This is to certify that the

thesis entitled

Evaluation of Habitat Enhancement Structures in Four Reservoirs of the Au Sable River, Michigan

presented by

Todd Christian Wills

has been accepted towards fulfillment of the requirements for

M.S. degree in Fish. & Wildl.

Mary T Bremigan
Major professor

Date June 24, 2002

EVALUATION OF HABITAT ENHANCEMENT STRUCTURES IN FOUR RESERVOIRS OF THE AU SABLE RIVER, MICHIGAN

By

Todd Christian Wills

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

2002

ABSTRACT

EVALUATION OF HABITAT ENHANCEMENT STRUCTURES IN FOUR RESERVOIRS OF THE AU SABLE RIVER, MICHIGAN

By

Todd Christian Wills

Addition of habitat enhancement structure to aquatic systems is a common practice by fisheries managers hoping to increase spawning success, production, and angler catch rates of important game species. However, quantitative evaluations of these efforts are few and typically do not determine the extent to which natural habitat mediates effects of habitat enhancement structures. I evaluated the effects of two types of habitat enhancement structure on four functional fish groups in four reservoirs of the Au Sable River, Michigan. Using a combination of sampling methods, I compared several response variables (including relative abundance, nesting, and angler catch rates) between areas with and without structures, as well as before and after structure placement, across a gradient of natural habitat conditions. Significant treatment effects of half-log habitat enhancement structures occurred in some cases, but no significant treatment effects of AquaCrib® structures were detected. Smallmouth bass (*Micropterus dolomieu*) responded to half-logs, with significantly greater relative abundance, nest density, and nest success in areas with half-logs compared to areas without half-logs. Other functional groups displayed few significant differences in response variables between areas with and without structure, or before and after structure placement. Habitat effects varied with reservoir and functional group, but generally influenced response variables more than the presence of habitat enhancement structure.

ACKNOWLEDGMENTS

I wish to express my deepest appreciation and a sincere thank you to my major professor, Dr. Mary Bremigan, for her support, encouragement, and friendship. Dr. Bremigan made herself available at any time to address my questions and concerns while also giving me the freedom to tailor my research to my personal interests. It was a pleasure and an honor to pursue my graduate studies under her direction. I also owe a great deal of thanks to my graduate committee, Dr. Daniel Hayes and Dr. Gary Mittelbach, for providing encouragement and advice in developing my research, as well as constructive criticism on an earlier draft of this thesis. Dr. Hayes also provided statistical advice and support for which I am most grateful. I am indebted to the numerous graduate students, undergraduate students, and technicians that provided field and laboratory assistance, especially K. Cheruvelil, J. Chiotti, N. Dorn, S. Hanson, P. Hrodey, A. Mahan, S. Makosky, C. Meier, V. Moore, D. Myers, B. Ordell, N. Pfost, G. Steinhart, M. Wesener, and S. Wills. I would also like to thank H. Jennings and B. Stuber of the USDA Forest Service and K. Kruger and K. Newman of the Michigan Department of Natural Resources for logistical support. The Northeast Michigan Sportsman's Club installed the habitat enhancement structures studied. Funding for this research was provided by the Michigan Department of Natural Resources and the USDA Forest Service.

TABLE OF CONTENTS

LIST OF TABLES

Table 7. P-values from mixed-effect analysis of variance modeling the effects of treatment, macrophyte cover, coarse woody material (CWM) cover, and substrate on smallmouth bass nest density and nest success. A total of 126 individual nests were monitored throughout the entire spawning season in 2001. Treatment refers to the presence or absence of half-log habitat enhancement structures. NS=not significant.

LIST OF FIGURES

Figure 9. Mean smallmouth bass nest density (nests/ha, top) and nest success (%, bottom), ± 95% CI, by substrate from data collected in 2001 in Cooke and Foote ponds. Note difference in y-axes between nest density and nest success.

Figure 10. Relationship between macrophyte cover and smallmouth bass nest density (nests/ha, top) and nest success (%, bottom) for treatment and reference areas from data collected in 2001 in Cooke and Foote ponds. Note difference in y-axes between nest density and nest success.

INTRODUCTION

Fisheries managers have long recognized the potential of habitat enhancement structures to attract and hold fish (Brown 1986). The first state management agency to document the use of habitat enhancement structures was the Michigan Conservation Department, which added brush shelters and gravel piles to lakes in the early 1930's (Hazzard 1937). Since that time, numerous state and federal agencies and local organizations have undertaken habitat enhancement projects in both freshwater and marine systems using a variety of materials (Tugend et al. 2002). These habitat enhancement structures are added to aquatic systems when natural habitat is perceived to be lacking or insufficient (Prince et al. 1977), with the goal of providing additional cover and concentrating fish, thereby increasing recruitment, survival, growth, and angler catch rates (Johnson and Stein 1979).

The mechanisms by which habitat enhancement structures can produce these positive effects are varied. For example, habitat enhancement structures have been proposed to increase recruitment by providing cover for spawning (Vogele and Rainwater 1975, Hoff 1991, Patrick 1996, Hunt 2000), thereby increasing nest density. Ultimately nest success may benefit if structures provide habitat that allows adults to more effectively protect their young (Hoff 1991). Structures can also offer refuge from predation and alter survival by increasing cover (Bohnsack and Sutherland 1985, Johnson et al. 1988, Moring and Nicholson 1994), providing shade (Helfman 1979, Helfman 1981, Johnson and Lynch 1992), and providing sites for orientation and schooling (Klima and Wickham 1971, Bohnsack and Sutherland 1985). Accordingly, forage abundance in the vicinity of structures may be enhanced (Wege and Anderson 1979, Aadland 1982, Bohnsack and Sutherland 1985, Moring et al. 1989), in turn increasing the abundance, feeding efficiency, and growth of predators (Wege and Anderson 1979, Bohnsack 1989). Habitat enhancement structures, particularly in the form of artificial reefs, have also been proposed to increase public access by making it easier for anglers to locate fish, and to increase angler catch rates by concentrating fish (Bohnsack 1989).

Numerous studies have demonstrated that habitat enhancement structures succeed in concentrating fish in natural lakes (Wilbur 1974, Moring and Nicholson 1994) and reservoirs (Brouha 1974, Paxton and Stevenson 1979, Prince and Maughan 1979a, Brown 1986, Kayle 1986, Moring et al. 1989, Mabbott 1991, Rogers and Bergersen 1999). However, the extent of their effects varies for several reasons. For example, the degree to which attraction occurs is often dependent upon the species present (Hubbs and Eschmeyer 1938, Rodeheffer 1939, 1945), diel fluctuations in fish distribution (Moring and Nicholson 1994), the age of the structure (Wilbur 1978, Moring and Nicholson 1994), and/or the structure's physical attributes. In particular, the average number of individuals and species attracted increases with structural complexity achieved by increasing the volume, size, and surface area of habitat enhancement structures (Wickham et al. 1973, Shulman 1984, Rountree 1989, Graham 1992, Potts and Hulbert 1994). Further, fish abundance varies with structure interstice size (the space within structures) in a complex fashion (Brouha 1974, Wege and Anderson 1979, Johnson et al. 1988, Lynch and Johnson 1989, Walters et al. 1991).

Morphometric characteristics of the lakes and reservoirs where habitat enhancement structures are installed also influence their effectiveness. Habitat enhancement structures may be relatively ineffective in systems with topographically complex bottoms (Pardue and Nielsen 1979) and/or alternative natural habitat (Wilbur 1978, Mitzner 1981, Madejczyk et al. 1998, Rogers and Bergersen 1999). The depth at which habitat enhancement structures are placed also influences structure use, although this is often dependent upon the foraging and habitat preferences of resident species (Rodeheffer 1945, Kayle 1986, Walters et al. 1991, Johnson and Lynch 1992). Reservoirs, in particular, often make ideal candidates for habitat enhancement projects. Reservoir systems often lack natural habitat due to the removal of standing timber prior to or following flooding, decay of timber, rapid siltation of rocky reefs and other firm substrate in littoral areas, and/or lack of aquatic vegetation caused by fluctuating water levels (Prince and Maughan 1978).

Although federal and state agencies conduct periodic investigations of the effects of habitat enhancement structures on fish populations, relatively little information is available in the primary literature to aid managers in decisions regarding exactly how much, what kind, or where habitat enhancement structures should be added to a system to attain desired production goals (Bassett 1994, Rogers and Bergersen 1999). This uncertainty remains in part because many investigations have been inadequately documented, and rarely have assessments determined the effects of habitat enhancement structures on system-wide abundance of fish. In addition, many assessments have lacked controls, pre-treatment data, and statistical analysis, while most have also failed to compare the effectiveness of different structure types within systems (Bassett 1994).

By identifying the conditions under which habitat enhancement structures are most effective, fisheries managers can most successfully and economically use structure as a tool for increasing reproduction, survival, growth, and angler catch rates of sport fishes in systems with insufficient natural habitat (Johnson and Stein 1979). Within this context, I evaluated two types of structure, half-logs and AquaCribs®, in four reservoirs of the Au Sable River, Michigan. I used a combination of two approaches to do so: (1) comparisons within reservoirs between similar areas with and without added structure, and (2) comparisons within a reservoir before and after structure placement. The natural habitat in these reservoirs varied, allowing me to evaluate the effectiveness of the structures across a gradient of natural habitat and turbidity. In so doing, I sought to develop management recommendations for placement of habitat enhancement structures such that future endeavors are most beneficial and cost-effective.

I hypothesized that areas with habitat enhancement structures would concentrate fish, increase nest densities, and increase angler catch rates compared to areas without structures. I also hypothesized that habitat enhancement structures would influence predator-prey interactions. Specifically, I expected that invertebrates would colonize the half-logs, and that prey biomass in gut contents from smallmouth bass and largemouth bass (*Micropterus salmoides*) would be greater in areas with structures than in areas without structures. Overall, I expected the intensity of effects to increase with decreasing natural habitat.

METHODS

Study reservoirs

Consumer's Energy Company created six reservoirs on the Au Sable River (Figure 1) between 1911 and 1924, four of which were included in this study. In general, the reservoirs are mesotrophic in nature with short retention times ranging from 1 to 12 days. Two of the reservoirs are operated to simulate run-of-river flow (Alcona and Foote ponds), while the other two (Loud and Cooke ponds) are peaking operations with daily water level fluctuations reaching 0.49 and 0.30 m, respectively (Table 1, Kinney et al. 1999). Turbidities are moderate, and decrease from upstream to downstream reservoirs. The reservoirs contain widespread littoral habitat supporting a moderate amount of vegetation, which is unstable in some due to daily water level fluctuations.

Experimental approach

All field sampling occurred during the summers of 2000 and 2001. The Northeast Michigan Sportsman's Club placed habitat enhancement structures (half-logs and AquaCribs®, described below) in Loud, Cooke, and Foote ponds in the fall of 1999. In 2001, I placed structures in Alcona Pond as well as additional structures in Loud Pond. In Loud, Cooke, and Foote ponds I conducted within reservoir comparisons between areas with and without structures, only after structure placement, whereas in Alcona Pond I conducted within reservoir comparisons before and after structure placement (Table 2). In all reservoirs, sites were chosen for treatment (structure) and reference (no structure) pairs, to insure that within pairs, treatment and reference areas were as similar to each other as possible and that the paired sites represented a variety of habitat conditions throughout each reservoir. University and agency researchers chose sites for treatment and reference pairs in Loud, Cooke, and Foote ponds from habitat maps that distinguished vegetated and non-vegetated areas by dividing the shoreline into sections and choosing study sites haphazardly. In Alcona Pond I divided the shoreline into 100m sections and randomly assigned study sites. To ensure that structures in treatment areas did not affect fish behavior in reference areas, the reference area was located a minimum of 100m from the treatment area. Whenever possible, I paired one treatment area to one reference area. When this was not possible, one reference area was shared between two treatment areas. This occurred five times across all four reservoirs. Minimum distance between two consecutive treatment/reference pairs within reservoirs was 100m, but typically was at least 300m.

