-term nature of the study. Additionally, the experimental design may not have been powerful enough to detect differences between the means given the small sample sizes that were used.

I believe that the effectiveness of half-logs in my sites was controlled by four factors: the length of time since installation, the amount of cover already in place before installation, and, especially during the drought of 1988, stream discharge. To a lesser extent, I believe that increased angler fishing pressure may have "masked" higher densities in the test segments.

In most of my plots of density over time the control populations appeared to fluctuate in a manner similar enough to the test populations to prevent conclusions of a lag time between installation and colonization. Given information on smallmouth homing behaviour (85% of them return to the same spawning area annually, Scott and Crossman 1973), and personal observations of the sedentary nature of rock bass, a more long-term monitoring program would probably show a gradual density increase for both species in the test sites as compared to the control. Both smallmouth and rock bass left the study reaches of the river for the winter, returned in spring, and appeared to move very little during the late spring, summer and early fall (this last point supported by observations of numerous previously clipped fish in my shocking samples). Apparent spring and fall immigration and emigration from the stations corresponds with findings by Todd and Rabeni (in press). Given their sedentary nature, the older, established year classes would probably be reluctant to move into the log-enhanced sites therefore leaving colonization of these areas to yearling fish. This process of attracting in new year classes is a slow one and probably not detectable in the short span of this study.

White and Brynildson in their Guidelines for Management of Trout Stream Habitat in Wisconsin (1967) stated that desirable habitat, as well as food items, must already be in place to some extent for structure addition to be beneficial to salmonid populations. I have no doubt that this premise holds true for smallmouth and rock bass populations in the Red Cedar River. My data indicate that the logs were most successful in those sites which already had high proportions of cover (Sherwood Road, Dobie Road, Vanatta Road to a lesser extent). The station at M-52 had a lot of sand and little cover to begin with and no density increases occurred after log addition. It also exhibited the largest amount of silt and sand deposition around the logs; sediments which filled in the space below the structures rendering them useless as shelter.

Stream discharge significantly affected fish densities at my stations during the course of the study. This was especially evident during the drought of 1988 when abundances varied greatly and fish appeared to "pile up" in the deeper areas of the river. Vanatta, my deepest site in July 1988 (mean depth: 0.35 m), demonstrated a particularly high fish density (Figure 7) during a period of extremely low discharge in the Red Cedar River (Figure 16). During this time, the half-logs provided critical habitat in a number of places where the hydrology was such that pools were eroded below the logs and behind the spacer blocks. Measurements made at the height of the drought in July showed that the logs contributed an average of 27 square meters in pools to a given station. In some cases, these pools were the last holding area for the fish in a given site and therefore provided critical habitat.

There is little doubt that angling pressure can significantly depress population densities in habitat alteration experiments. Hunt's study (1966) on Lawrence Creek demonstrated that angler use and yield in habitat-improved stream sections increased nearly 200%. Since I was not able to monitor angler activities during my study, I can only assume that the test sites might have experienced some increase in fishing pressure. I did receive a number of eye-witness accounts of fishing activity at the stations; including descriptions of sizeable smallmouth and northern pike catches. In-stream structures which are highly visible concentrate fishermen as well as fish (Hunt 1966), therefore indicating a need for simultaneous creel census, increased public information efforts, and/or a shutdown of the fishery if accurate monitoring of population changes is to be accomplished.

The classic question asked in habitat manipulation experiments of this type is whether density increases are due to increased production, survival, or whether fish are merely being concentrated. The answer, I believe, lies in a combination of all three. The logs provide the perfect surroundings required by these two centrarchid species for nesting sites (nests were observed near the logs in many areas), therefore I would say that the reproductive carrying capacity of a given stream section is increased as is production of young of the year fish. My benthos data indicate that the logs provide invertebrate food items utilized by rock bass and smallmouth; a factor which could cause increased growth in the resident population as well as a concentration of fish from other areas of the river because of increased foraging opportunities. Lastly survival, particularly of young-of-the-year fish, is probably increased because of the protection which the half-logs confer (Gard 1961, Hunt 1971). They provide shady hiding areas where the juveniles can escape from predatory birds, mammals and other fish.