I arranged half-logs, a nesting and cover device constructed of a hardwood slab (approximately 2.4 m in length, 25 cm in width, and 5 cm thick) and two to three two-core masonry blocks (20 x 20 x 41cm), perpendicular to the shoreline 5m apart at the 1m depth contour in groups ranging from 4 to 97. The Northeast Michigan Sportsman's Club constructed the half-logs by bolting the masonry blocks to each end of one flat side of the hardwood slab, leaving 5-10cm of the slab overhanging at each end (Figure 2), similar to the half-log described by Hoff (1991). The club also assembled and installed AquaCribs® (Figure 2), a box-shaped shelter device (122 x 152 x 122cm) constructed of corrugated plastic, in clusters varying in number from 3 to 10, suspended 1m above the bottom over a depth interval of 2.7 to 5.5m. The numbers of half-log and AquaCrib® sites varied among reservoirs (Table 2).

Natural habitat and limnological data

In order to evaluate the effectiveness of half-log structures across different environmental contexts and compare the similarity of treatment and reference pairs, I characterized the natural habitat at each treatment and reference pair using the method described by Hunt (2000). A diver wearing a snorkel and mask made visual observations of natural habitat across the entire length of the transect over the middle depth contour of each area. The diver noted and recorded substrate composition (sand, clay, or gravel), presence and size of coarse woody material, and presence and size of macrophyte patches. I calculated percent cover of coarse woody material and macrophytes by summing the length of the individual habitat patches along the transect and dividing by the total length of the transect. Sampling took place once per site during early June of 2001 and early August of 2000 and 2001.

I collected limnological data biweekly from each of the four study reservoirs, using a YSI model 55 dissolved oxygen meter to derive temperature/dissolved oxygen profiles and a Secchi disk to gauge turbidity. I utilized HOBO® temperature loggers (two per reservoir, one each at an upstream and downstream location, at 1m depth) to monitor temperature over the duration of the field season, and an integrated tube sampler to collect water samples from the epilimnion (as determined by temperature/dissolved oxygen profiles) for chlorophyll a, total phosphorous and total nitrogen analysis. All samples were returned to the laboratory and processed using standard procedures (Murphy and Riley 1962, Menzel and Corwin 1965, Nusch 1980, Crumpton et al. 1992).

Fish concentration and predator-prey interaction

To evaluate the effectiveness of half-logs in concentrating fish, I used counts obtained by visual observation while snorkeling along transects (modified from Keast and Harker 1977, Moring and Nicholson 1994, Brown et al. 2000). Divers wearing a snorkel and mask conducted visual observations on the half-logs one day per week in each reservoir during the first two weeks of each month (June-August). Six treatment and reference pairs within the reservoir were randomly selected for observation on each sampling date. Separate divers swam each treatment and reference area of a pair simultaneously. At each half-log treatment area containing less than ten half-logs, the divers conducted three parallel transects to estimate fish abundance over the entire area where the half-logs were placed: the first transect was parallel to shore at the nearshore end of the half-logs (1m depth contour), the second at the middle of the half-logs, and the third at the deep end. At sites containing ten or more half-logs, a random subsample of five half-logs was chosen for observation. All nearshore transects began at the 1m depth contour and proceeded in a downstream direction parallel to the shore, beginning 5m before the first half-log encountered and ending 5m after the last one. Upon completion of the first transect, the swimmer reversed direction and completed the second transect, and then the third in an effort to minimize disturbance over the study area. Transects in each reference area were of the same length and at the same depths as transects at the corresponding treatment area. Divers marked transect starting and ending points on the shoreline with surveyor's tape and used a removable buoy system to ensure that all transect lengths and depths were equal between treatment and reference pairs. Divers established transect lengths for each area on the first sampling date that a site was randomly chosen for observation. All fish observed at each transect were identified to species and counted. I calculated relative abundance (fish/km) by averaging the three transect counts at each area and then dividing by the length of the transect.

I also used nighttime electrofishing to evaluate the effectiveness of half-logs in concentrating fish and their effects on fish foraging. Field personnel conducted one transect in the downstream direction with a boat-mounted electrofisher (7 amps pulsed D.C., 120hz) at the 1m depth contour at each of six randomly chosen treatment and reference pairs once per month per reservoir during the months of June, July, and August. All fish captured were identified and measured to provide estimates of relative abundance (fish/km) by species, and all smallmouth bass and largemouth bass were weighed. Field personnel used gastric lavage (12 volt electric water pump, 60gal/hr) to collect diets from all smallmouth and largemouth bass greater than 150mm TL. Large diet items such as crayfish and large fish that were not completely extracted by gastric lavage were removed by hand or with the aid of forceps. After funneling all smallmouth and largemouth bass diets into 10.16 x 15.24cm cloth bags, field personnel preserved the diets in 95% ethanol. Smallmouth and largemouth bass less than 150mm total length were sacrificed and preserved in 95% ethanol for stomach dissection.

In order to quantify possible forage items associated with half-logs, field personnel collected macroinvertebrates colonizing the half-log structures from five half-logs chosen randomly from each treatment site in Cooke and Foote ponds in August of 2001 by use of an air-vacuum apparatus. The samples were stored in 95% ethanol and returned to the laboratory for sorting, identification, and enumeration. Laboratory personnel added Rose Bengal to each sample to facilitate sorting, and then identified all invertebrates to order. Dry weights were estimated using regressions (*see Diet analysis* below). Due to the short amount of time that elapsed between invertebrate sampling and when the half-logs had been installed in Alcona and Loud ponds, I did not collect invertebrate data in these two reservoirs.

Visual observation and electrofishing were not possible as sampling methods for AquaCribs® due to the lower light levels at the depths where AquaCrib® were placed. Accordingly, I employed gill nets (15.24m length, 1.83m depth, 4-panel experimental mesh, 1.3cm, 1.9cm, 2.5cm, and 3.8cm mesh size) to evaluate the effectiveness of AquaCribs® in concentrating fish. I conducted netting once per week at each reservoir during monthly two-week periods in June, July, and August of 2000 and 2001, using short sets at two randomly selected treatment and reference pairs in an effort to minimize catch mortality. In 2000, I set the nets at the depth contour past the last visible cribs (4.6 to 5.5m) in mid-morning and removed them in the late afternoon. Few fish were caught during this time period. Therefore, in 2001 I set the nets in late afternoon and removed them the next morning. All fish captured were measured and recorded. I made no comparison of diets between treatment and control areas, as insufficient numbers of smallmouth bass and largemouth bass were captured to permit such comparisons.

Diet analysis

Laboratory personnel identified diet items to species for fish and to order for invertebrates and crayfish. When necessary, further distinctions were made below order for invertebrates to provide more accurate dry weight estimates. In order to determine dry weights using regressions (G. G. Mittelbach, Michigan State University, Kellogg Biological Station, unpublished data, Wilson and Sarnelle 2002) laboratory personnel measured head capsule width for most invertebrates, carapace length for crayfish, total length for zooplankton, and standard length for fish using a Numonics GraphicMasterII™ digitizer tablet connected to a Nikon SMZ-U stereo microscope (1:10 zoom) magnified at 0.75x. Diet items too large to measure using the digitizer were measured to the nearest millimeter with a ruler. I established five primary prey groups (crayfish, fish, macroinvertebrates, zooplankton, and total of all stomach contents) and determined diet composition by prey group on a dry weight (g) per gram of fish basis.

Attraction of nesting fish

I used visual observation (modified from Hunt 2000) to evaluate the use of half-logs by nesting smallmouth bass. Sampling took place two to three times per week during

May and early June in Cooke and Foote ponds in 2001. Divers wearing snorkel and mask sampled each treatment and reference pair within the reservoir on each sampling occasion. Divers swam transects over the middle depth contour at which the half-logs were located in treatment areas and over the same depth contour in reference areas using the aforementioned visual observation protocols. Each nest encountered within 2m of the transect was assigned a unique number and marked using a piece of surveyor's tape attached to a large metal washer. Divers recorded nest number, substrate, and presence/absence of fry (metric of nest success).

Angler catch rates

I utilized standardized angling to evaluate the effectiveness of both half-logs and AquaCribs® in concentrating fish for angler capture. Once per month per reservoir during June, July, and August 2000 and once per week per reservoir during June, July, and August 2001, two anglers fished six randomly selected treatment and reference pairs for ten minutes each with randomly assigned artificial or live baits. The first location to fish within each pair (treatment or reference) was assigned randomly; individual baits and lures were randomly assigned to each angler. Anglers measured, weighed, and recorded all fish captured to provide estimates of relative abundance (catch/hour).

Statistical analyses

In order to facilitate data analysis and interpretation, I placed the most abundant game fish species that were encountered during sampling into four groups: total (comprised of black crappie *Pomoxis nigromaculatis*, bluegill *Lepomis macrochirus*, largemouth bass, northern pike *Esox lucius*, pumpkinseed *Lepomis gibbosus*, rock bass *Amblopites rupestris*, smallmouth bass, walleye *Stizostedion vitreum*, and yellow perch

Perca flavescens), smallmouth bass, other piscivores (included largemouth bass, northern pike, and walleye), and planktivores (consisted of black crappie, bluegill, pumpkinseed, rock bass, and yellow perch). All data were analyzed using SAS version 8.0 (SAS Institute Inc. 1999). When appropriate, I transformed the data to meet the necessary distributional assumptions.

Within-reservoir comparisons. I used data collected from Cooke and Foote ponds in 2000 and 2001 and data collected from Alcona and Loud ponds in 2001 for within-reservoir comparisons between treatment and reference areas (Table 2). In order to extrapolate results beyond the four reservoir systems studied, I used mixed-effect analysis of variance (ANOVA, SAS Institute 1999). For each functional group, I used mixed-effect ANOVA to determine if the mean difference in relative abundance derived from visual observation and electrofishing (comparing treatment versus reference areas) varied predictably as a function of natural habitat. I conducted a similar analysis to determine if the mean difference in smallmouth bass nest density in treatment versus reference areas varied predictably as a function of natural habitat. For each functional group, I used mixed-effect ANOVA to determine if the mean difference in relative abundance derived from angling and gill netting (comparing treatment versus reference areas) varied predictably as a function of treatment. I used mixed-effect ANOVA again to determine if the mean difference in prey dry weight (grams prey per gram of fish, treatment versus reference) from gut contents of smallmouth bass and largemouth bass varied predictably among reservoirs as a function of natural habitat. For all mixed-effect models, I treated treatment and substrate as fixed effects and reservoir and site (nested within reservoir) as random effects. Percent cover of coarse woody material (CWM) and macrophytes were treated as covariates. In order to make comparisons among the four reservoirs studied, I used fixed-effect ANOVA (SAS Institute 1999) to determine if the mean difference in relative abundance (treatment versus reference) for each functional group derived from visual observation, electrofishing, angling, and gill netting varied predictably among reservoirs. Separate analyses were conducted for each functional group and sampling technique combination. Reservoir and treatment were treated as fixed effects, while site (nested within reservoir) was treated as a blocking factor. Rejection criterion was set at $\alpha=0.05$ for both analyses.

Before and after comparisons. I used data collected from Alcona Pond in 2000 and 2001 for within-reservoir comparisons before and after structure placement. I used mixed-effect ANOVA to determine if the mean difference in relative abundance derived from visual observation and electrofishing (comparing treatment versus reference areas) for each functional group varied according to year and treatment. Insufficient angling data were collected to permit comparisons before and after structure placement. I treated treatment and year as fixed effects, and individual sites as a random effect. I also used mixed-effect ANOVA to determine if the mean difference in prey biomass (treatment versus reference) from gut contents of smallmouth bass collected from electrofishing varied according to year and treatment (low catch of largemouth bass prevented analysis). I treated treatment and year as fixed effects, and individual sites as a random effect. Rejection criterion was set at $\alpha=0.05$ for all analyses.

RESULTS

Natural habitat and limnology

Substrate composition and macrophyte and CWM cover at study sites varied among reservoirs. No clear pattern was evident in substrate composition along a gradient from upstream to downstream reservoirs. The predominant substrate type in the reservoirs (Figure 3a) was sand (Alcona, Cooke, and Foote ponds) or gravel (Loud Pond). Clay comprised greater than 30% of total substrate cover in only one reservoir (Cooke Pond). Macrophyte cover appeared to increase along the upstream-downstream gradient, with cover less than 20% at sites in the two upstream reservoirs, and cover greater than 60% at sites in the two downstream reservoirs (Figure 3b). CWM cover displayed a contrasting pattern. CWM cover was highest (~8%) at sites in Alcona Pond, the most upstream reservoir, and uniformly lower (less than 3%) at sites in the three downstream reservoirs (Figure 3c).

Mean summer epilimnetic temperature was similar among reservoirs (Table 3). All reservoirs, with the exception of Loud Pond in 2000, displayed thermal stratification by late summer. Chlorophyll a concentration was similar across all study reservoirs, ranging from ~2.5 ug/L in Loud Pond to ~4 ug/L in Alcona Pond (Table 3). Total phosphorous concentration ranged from 14.1 ug/L in Foote Pond to 24.3 ug/L in Loud Pond and displayed no clear pattern along a gradient from upstream to downstream reservoirs (Table 3). Conversely, total nitrogen concentration increased along a gradient from upstream to downstream reservoirs, ranging from 192.5 ug/L in Alcona Pond to 524.8 ug/L in Foote Pond (Table 3).

Fish concentration

Half-logs within and among reservoirs. Presence of half-logs had a significant positive effect on smallmouth bass abundance as indicated by the mixed-effect models for both visual observation and electrofishing (Table 4, Figure 4). Although no other significant effects of half-logs on CPE were documented, in most cases (with the exception of piscivore CPE from visual observation samples), point estimates of mean CPE were higher in treatment areas compared to reference areas (Figure 4). CPE of all functional groups was higher for electrofishing than visual observation, although patterns of relative abundance among functional groups were similar between the two sampling methods (Figure 4).

Two functional groups, piscivores and smallmouth bass, demonstrated significant variation with natural habitat (Table 4), although the direction of response to habitat differed among habitat types and between functional groups. Piscivore CPE from visual observation varied with both macrophyte and CWM cover. As macrophyte cover increased, piscivore CPE decreased. Conversely, as CWM cover increased, piscivore CPE increased. Similarly, smallmouth bass CPE, both from visual observation and electrofishing, increased with CWM cover. In addition, electrofishing data indicate the presence of a significant treatment*macrophyte cover interaction for smallmouth bass CPE. Smallmouth bass CPE at treatment areas containing half-logs decreased with increasing macrophyte cover, while the opposite trend was present at reference areas. Hence, the largest difference in smallmouth bass CPE between treatment and reference areas occurred at sites with low macrophyte cover.

All functional groups, with the exception of piscivores from visual observation data, demonstrated significant variation among reservoirs (Table 5a and b) as indicated by the fixed-effect models. In general, CPE from visual observation for all functional groups increased from upstream to downstream reservoirs. Total, planktivore, and smallmouth bass visual observation CPE appeared highest in Foote Pond, followed by Cooke, Alcona, and Loud ponds. Total and planktivore electrofishing CPE demonstrated no clear pattern with respect to the upstream/downstream gradient, although the highest CPE for both functional groups occurred in Foote Pond. In contrast, piscivore and smallmouth bass electrofishing CPE decreased from upstream to downstream reservoirs. CPE of these two functional groups was highest in Alcona Pond and decreased in subsequent downstream reservoirs. Site, as well as the interaction between reservoir and site, served as significant sources of variation within functional groups for both methods (Table 5a and b), reflective of within-reservoir variability.

Treatment did not appear to be a significant source of variation in CPE (with the exception of smallmouth bass) for visual observation. However, for electrofishing, total and piscivore CPE were higher at treatment areas containing half-logs compared to reference areas in most instances (Figure 5). Among the four reservoirs, CPE at treatment and reference areas was similar (with the exception of piscivore CPE), as no significant reservoir*treatment interaction occurred for either visual observation or electrofishing (Table 5a and b). Piscivore electrofishing CPE displayed significant variability among reservoirs, site, and treatment, as demonstrated by the presence of significant site*treatment and reservoir*site*treatment interactions (Table 5b).

Half-logs before/after placement. In Alcona Pond, no significant treatment*year interaction occurred for any of the four functional groups (Table 6), indicating that half-log structures did not significantly concentrate fish after their placement (Figure 6). Year presented a significant source of variability, with piscivore CPE significantly higher in 2001 compared to 2000 for visual observation, but total and planktivore CPE significantly higher in 2001 compared to 2000 for electrofishing (Table 6). Treatment was significant for smallmouth bass sampled by electrofishing across both years (Table 6), with higher CPE in treatment areas containing half-logs compared to reference areas without half-logs (Figure 6) both before and after structure placement.

AquaCribs® within and among reservoirs. Presence of AquaCribs® had no significant effect on the abundance of any of the four functional groups as represented by both the mixed-effect (Table 4) and fixed-effect models (Table 5c, d). Reservoir was a significant source of variability for planktivore CPE in gill nets, and a reservoir*site interaction was present for total and planktivore gill net CPE, further reflecting within and among reservoir variability (Table 5c). Planktivore CPE in gill nets was nearly ten times higher in Foote Pond (0.29 fish/hour) compared to Cooke Pond (0.03 fish/hour). Significant within-reservoir variability was present for smallmouth bass CPE in gill nets (Table 5c). For piscivores, the effect of treatment on CPE varied among reservoirs as indicated by a significant reservoir*treatment interaction (Table 5c). In Cooke Pond the presence of AquaCribs® had a positive effect on piscivore CPE (0.03 fish/hour at treatment areas compared to 0.01 fish/hour at reference areas). Conversely, in Foote Pond the presence of AquaCribs® had a negative effect on piscivore CPE (0.02 fish/hour at treatment areas compared to 0.05 fish/hour at reference areas).

Invertebrate biomass and diet analysis

Invertebrate samples from half-logs in Cooke and Foote ponds were dominated by zebra mussels (*Dreissena polymorpha*), which constituted over 99% of the total invertebrate biomass present. Amphipods, diptera, ephemeroptera, and trichoptera species made up less than 1% of the total invertebrate biomass present. Excluding zebra mussels, amphipods comprised 64% of the total biomass of the four other invertebrate orders, followed by trichoptera (24%), diptera (6%), and ephemeroptera (5%).

Total prey dry weight (per gram of fish) in smallmouth bass and largemouth bass diets did not vary significantly between treatment and reference areas, or with natural habitat, within any of the four reservoirs. For smallmouth bass, invertebrates were the most abundant diet item (~48% of prey weight per gram of fish), followed by fish (~35%), crayfish (~12%), and zooplankton (~5%, Figure 7a). For largemouth bass, fish were the most abundant prey item, comprising nearly 70% of the total prey dry weight per gram of fish. Invertebrates were the second most abundant prey item for largemouth bass, constituting over 20% of prey weight, while crayfish were the third most abundant prey item (Figure 7b). Zooplankton were not found in any of the largemouth bass stomachs for within-reservoir analysis. In the before/after study, total prey dry weight per gram of smallmouth bass did not differ significantly between treatment and reference areas after structure placement in Alcona Pond. Invertebrates were the most abundant prey item in both years (~45-55% by year), followed by fish (~35-40% by year), crayfish (~10-20% by year), and zooplankton (less than 10% by year, Figure 7c, d).

Attraction of nesting fish

Smallmouth bass nest density and nest success (Figure 8) were significantly higher in treatment areas with half-logs compared to reference areas (Table 7). In addition to treatment, substrate and macrophyte cover were also important factors related to smallmouth bass nest density and nest success. Mean nest success was highest in areas with gravel substrate (Figure 9), and mean nest density decreased with increasing percent macrophyte cover (Figure 10). A significant treatment*macrophyte cover interaction was present for mean smallmouth bass nest density and nest success (Figure 10). Mean nest density and nest success were higher at treatment areas compared to reference areas at low macrophyte cover, but this pattern became less noticeable as macrophyte cover increased.

Angler catch rates

AquaCribs® and half-logs. Presence of half-logs or AquaCribs® had no influence on angler catch rates for any of the four functional groups. Mixed-effect (Table 4) and fixed-effect (Table 5d) models of mean angling CPE data by functional group at AquaCribs® and half-logs indicate no significant treatment effects for either structure type. Reservoir was a significant source of variability for several functional groups as indicated from the fixed-effect models (Table 5d). Total angler CPE when fishing at half-log sites (across treatment and reference areas) was highest in Cooke Pond (0.57 fish/hour), followed by Foote Pond (0.50 fish/hour), Loud Pond (0.44 fish/hour), and Alcona Pond (0.24 fish/hour). Angler CPE of smallmouth bass at AquaCrib® sites (across treatment and reference areas) was higher in Foote Pond (0.06 fish/hour) compared to Cooke Pond (0.002 fish/hour). Site was a source of variability for total and planktivore angler CPE when fishing at both half-log and AquaCribs®, reflective of within-reservoir variability for CPE of both functional groups. Additionally, reservoir*site and site*treatment interactions existed for smallmouth bass CPE at AquaCribs®, representing further within-reservoir variability in CPE as well as the influence of site-specific characteristics on treatment effectiveness.

DISCUSSION

I specifically sought to address the uncertainty surrounding where to add structures within a system, paying particular respect to the effects of pre-existing natural habitat conditions on structure use, so that future habitat enhancement efforts are most beneficial and cost-effective. To do so, I used two statistical models: mixed-effect and fixed-effect ANOVA. In the mixed-effect models, reservoirs and sites within reservoirs were treated as random effects so that the results of the analyses could be extrapolated beyond the four reservoir systems I studied, thus emphasizing a general understanding of how natural habitat influences the effects of habitat enhancement structure. However, I also felt that useful information could be gained by treating the four reservoirs as unique entities with inherently different characteristics. Hence, I also used fixed-effect ANOVA models to draw inference specifically among these four reservoirs and their unique habitat conditions.

Both statistical models reflected similar results, indicating that addition of habitat enhancement structures had little effect on the four functional groups of fish I studied. Each model also demonstrated the importance of pre-existing natural habitat conditions. Habitat variables such as macrophyte cover, CWM cover, and substrate within study sites were an important source of variability in CPE for certain functional groups as reflected by the mixed-effect models. Accordingly, individual study sites, as well as reservoirs, each varying in their specific habitat characteristics, were an important source of variability in CPE in the fixed-effect models. In other words, natural habitat appeared to influence CPE more so than did the presence of habitat enhancement structures. Thus, before any habitat enhancement project is undertaken, the characteristics of the individual system of interest, as well as specific locations within systems, must be taken into account before structures are placed to ensure their necessity and/or effectiveness.