In my estimation, half-logs can provide a simple, economical habitat improvement structure for managers seeking to increase densities of smallmouth bass and rock bass in warm water stream systems. Future research, however, must include long-term, time-series designs and analysis to discern the effectiveness of such techniques. Research efforts should also address the attributes of a successful half-log: "successful" meaning one which attracts and maintains fish. If a determination could be made of optimal placement and optimal candidate site characteristics, projects like this could be made much more cost-effective. Managers must realize that cover addition is not a panacea for low sport fish densities: an integral part of the habitat management process must be ongoing re-evaluation of methodology. Refinement of habitat improvement strategies currently in use could prove invaluable to fisheries personnel in both the government and private sector seeking to provide quality warm water fishing opportunities to the publics they serve.

SUMMARY

1. Smallmouth density increased by 24 percent in stream segments where cover had been added using half-log structures.
2. Rock bass density increased by 99 percent in similarly altered warm water stream segments.
3. Neither of the above changes were significant at the 0.05 level, but data trends indicate that longer-term monitoring might demonstrate more definite population increases.
4. The types of invertebrates found in the gastrointestinal tracts of rock bass and smallmouth bass were similar to those found on the logs, indicating that half-logs may provide food items.
5. Longer-term studies are needed to identify the effects of cover increase on centrarchid densities.

LITERATURE CITED

Anderson, N.H., J.R. Sedell, L.M. Roberts and F.J. Triska. The role of aquatic invertebrates in processing of wood debris in coniferous forest streams. American Midland Naturalist 100:64-82.

Anderson, N.H. and J.R. Sedell. 1979. Detritus processing macroinvertebrates in stream ecosystems. Ann. Rev. Entomol. 29:25-46.

Angermeier, P.L. and J.R. Karr. 1984. Relationships between woody debris and fish habitat in a small warm-water stream. Transactions of the American Fisheries Society 113:716-726.

Benke, A.C., T.C. VanArdsall, D.M. Gillespie and F.K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. Ecological Monographs 54:25-63.

Boussu, M.F. 1954. Relationships between trout populations and cover on a small stream. Journal of Wildlife Management 18:229-239.

Brown, E.H. Jr.. 1960. Little Miami River headwater stream investigations. Ohio Department of Natural Resources, Columbus, Ohio.

Brynildson, C., and J. Truog. 1965. The structure of the smallmouth bass population in Livingston Branch, Iowa County, 1958-64. Wisconsin Conservation Department Invest. Memo. (South. Area) No. 258.

Burgess, S.A. and J.R. Bider. 1980. Effects of stream habitat improvements on invertebrates, trout populations and mink populations. Journal of Wildlife Management 44:871-880.

Clady, M.D. 1975. Early survival and recruitment of small-mouth bass in northern Michigan. Journal of Wildlife Management 39(1):194-200.

Cleary, R.E. 1956. Observations on factors affecting small-mouth bass production in Iowa. Journal of Wildlife Management 20(4):354-359.

Coble, D.W. Smallmouth bass. In Black bass biology and management. H. Clepper and R.H. Stroud Eds. pp. 21-33. Sport Fisheries Institute Publication. Washington, D.C.

Covington, W.G., R.E. Marteney, and C.F. Rabeni. 1983. Population characteristics of sympatric smallmouth bass and rock bass in the Jacks Fork and Current Rivers, Missouri. Trans. Missouri Acad. Sci. 17:27-35.

Eadie, J. McA., and A. Keast. 1984. Resource heterogeneity and fish species diversity in lakes. Canadian Journal of Zoology 62: 1689-1695.

Everhart, W.H. 1949. Body length of the smallmouth bass at scale formation. Copeia 2:110-115.

Fajen, O.F. 1975. The standing crop of smallmouth bass and associated species in Courtois Creek, 1958-68. In: Black bass biology and management. H. Clepper and R.H. Stroud, eds. pp. 252-262. Sport Fisheries Institute Publication, Washington, D.C.

Fajen, O.F. 1981. Warmwater stream management with emphasis on bass streams in Missouri. In Warmwater streams symposium. L.A. Krumholz, editor. pp. 252-262. Sport Fisheries Institute Publication, Washington D.C.