Using a variety of sampling methods, numerous studies have found that habitat enhancement structure in ponds, lakes, and reservoirs concentrate fish (Brouha 1974, Reeves et al. 1978, Prince and Maughan 1979a, Prince and Maughan 1979b, Pierce and Hooper 1980, Smith et al. 1981, Aadland 1982, Kayle 1986, Moring et al. 1989, Mabbott 1991, Moring and Nicholson 1994). In particular, several studies have indicated that black bass (*Micropterus* sp.) demonstrate an affinity towards structure (Reeves et al. 1978, Prince and Maughan 1979a, Prince and Maughan 1979b, Pierce and Hooper 1980, Smith et al. 1981, Dufour 1989, Rogers and Bergersen 1999). I found similar results for smallmouth bass in my study; however, contrary to the results of past research, the two structure types I studied in four reservoirs had little apparent effect at concentrating other species. I did find significant variability in CPE among reservoirs, supporting the notion that characteristics inherent to the system of study may influence fish assemblages more so than the presence of habitat enhancement structure. While the earliest work conducted in lentic systems indicated structure effectiveness is influenced by structure type and species present (Hubbs and Eschmeyer 1937, Rodeheffer 1939, Rodeheffer 1945), more recent research has found variability in structure effectiveness due to inherent characteristics of the system under study. For example, the amount of alternative complex physical habitat available negatively affected structure use by fish in research conducted by Mitzner (1981) and Rogers and Bergersen (1999).

Few studies have examined the effects of structure on fish diets and growth; therefore, the amount of information available in the literature to support or refute claims of increased foraging success and growth is limited. Prince et al. (1976) and Aadland (1982) found increased periphyton growth on reefs but did not document foraging patterns or diets of fish. Pardue and Nielsen (1979) found similar results on wooden substrates, but no increase in the production of tilapia (*Tilapia aurea* and *Tilapia mossambica*) or bluegill biomass. Dufour (1989) found a correlation between invertebrates present in smallmouth bass and rock bass stomach contents and invertebrates colonizing half-logs in a river, while Wege and Anderson (1979) found greater largemouth bass growth in ponds with structure. Due to the relatively small amount of structure added per surface acre of reservoir in my study, I made no attempt to quantify change in growth of any of the species encountered. While data collected from half-logs indicate that some invertebrates do indeed colonize the structures, I found no significant difference in dry weight of gut contents of largemouth bass and smallmouth bass between treatment and reference areas. My sampling protocols assumed that fish would be actively feeding in the treatment and reference areas during sampling, an assumption that may not be valid. Although treatment and reference areas were sampled within minutes of each other, fish were free to move about each area before sampling. Accordingly, fish that were foraging in the vicinity of structures may have moved away from the sampling area, while fish that were foraging outside of the vicinity of structures may have moved into the sampling area. Thus, detecting any change in fish diets would be difficult.

In addition to congregation at structures throughout the summer, other studies have demonstrated that black bass display a preference towards structure during the nesting season. Vogele and Rainwater (1975) found higher numbers of spawning spotted bass (*Micropterus punctulatus*) and largemouth bass around brush shelters in an Arkansas reservoir, but noted that smallmouth bass showed no preference towards structure. In contrast, Coble (1975) and Miller (1975) noted that smallmouth bass preferred overhead cover throughout all life stages, including nesting. Accordingly, Hoff (1991) found dramatic increases in smallmouth bass nest density, nest success, and juvenile abundance in northern Wisconsin lakes after treatment with half-logs. Patrick (1996) found similar results for smallmouth bass nest density and nest success in a Tennessee reservoir. Hunt (2000) found that spawning largemouth bass were attracted to half-log structures, but that the degree to which this occurred was dependent upon the amount of complex physical habitat nearby. My results are consistent with those of Hoff (1991), Patrick (1996) and Hunt (2000). Half-log habitat enhancement structures significantly increased smallmouth bass nest density and nest success in comparison to areas without structure. But, natural habitat conditions were an important factor in determining nest density and nest success in areas with structure. As Hunt (2000) discovered for largemouth bass, the amount of available physical habitat played a key role in determining the nesting habits of smallmouth bass near half-logs.

Standardized angling has been a widely used method for evaluating the effectiveness of structure in attracting fish and increasing angler catch rates (Petit 1972, Brouha 1974, Wilbur 1978, Paxton and Stevenson 1979, Wege and Anderson 1979, Rogers and Bergersen 1999). Several studies have demonstrated that angler catch rates are higher in areas with structure compared to areas without structure (Petit 1972, Wilbur 1978, Paxton and Stevenson 1979, Wege and Anderson 1979, Rogers and Bergersen 1999), and catch rates, as similar to concentration in general, are dependent upon structure type and species present (Paxton and Stevenson 1979, Rogers and Bergersen 1999). In my study, angler catch rates for all functional groups were similar between areas with and without structure, further supporting the ineffectiveness of structure in concentrating fish in my systems of study.

Several studies have noted the effectiveness of different structure types used in habitat enhancement projects. Hubbs and Eschmeyer (1937) were the first to realize that different structure types vary in their effectiveness at concentrating fish. Brouha (1974) noted that centrarchid species displayed a preference towards reefs constructed of trees compared to reefs constructed of tires. Similarly, Rogers and Bergersen (1999) noted that largemouth bass displayed preferences towards varying types of synthetic structures. Although I did not directly compare the effectiveness of half-logs and AquaCribs®, I feel that it is important to note that half-logs, the simpler of the two structures I studied appeared more effective, outperforming the more complex and expensive AquaCribs®. In addition to being considerably more inexpensive than the AquaCribs®, half-logs are comprised of materials readily available for purchase at any hardware store or lumberyard and are simple and efficient to assemble.

In summary, I suspect that the abundance of natural habitat present in the reservoirs that I studied influenced the effectiveness of the habitat enhancement structures in concentrating fish. In each reservoir, abundant natural habitat is present in the form of standing timber, CWM, and macrophytes. Accordingly, when considering my study reservoirs as a whole, the amount of habitat enhancement structure added (compared to the available natural habitat present) is relatively small. I believe that this contributed to the paucity of significant structure effects in my study. In other words, the amount of structure added (compared to existing natural structure) is insufficient to attract most fish and increase concentration. Therefore, fisheries managers must carefully consider the system as a whole when undertaking any habitat enhancement effort. Managers can plan ahead and improve the likelihood of success of habitat enhancement projects by considering the amount of natural habitat available within a particular system. Additionally, managers may also consider structure placement with regards to the species present within the system and their life history and habitat needs to ensure greater chances of success. Smallmouth bass, a species that has demonstrated an affinity towards overhead cover (Coble 1975, Miller 1975) and has benefited from structure in the past (Hoff 1991, Patrick 1996), responded positively in my study as well. Through consideration of such species-specific habitat requirements, as well as available natural habitat and cost-effectiveness of various structure types, fisheries managers can plan beneficial and economical habitat enhancement efforts.

APPENDIX

Tables and figures

Table 1. Physical characteristics of the Au Sable River study reservoirs based on data from Consumer's Power Company, the Federal Energy Regulatory Commission, the United States Forest Service (Kinney et al. 1999), and this study. Reservoirs are ordered from upstream to downstream. Shoreline development factor describes the irregularity of the shoreline and is expressed as the ratio of the length of the shoreline to the circumference of a circle of area equal to that of the lake surface, with a minimum value of 1.0 for a circular lake. Water level fluctuation is the maximum daily change in water level resulting from hydroelectric dam operation.

Impoundment	**Surface Area (ha)**	**Mean/Max. Depth (m)**	**Shoreline Development Factor**	**Retention Time (days)**	**Water Level Fluctuation (m)**
Alcona	407	3.8/12.2	2.25-3.93(est.)	5.2	0
Loud	301	2.9/7.9	2.25	2.5	0.49
Cooke	658	5.0/11.6	3.57	9.4	0.30
Foote	689	5.8/10.7	3.93	11.4	0.30

Table 2. Experimental design and number of sites per reservoir. "Before/after" indicates within-reservoir comparison before and after structure placement. "After only" indicates within-reservoir comparison after structure placement.

Reservoir	**Alcona**	**Loud**	**Cooke**	**Foote**
Design and Analysis	Before/after and After only[1]	After only	After only	After only
Year of structure placement	2001	1999 and 2001[2]	1999	1999
No. of Log Sites	10	11	10	9
No. of Crib Sites	0	0	8	23

[1]Data from 2000 and 2001 used for before/after analysis. Data from 2001 only used for after only analysis.

[2]Some structures placed in fall 1999. Additional structures placed in early summer 2001.

Table 3. Limnological characteristics of the Au Sable River study reservoirs based on data from Consumer's Power Company, the Federal Energy Regulatory Commission, the United States Forest Service (Kinney et al. 1999), and this study. Reservoirs are ordered from upstream to downstream. Temperature represents the mean summer epilimnetic temperature (1m depth), June through August of 2000 and 2001. Dissolved oxygen represents the range of dissolved oxygen levels observed across all depths during summer. Chlorophyll a, total phosphorous, and total nitrogen are mean summer values from samples taken in June through August of 2000 and 2001.

Impoundment	Temperature (°C)	Dissolved Oxygen (mg/L)	Chlorophyll a (ug/L)	Total Phosphorous (ug/L)	Total Nitrogen (ug/L)	Secchi Depth (m)	Conductivity (umhos)
Alcona	22.4	3.5-9.2	4.1	17.7	192.5	1.7	304
Loud	22.3	3.0-9.6	2.5	24.3	208.8	1.9	316
Cooke	22.4	0.1-9.0	3.0	22.5	364.8	3.4	303
Foote	22.3	0.1-9.2	2.6	14.1	524.8	3.9	307

Table 4. P-values from mixed-effect analysis of variance modeling the effects of treatment, macrophyte cover, coarse woody material (CWM) cover, and substrate on catch-per-effort by functional group. Treatment refers to the presence or absence of half-log habitat enhancement structures. N refers to the total number of areas sampled. NS=not significant. No significant treatment effects were found for gill netting at AquaCribs® (N=67), angling at half-logs (N=112), or angling at AquaCribs® (N=189).

Sampling Method	**Functional Group**	**Treatment**	**Macrophyte Cover (%)**	**CWM Cover (%)**	**Substrate**	**Significant Interactions**
Visual Observation N=369	**Total**	NS	NS	NS	NS	None
	Planktivore	NS	NS	NS	NS	None
	Piscivore	NS	p=0.0001	p=0.0160	NS	None
	Smallmouth Bass	p=0.0222	NS	p=0.0029	NS	None
Electrofishing N=235	**Total**	NS	NS	NS	NS	None
	Planktivore	NS	NS	NS	NS	None
	Piscivore	NS	NS	NS	NS	None
	Smallmouth Bass	p=0.0202	NS	p=0.0449	NS	Treatment* Macrophyte Cover

Table 5. P-values from fixed-effect analysis of variance modeling the effects of reservoir and treatment on catch-per-effort by functional group. Individual sampling sites were treated as a blocking factor. NS=not significant.

Sampling Method	Structure Type	Functional Group	Reservoir	Site	Treatment	Significant Interactions
a. Visual Observation	**Half-logs** N=369	**Total**	p<0.0001	p<0.0001	NS	Reservoir*Site
		Planktivore	p<0.0001	p=0.0001	NS	Reservoir*Site
		Piscivore	NS	NS	NS	Reservoir*Site
		Smallmouth Bass	p<0.0001	p<0.0006	p=0.0103	Reservoir*Site
b. Electrofishing	**Half-logs** N=235	**Total**	p<0.0001	p=0.0016	p=0.0459	NS
		Planktivore	p<0.0001	p=0.0023	NS	NS
		Piscivore	p=0.0001	p=0.0006	p=0.0363	Site*Treatment, Reservoir*Site*Treatment
		Smallmouth Bass	p=0.0002	p=0.0013	NS	Reservoir*Site
c. Gill Netting	**AquaCribs** N=67	**Total**	NS	NS	NS	Reservoir*Site
		Planktivore	p=0.0094	NS	NS	Reservoir*Site
		Piscivore	NS	NS	NS	Reservoir*Treatment
		Smallmouth Bass	NS	p=0.0103	NS	NS
d. Angling	**Half-logs** N=112	**Total**	p=0.0250	p=0.0011	NS	NS
		Planktivore	p=0.0399	p=0.0009	NS	NS
		Piscivore	NS	NS	NS	NS
		Smallmouth Bass	NS	NS	NS	NS
	AquaCribs N=189	**Total**	NS	p=0.0379	NS	NS
		Planktivore	NS	p=0.0118	NS	NS
		Piscivore	NS	NS	NS	NS
		Smallmouth Bass	p=0.00507	NS	NS	Reservoir*Site, Site*Treatment

Table 6. P-values from mixed-effect analysis of variance modeling the effects of year, treatment, and year*treatment interaction on catch-per-effort by functional group in Alcona Pond. Treatment refers to the presence or absence of half-log habitat enhancement structures. N refers to the total number of areas sampled. NS=not significant.

Sampling Method	Functional Group	Year	Treatment	Year* Treatment Interaction
Visual	**Total**	NS	NS	NS
Observation	**Planktivore**	p=0.0009	NS	NS
N=92	**Piscivore**	NS	NS	NS
	Smallmouth Bass	NS	NS	NS
Electrofishing	**Total**	p=0.0043	NS	NS
N=58	**Planktivore**	NS	NS	NS
	Piscivore	p=0.0027	NS	NS
	Smallmouth Bass	NS	p=0.0459	NS

Table 7. P-values from mixed-effect analysis of variance modeling the effects of treatment, macrophyte cover, coarse woody material (CWM) cover, and substrate on smallmouth bass nest density and nest success. A total of 126 individual nests were monitored throughout the entire spawning season in 2001. Treatment refers to the presence or absence of half-log habitat enhancement structures. NS=not significant.

Metric	**Treatment**	**Macrophyte Cover (%)**	**CWM Cover (%)**	**Substrate**	**Significant Interactions**
Nest Density	p=0.0018	p=0.0029	NS	p=0.0464	Treatment* Macrophyte Cover
Nest Success	p=0.0246	NS	NS	p=0.0133	Treatment* Macrophyte Cover

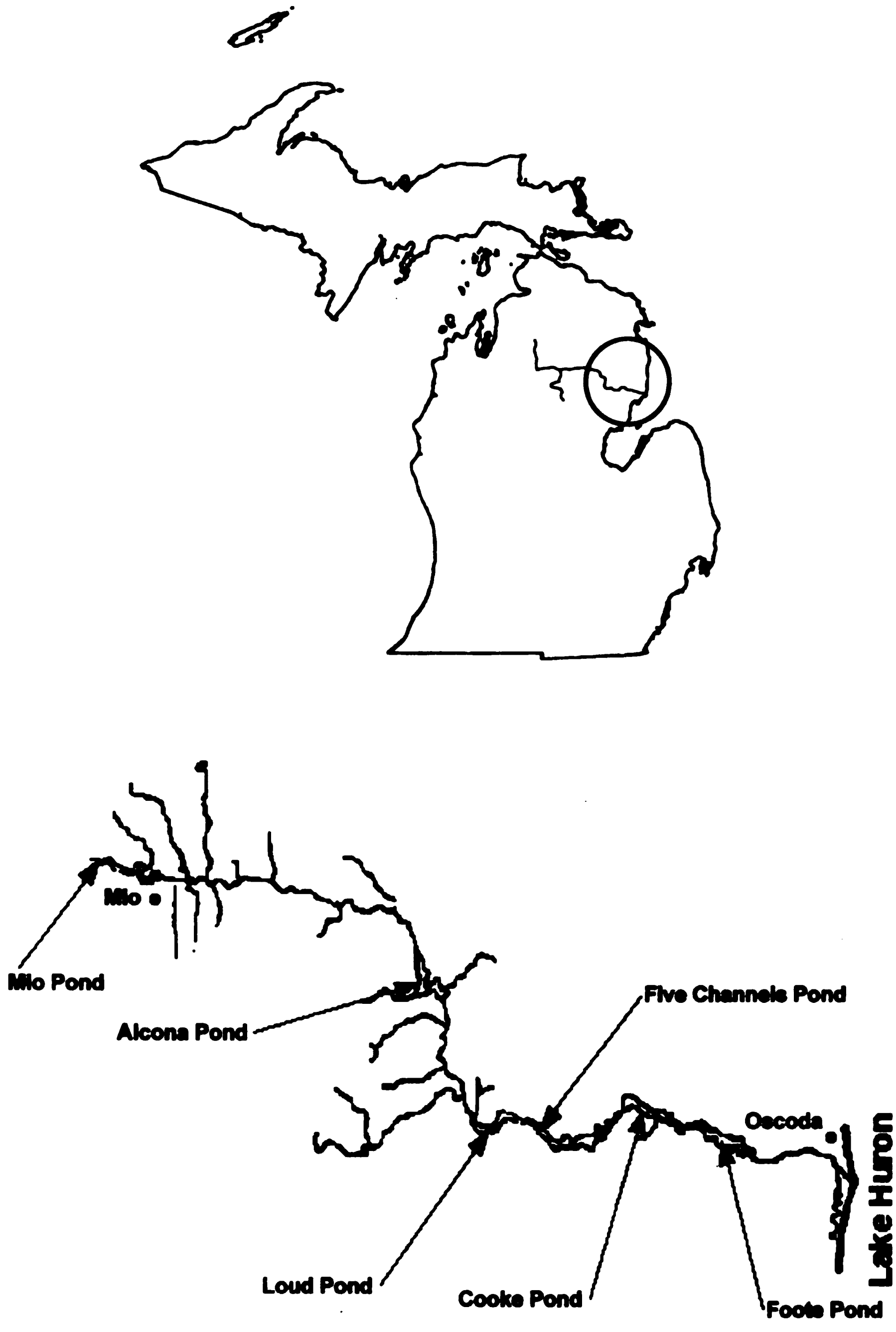
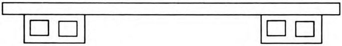
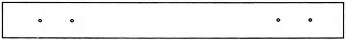


Figure 1. Location of the Au Sable River, Michigan (top) and the four study reservoirs (bottom).

Half-log, Side View



Half-log, Top View



AquaCrib®

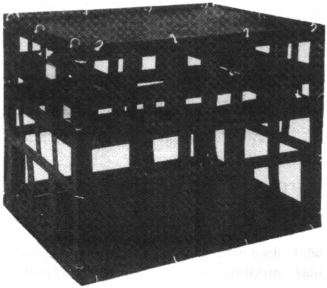


Figure 2. Side and top views of a half-log structure (top) and three-dimensional view of an AquaCrib® structure (bottom).

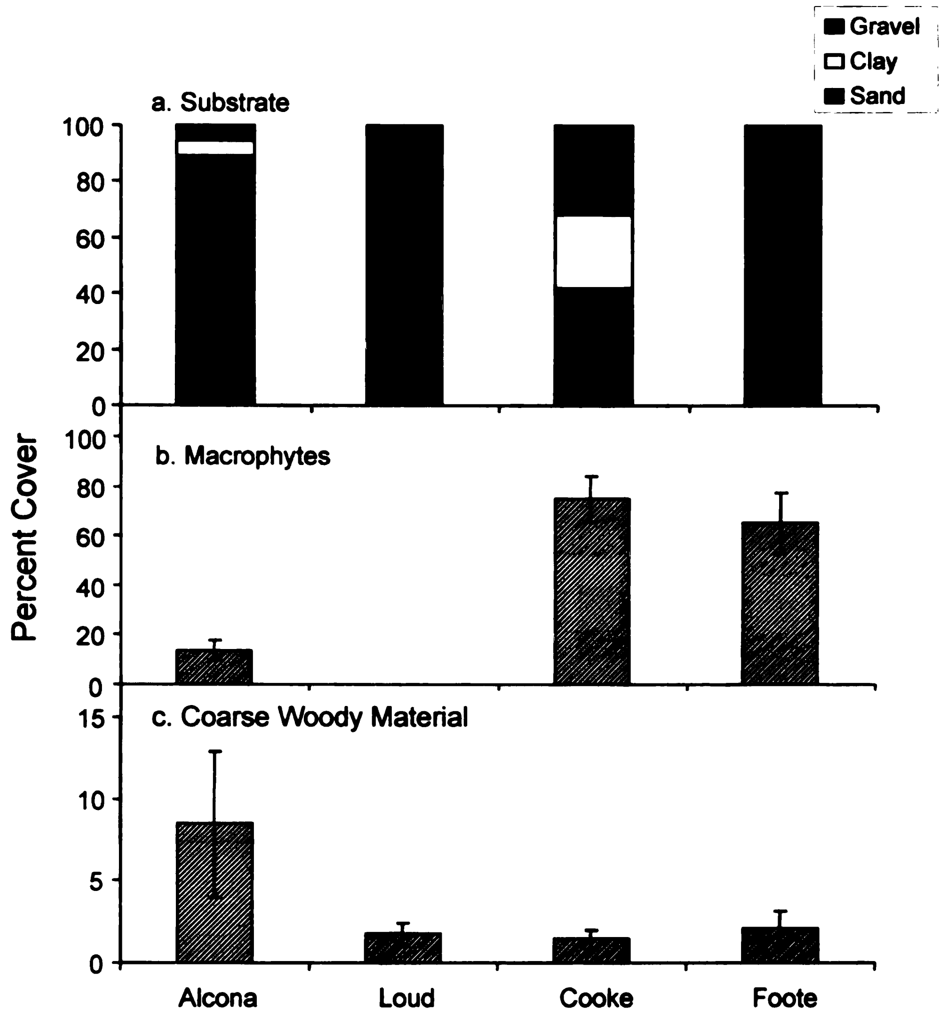


Figure 3. Percent cover of habitat variables in each of the four study reservoirs. Reservoirs are presented from upstream (Alcona) to downstream (Foote). Substrate (a) is the total cover (%) of each of three substrate classes summed across all study sites. Macrophytes (b) and coarse woody material (c) are mean cover (%, ± 1 SE) averaged across all study sites. Note y-axes differ among substrate, macrophytes, and coarse woody material.