Gard, R. 1961. Creation of trout habitat by construction of small dams. Journal of Wildlife Management 25:384-390.

George, E.L., and W.F. Hadley. 1979. Food and habitat partitioning between rock bass (Ambloplites rupestris) and smallmouth bass (Micropterus dolomieui). Transactions of the American Fisheries Society 108:253-261.

Gerking, S.D. 1953. Evidence for the concepts of home range and territory in stream fishes. Ecology 34(2):347-365.

Gerking, S.D. 1959. The restricted movement of fish populations. Biological Reviews 34:221-242.

Haines, T.A. and R.L. Butler. 1969. Responses of yearling smallmouth bass (Micropterus dolomieui) to artificial shelter in a stream aquarium. Journal of the Fisheries Research Board of Canada 26:21-31.

Hallam, J.C. 1959. Habitat and associated fauna of four species of fish in Ontario streams. Journal of the Fisheries Research Board of Canada 16:147-173.

Hubbs, C.L., and R.M. Bailey. 1938. The small-mouthed bass. Bulletin of the Cranbrook Institute of Science #10. 92 pp.

Hunt, R.L. 1966. Production and angler harvest of wild brook trout in Lawrence Creek, Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin 35. 52 pp.

Hunt, R.L. 1971. Responses of a brook trout population to habitat development in Lawrence Creek. Wisconsin Department of Natural Resources Technical Bulletin 48. 35 pp.

Hunt, R.L. 1978. Instream enhancement of trout habitat. A presentation at the Symposium on Wild Trout Management at San Jose, CA. California Trout Inc. and California-Nevada Chapter of the American Fisheries Society. pp. 19-27.

Hunt, R.L. 1982. An evaluation of half-logs to improve brown trout habitat in Emmons Creek. Wisconsin Department of Natural Resources Technical Report No. 116. pp. 31-61.

Huntsberger, D.V. and P. Billingsley. 1981. Elements of statistical inference. Allyn and Bacon, Inc., Toronto. 505 pp.

Hutchinson, H.G. 1957. Concluding remarks. Cold Spring Harbor Symposia on Quantitative Biology 22:415-427.

Hynes, H.B.N. 1961. The ecology of running waters. University of Toronto Press. Toronto. 555 pp.

Kerr, S.R. 1980. Niche theory in fisheries ecology. Transactions of the American Fisheries Society 109:254-260.

Lachner, E.A. 1950. Food, growth and habits of fingerling northern smallmouth bass, Micropterus dolomieui, in trout waters of western New York. Journal of Wildlife Management 14(1):50-56.

Linton, K.J. and R.C. Ball. 1965. A study of the fish populations in a warm water stream. Quarterly Bulletin of the Michigan Agricultural Experiment Station, Michigan State University. 48(2):255-285.

MacCrimmon, H.R., and W.H. Robbins. 1981. Influence of temperature, water current, illumination, and time on activity and substrate selection in juvenile smallmouth bass (Micropterus dolomieui). Canadian Journal of Zoology 59:2322-2330.

Mahon, R., E.L. Balon, and D.L.G. Noakes. 1979. Distribution, community structure, and production of fishes in the upper Speed River, Ontario: a preimpoundment study. Env. Biol. Fish. 4:219-244.

McNaughton, S.J. and L.L. Wolf. 1979. General Ecology. Second Edition. Holt, Rinehart and Winston. 702 pp.

Miller, R.J. 1975. Comparative behavior of centrarchid basses. In: Black bass biology and management. H. Clepper and R.H. Stroud. Eds. pp. 85-94. Sport Fisheries Institute Publication.

Okeyo, D.O. and T.J. Hassler. 1985. Growth, food and habitat of Age 0 smallmouth bass in Clair Engle reservoir, California. California Fish and Game 71(2):76-87.

Oliver, J.D. and G.F. Holeton. 1979. Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores, and environmental temperature. 108:130-136.

Ontario Ministry of Natural Resources. 1972. Community fisheries involvement program field manual; Part 1: Trout Stream Rehabilitation.

Palomis, T.J. 1988. Annual production and food habits of smallmouth bass (Micropterus dolomieui) and rock bass (Ambloplites rupestris) in a southern Minnesota stream. M.S. Thesis. University of Minnesota, Minneapolis Minnesota. 88 pp.