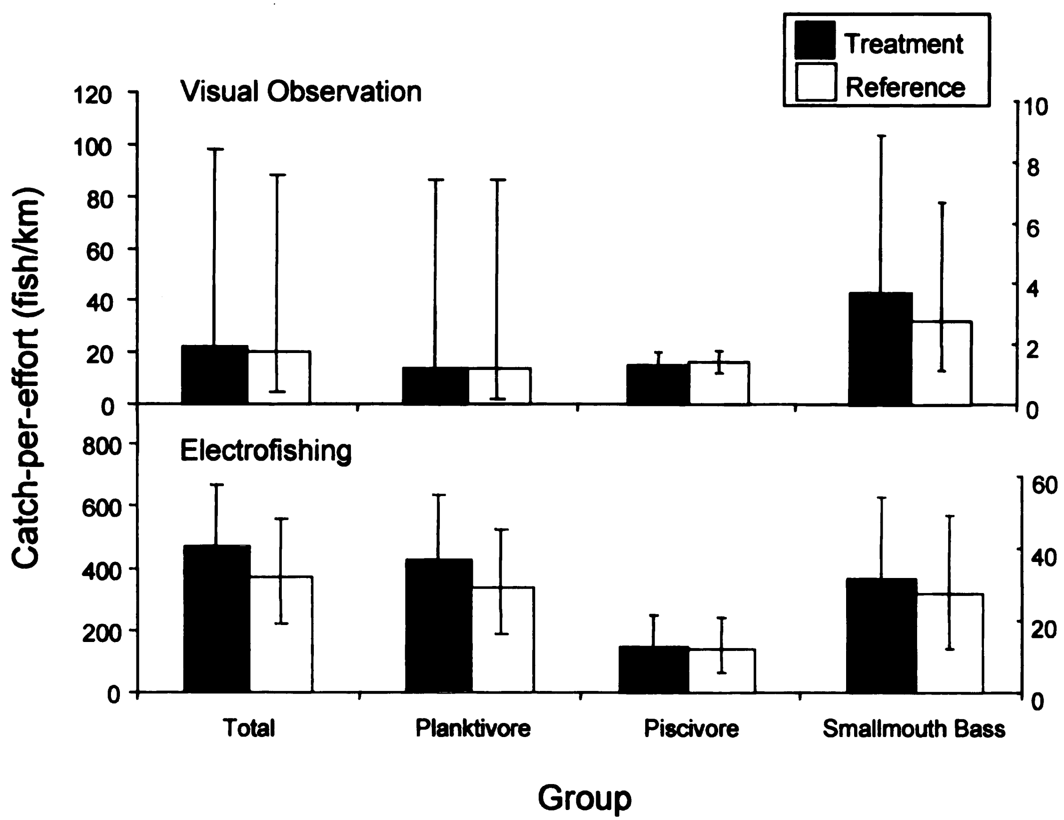


Figure 4. Mean catch-per-effort (CPE, fish/km, ± 95% CI) of the four functional fish groups for treatment and reference areas for snorkeling (top) and electrofishing (bottom). Total and planktivore CPE correspond to the left y-axis; piscivore and smallmouth bass CPE correspond to the right y-axis. Note y-axes differ among functional groups and sampling methods.

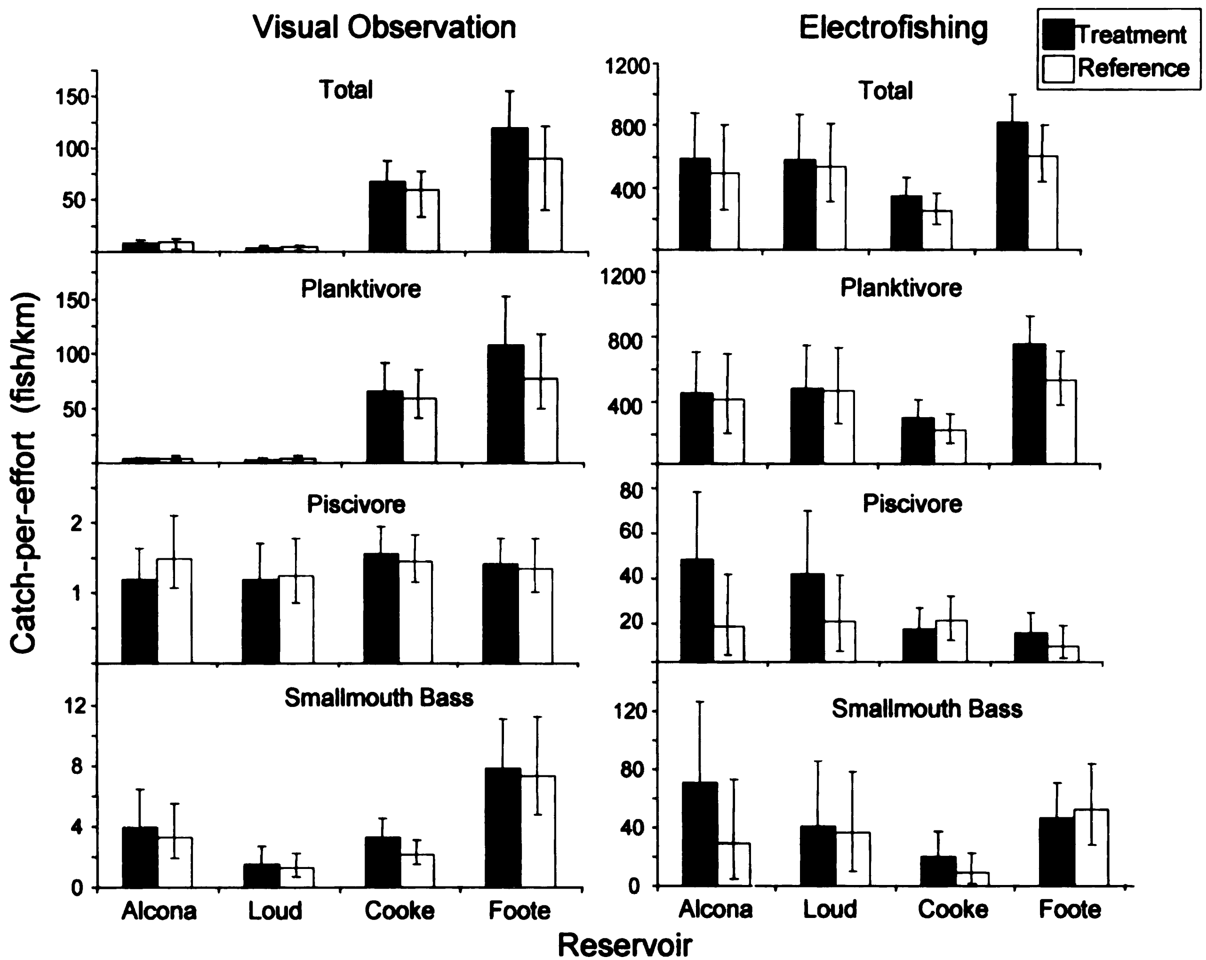


Figure 5. Mean catch-per-effort (fish/km, ± 95% CI) of the four functional fish groups for treatment and reference areas in each reservoir for snorkeling (left) and electrofishing (right). Reservoirs are presented from upstream (Alcona) to downstream (Foote). Note y-axes differ among functional groups and sampling methods.

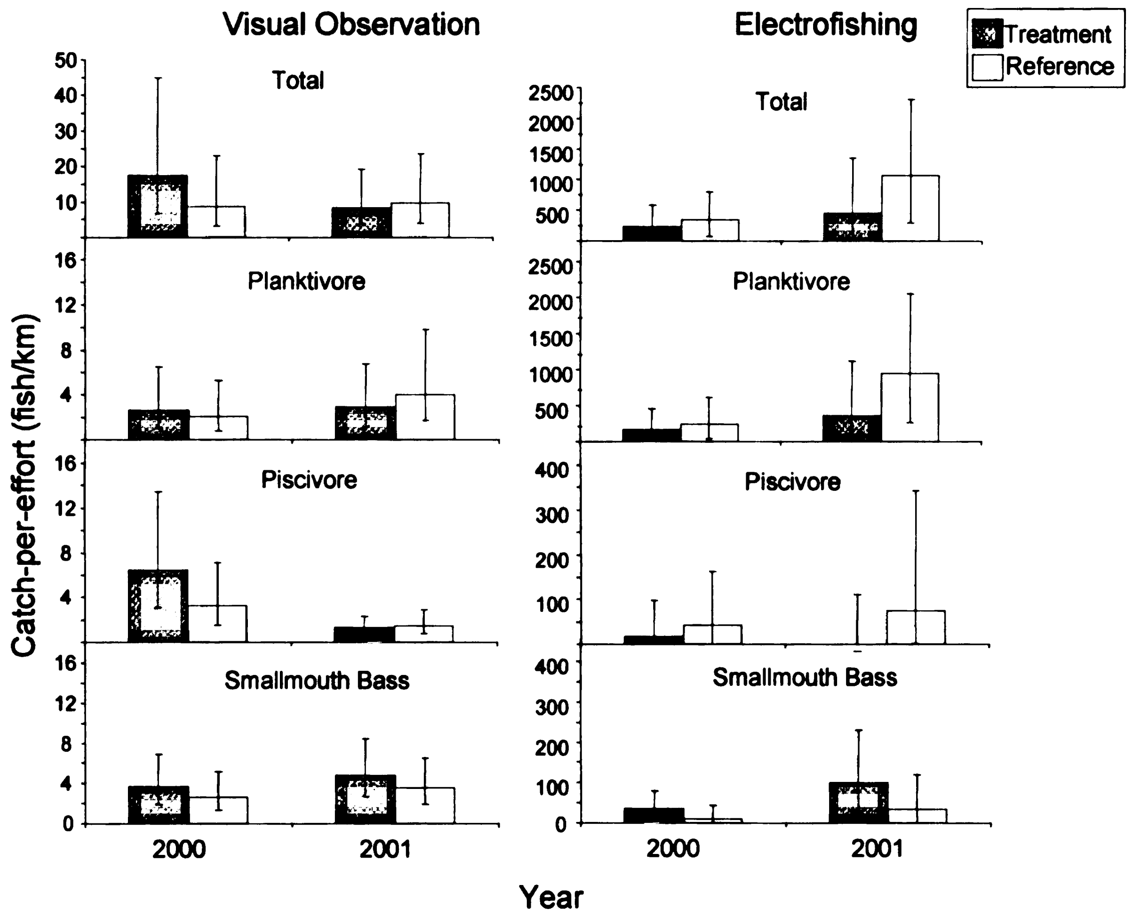


Figure 6. Mean catch-per-effort (fish/km, ± 95% CI) of the four functional fish groups for treatment and reference areas and year for snorkeling (left) and electrofishing (right) before and after structure placement in Alcona Pond. Data before structure placement were collected in 2000; data after structure placement were collected in 2001. Note y-axes differ among functional groups and sampling methods.

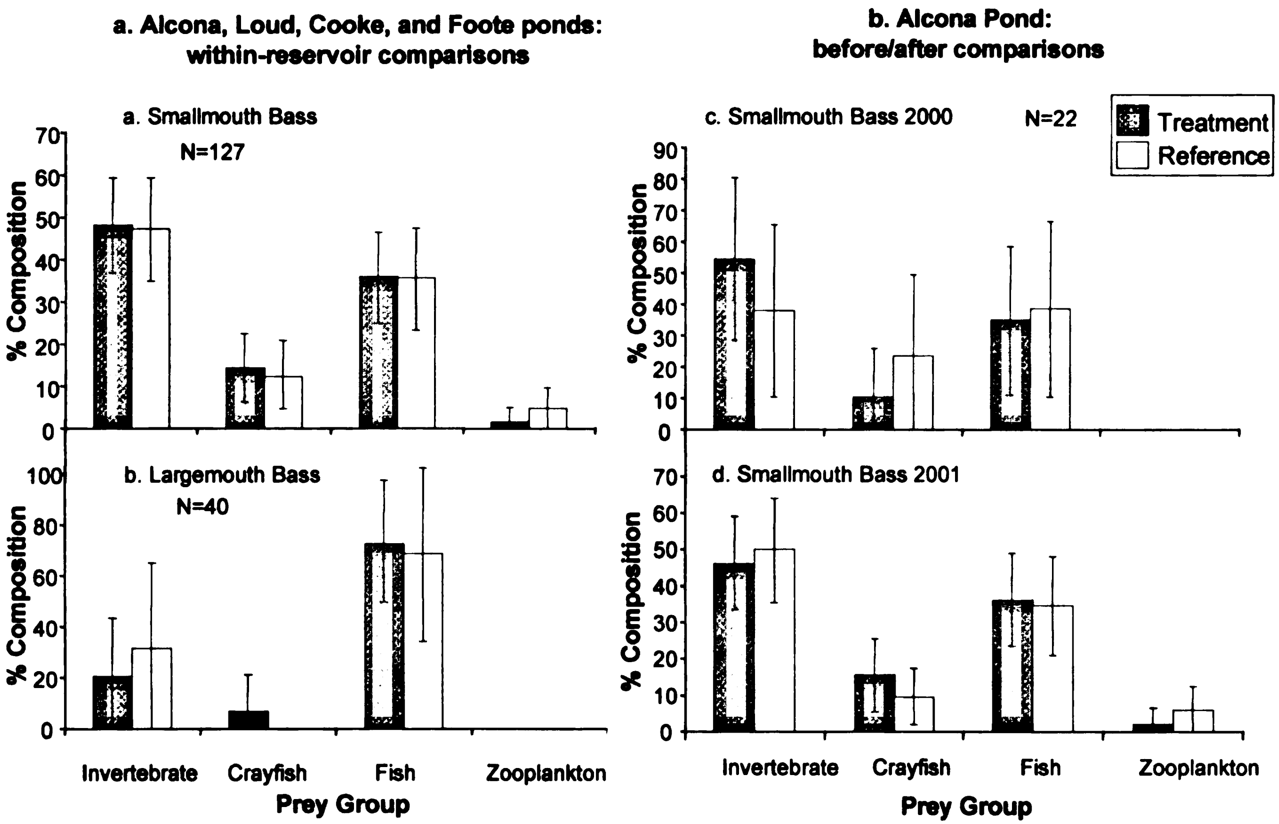


Figure 7. Mean diet composition (grams of prey per gram of fish, ± 95% CI) of the four prey groups by treatment for smallmouth bass and largemouth bass diets from within-reservoir comparisons (a, b) and smallmouth bass from before/after comparisons (c, d). Mean percent composition is averaged across all study sites and reservoirs. Note y-axes differ among prey groups and species for within-reservoir comparisons, as well as among prey groups and year for before/after comparisons.

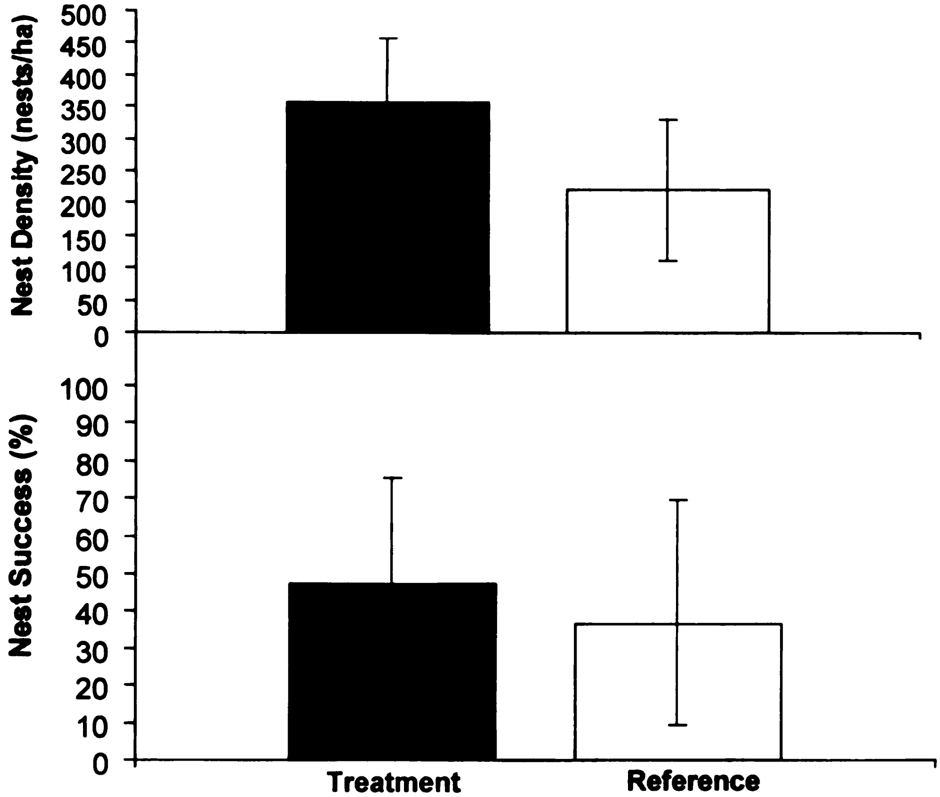


Figure 8. Mean smallmouth bass nest density (nests/ha, top) and nest success (%, bottom), ± 95% CI, in treatment and reference areas from data collected in 2001 in Cooke and Foote ponds. Nest success was defined as the presence of swim-up fry. Note difference in y-axes between nest density and nest success.

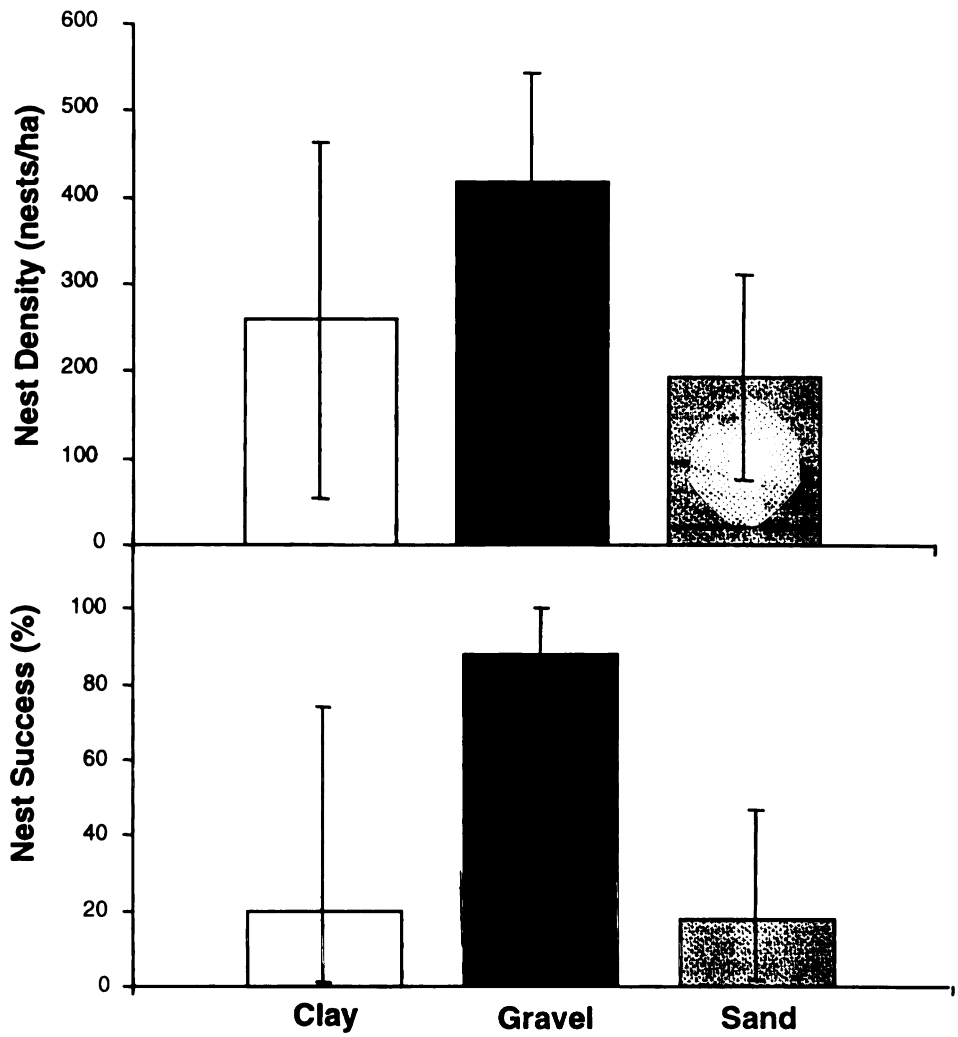


Figure 9. Mean smallmouth bass nest density (nests/ha, top) and nest success (%, bottom), ± 95% CI, by substrate from data collected in 2001 in Cooke and Foote ponds. Note difference in y-axes between nest density and nest success.

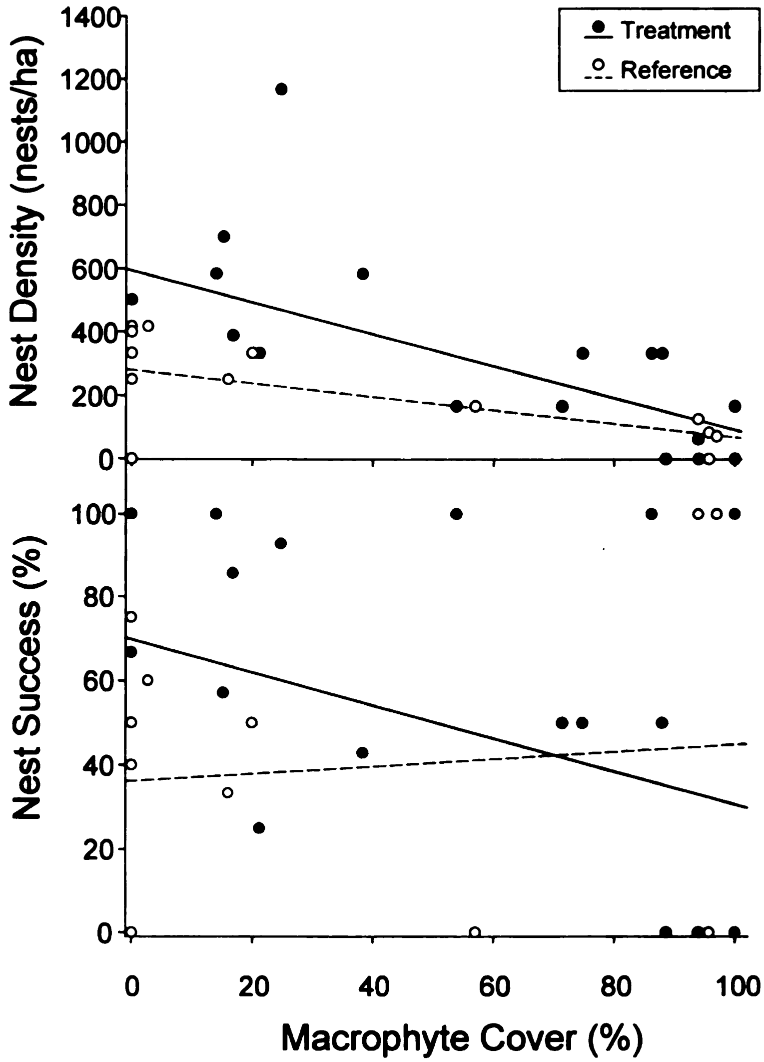


Figure 10. Relationship between macrophyte cover and smallmouth bass nest density (nests/ha, top) and nest success (%, bottom) for treatment and reference areas from data collected in 2001 in Cooke and Foote ponds. Note difference in y-axes between nest density and nest success.

LITERATURE CITED

LITERATURE CITED

Aadland, L. P. E. 1982. Artificial reefs as a management tool to improve sport fishing in North Dakota reservoirs. Master's Thesis. North Dakota State University, Fargo.

Bassett, C. E. 1994. Use and evaluation of fish habitat structures in lakes of the eastern United States by the USDA Forest Service. Fifth International Conference on Aquatic Habitat Enhancement, Long Beach, CA. Bulletin of Marine Science 55: 1137-1148.

Bohnsack, J. A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bulletin of Marine Science 44: 631-645.