Paragamian, V.L. and D.W. Coble. 1975. Vital statistics of smallmouth bass in two Wisconsin rivers, and other waters. Journal of Wildlife Management 39(1):201-210.

Paragamian, V.L. 1986. Production of smallmouth bass in the Maquoketa River, Iowa. J. Freshwater Ecology 4:141-148.

Paragamian, V.L. 1981. Some habitat characteristics that affect abundance and winter survival of smallmouth bass in the Maquoketa River, Iowa. In: Warmwater Streams Symposium. pp. 45-53. American Fisheries Society, Bethesda, Maryland.

Pflieger, W.L. 1966. Reproduction of the smallmouth bass (Micropterus dolomieui) in a small Ozark stream. American Midland Naturalist 76(2):410-418.

Probst, W.E., C.F. Rabeni, W.G. Covington and R.E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Transactions of the American Fisheries Society. 113:283-294.

Reynolds, J.B. 1965. Life history of the smallmouth bass, *Micropterus dolomieui* Lacepede, in the Des Moines River, Iowa. Iowa State J. Sci. 4:417-436.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191. 230 pp.

Ritter, J.A. and H.R. MacCrimmon. 1973. Influence of environmental experience on response of yearling rainbow trout (*Salmo gairdneri*) to a black and white substrate. Journal of the Fisheries Research Board of Canada 30:1740-1742.

Saunders, J.W. and M.W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Transactions of the American Fisheries Society 91(2):185-188.

Scott, W.B. and E.J. Crossman. 1979. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada.

Shearer, C.A. 1972. Fungi of the Chesapeake Bay and its tributaries III. The distribution of wood inhabiting Ascomycetes and Fungi Imperfecti of the Patuxent River. American Journal of Botany 59:961-969.

Shuter, B.J., J.A. MacLean, F.E.J. Fry, and H.A. Regier. 1980. Stochastic simulation of temperature effects on first-year survival of smallmouth bass. Transactions of the American Fisheries Society. 109:1-34.

Smith, R.L. 1977. Elements of ecology and field biology. New York, N.Y. 497 pp.

Surber, E. 1939. A comparison of four eastern smallmouth bass streams. Transactions of the American Fisheries Society 68:322-333.

Surber, E.W. 1941. A quantitative study of the food of the smallmouth black bass, *Micropterus dolomieui*, in three eastern streams. Ibid., 70:311-334.

Tarzwell, C.M. 1936. Progressive lake and stream improvement. Proceedings of the North American Wildlife Conference 1:119-134.

Todd, B.L. and C.F. Rabeni. In Press. Movement patterns and habitat use of stream-dwelling smallmouth bass.

Trautman, M.B. and D.K. Gartman. 1974. Re-evaluation of the effects of man-made modifications on Gordon Creek between 1887 and 1973 and especially as regards its fish fauna. Ohio J. Sci. 74(3): 162.

Triska, F.J., J.R. Sedell, K. Cromack, S.V. Gregory and F.M. McCorison. 1984. Nitrogen budget for a small coniferous forest stream. Ecological Monographs 54:119-140.

Turner, G.E. and H.R. MacCrimmon. 1970. Reproduction and growth of smallmouth bass, Micropterus dolomieui, in a Pre-cambrian lake. J. Fish. Res. Bd. Canada 27:395-400.

Wesche, T.A. 1976. Development and application of a trout cover rating system for IFN determinations. Pages 224-234 in Proceedings of the Symposium and specialty conference on instream flow needs at Boise, Idaho, Vol. II. American Fisheries Society Publications. 323 pp.

White, R.J. 1971. Stream improvement. Pages 106-110 in R.D. Teague, editor. A manual of wildlife conservation. The Wildlife Society, Washington, D.C. 210 pp.

White, R.J. 1975. Trout population responses to streamflow fluctuation and habitat management in Big Roche-a-Cri Creek, Wisconsin. Internationle Vereinigung fur Theoretische and Angewandte Limnologie Verhandlungen 19:2469-2477.

White, R.J. and O.M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin 39. 54 pp.