Bohnsack, J. A. and D. L. Sutherland. 1985. Artificial reef research: a review with recommendations for future priorities. Bulletin of Marine Science 37: 11-39.

Brouha, P. 1974. Evaluation of two reef materials and point or cove locations for construction of artificial reefs in Smith Mountain Lake, Virginia. Master's Thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Brown, A. B. 1986. Modifying reservoir fish habitat with artificial structures. Reservoir fisheries management: strategies for the 80's. G. E. Hall and M. J. Van Den Avyle. Bethesda, American Fisheries Society, Southern Division, Reservoir Committee: 98-102.

Brown, P. J., D. C. Josephson, and C. C. Krueger. 2000. Summer habitat use by introduced smallmouth bass in an oligotrophic Adirondack lake. Journal of Freshwater Ecology 15: 135-144.

Coble, D.W. 1975. Smallmouth bass. Black bass biology and management. R. H. Stroud and H. Clepper. Washington D.C., Sport Fishing Institute: 21-22.

Crumpton, W. G., T. M. Isenhart, and P. D. Mitchell. 1992. Nitrate and organic N analyses with second-derivative spectroscopy. Limnology and Oceanography 37: 907-913.

DuFour, J. A. 1989. Evaluation of half-logs as habitat improvement structures for smallmouth bass *Micropterus dolomieui* and rock bass *Ambloplites rupestris*. Master's Thesis. Michigan State University, East Lansing.

Graham, R. J. 1992. Visually estimating fish density at artificial structures in Lake Anna, Virginia. North American Journal of Fisheries Management 12: 204-212.

Hazzard, A. S. 1937. Results of stream and lake improvement in Michigan. Transactions of the 2nd North American Wildlife and Natural Resources Conference 1937: 620-624.

Helfman, G. S. 1981. The advantage to fishes of hovering in shade. Copeia: 392-400.

Helfman, G. S. 1979. Fish attraction to floating objects in lakes. Response of fish to habitat structure in standing water. R. A. Stein and D. L. Johnson, North Central Division American Fisheries Society. Special Publication 6: 49-57.

Hoff, M. H. 1991. Effects of increased nesting cover on nesting and reproduction of smallmouth bass in northern Wisconsin lakes. Proceedings of the First International Smallmouth Bass Symposium: 39-43.

Hubbs, C. L. and R. W. Eschmeyer. 1937. Providing shelter, food, and spawning facilities for game fishes of our inland lakes. Transactions of the 2nd North American Wildlife and Natural Resources Conference: 613-619.

Hubbs, C. L. and R. W. Eschmeyer. 1938. The improvement of lakes for fishing. A method of fish management. Bulletin of the Institute for Fisheries Research 2: 1-235.

Hunt, J. 2000. Enhancing largemouth bass spawning: behavioral and habitat considerations. Black Bass 2000: Conservation. Bethesda, American Fisheries Society. *In review.*

Johnson, D. L., R. A. Beaumier, and W. E. Lynch, Jr. 1988. Selection of habitat structure interstice size by bluegills and largemouth bass in ponds. Transactions of the American Fisheries Society 117: 171-179.

Johnson, D. L. and W. E. Lynch, Jr. 1992. Panfish use of and angler success at evergreen tree, brush, and stake-bed structures. North American Journal of Fisheries Management 12: 222-229.

Johnson, D. L. and R. A. Stein. 1979. Response of fish to habitat structure in standing water, North Central Division, American Fisheries Society.

Kayle, K. A. 1986. Fish use of different habitat structure locations and configurations within a reservoir. Master's Thesis. The Ohio State University, Columbus.

Keast, A. and J. Harker. 1977. Strip counts as a means of determining densities and habitat utilization patterns in lake fishes. Environmental Biology of Fishes 12: 181-188.

Kinney, J., R. Stuber, and K. Krueger. 1999. Au Sable River Impoundment Assessments, Michigan Department of Natural Resources and USDA Forest Service.

Klima, E. F. and D. A. Wickham. 1971. Attraction of coastal pelagic fishes with artificial structures. Transactions of the American Fisheries Society 100: 86-99.

Lynch, W. E. J. and D. L. Johnson. 1989. Influences of interstice size, shade, and predators on the use of artificial structures by bluegills. North American Journal of Fisheries Management 9: 219-225.

Mabbott, L. B. 1991. Artificial habitat for warmwater fish in two reservoirs in southern Idaho. Warmwater Fisheries Symposium I, Phoenix, AZ, USDA Forest Service, Rocky Mountain For. and Range Exp. Sta., Gen. Tech. Rep. RM-207: 62-66.

Madejczyk, J. C., N. D. Mundahl, and R. M. Lehtinen. 1998. Fish assemblages of natural and artificial habitats within the channel border of the Upper Mississippi River. American Midland Naturalist 139: 296-310.

Menzel, D. W. and N. Corwin. 1965. The measurement of total phosphorous in seawater based on the liberation of organically bound fractions by persulfate oxidation. Limnology and Oceanography 10: 280-282.

Miller, R.J. 1975. Comparative behavior of centrarchid basses. Black bass biology and management. R. H. Stroud and H. Clepper. Washington D.C., Sport Fishing Institute: 85-94.

Mitzner, L. 1981. Assessment and development of underwater structure to attract and concentrate fish, Iowa Conservation Commission, Federal Aid in Fish Restoration, F-94-R, Study 1, Final Report, Des Moines.

Moring, J. R., M. T. Negus, R. D. McCullough, and S. W. Herke. 1989. Large concentrations of submerged pulpwood logs as fish attraction structures in a reservoir. Bulletin of Marine Science 44: 609-615.

Moring, J. R. and P. H. Nicholson. 1994. Evaluation of three types of artificial habitats for fishes in a freshwater pond in Maine, USA. Fifth International Conference on Aquatic Habitat Enhancement, Long Beach, CA. Bulletin of Marine Science 55: 1149-1159.

Murphy, J. and L. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27: 31-36.

Nusch, E. A. 1980. Comparisons of different methods for chlorophyll and phaepigment determination. Archiv für Hydrobiologie Beiheft Ergebnisse der Limnologie 14: 14-36.

Pardue, G. B. and L. A. Nielsen. 1979. Invertebrate biomass and fish production in ponds with added attachment surface. Response of fish to habitat structure in standing water. R. A. Stein and D. L. Johnson, North Central Division American Fisheries Society. Special Publication 6: 34-37.

Patrick, K. A. 1996. Utilization of half-log structures as spawning sites for smallmouth bass in Norris Reservoir, Tennessee. The University of Tennessee, Knoxville.

Paxton, K. O. and F. Stevenson. 1979. Influence of artificial structure on angler harvest from Killdeer Reservoir, Ohio. Response of fish to habitat structure in standing water. R. A. Stein and D. L. Johnson, North Central Division American Fisheries Society. Special Publication 6: 70-76.

Petit, C. D. III 1972. Stake beds as crappie concentrators. Proceedings of the Annual Conference of Southeastern Game and Fish Commissioners 26: 401-406.

Pierce, B. E. and G. R. Hooper. 1980. Fish standing crop comparisons of tire and brush fish attractors in Barkley Lake, Kentucky. Annual Conference of Southeastern Association of Game and Fish Commissioners 33: 688-691.

Potts, T. A. and A. W. Hulbert. 1994. Structural influences of artificial and natural habitats on fish aggregations in Onslow Bay, North Carolina. Fifth International Conference on Aquatic Habitat Enhancement, Long Beach, CA. Bulletin of Marine Science 55: 609-622.

Prince, E. D., R. J. Strange, and G.M. Simmons, Jr. 1976. Preliminary observations on the productivity of periphyton attached to a freshwater artificial tire reef. Annual Conference of Southeastern Association of Game and Fish Commissioners 30: 207-215.

Prince, E. D., O. E. Maughan, and P. Brouha. 1977. How to build a freshwater artificial reef. Blacksburg, Sea Grant Division, Virginia Polytechnic Institute and State University.

Prince, E. D. and O. E. Maughan. 1979a. Attraction of fishes to tire reefs in Smith Mountain Lake, Virginia. Response of fish to habitat structure in standing water. R. A. Stein and D. L. Johnson, North Central Division American Fisheries Society. Special Publication 6: 19-25.

Prince, E. D. and O. E. Maughan. 1979b. Telemetric observations of largemouth bass near underwater structures in Smith Mountain Lake, Virginia. Response of fish to habitat structure in standing water. R. A. Stein and D. L. Johnson, North Central Division American Fisheries Society. Special Publication 6: 19-25.

Prince, E. D. and O. E. Maughan. 1978. Freshwater artificial reefs: biology and economics. Fisheries 3: 5-9.

Reeves, W. C., G. R. Hooper, and B.W. Smith. 1978. Preliminary observations of fish attraction to artificial midwater structures in freshwater. Annual Conference of Southeastern Association of Game and Fish Commissioners 31: 471-476.

Rodeheffer, I. A. 1939. Experiments in the use of brush shelters by fish in Michigan lakes. Papers of the Michigan Academy of Science, Arts, and Letters 24: 183-193.

Rodeheffer, I. A. 1945. Fish populations in and around brush shelters of different sizes placed at varying depths and distances apart in Douglas Lake, Michigan. Papers of the Michigan Academy of Science, Arts, and Letters 30: 321-345.

Rogers, K. B. and E. P. Bergersen. 1999. Utility of synthetic structures for concentrating adult northern pike and largemouth bass. North American Journal of Fisheries Management 19: 1054-1065.

Rountree, R. A. 1989. Association of fishes with fish aggregation devices: effects of structure size on fish abundance. Bulletin of Marine Science 44: 960-972.

SAS Institute Inc. 1999. SAS user's guide: statistics, version 8.0. SAS Institute, Cary, North Carolina.

Shulman, M. J. 1984. Resource limitation and recruitment patterns in a coral reef fish assemblage. Journal of Experimental Marine Biology and Ecology 74: 85-109.

Smith, B. W., G. R. Hooper, and C.S. Lawson. 1981. Observation of fish attraction to improved artificial midwater structures in freshwater. Annual Conference of Southeastern Association of Game and Fish Commissioners 34: 404-409.

Tugend, K. I., M. S. Allen, and M. Webb. 2002. Use of artificial habitat structures in U.S. Lakes and Reservoirs: a survey from the Southern Division AFS Reservoir Committee. Fisheries 27: 22-27.

Vogele, L. E. and W. C. Rainwater. 1975. Use of brush shelters as cover by spawning black basses (*Micropterus*) in Bull Shoals Reservoir. Transactions of the American Fisheries Society 104: 264-269.

Walters, D. A., W. E. Lynch, Jr., and D. L. Johnson. 1991. How depth and interstice size of artificial structures influence fish attraction. North American Journal of Fisheries Management 11: 319-329.

Wege, G. J. and R. O. Anderson. 1979. Influence of artificial structure on largemouth bass and bluegills in small ponds. Response of fish to habitat structure in standing water. R. A. Stein and D. L. Johnson, North Central Division American Fisheries Society. Special Publication 6: 59-69.

Wickham, D. A., J. W. Watson, Jr. and L. H. Ogren. 1973. The efficacy of midwater artificial structures for attracting pelagic sport fish. Transactions of the American Fisheries Society 102: 563-572.

Wilbur, R. L. 1974. Florida's fresh water fish attractors. Fishery Bulletin No. 6, Florida Game and Fresh Water Fish Commission.

Wilbur, R. L. 1978. Two types of fish attractors compared in Lake Tohopekaliga, Florida. Transactions of the American Fisheries Society 107: 689-695.

Wilson, A. E. and O. Sarnelle. 2002. Relationship between zebra mussel biomass and total phosphorous in European and North American lakes. Archiv fur Hydrobiologie 153: 339-351.