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Fish Populations Associated with Habitat-Modified Piers and Natural Woody Debris in Piedmont Carolina Reservoirs

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Abstract.—A primary concern associated with reservoir shoreline residential development is reduction of littoral habitat complexity and diversity. One potential approach to compensate for this is the deployment of artificial-habitat modules under existing piers, but the benefit of this practice has not been demonstrated. To evaluate the effect of pier habitat modifications on fish populations in two Piedmont Carolina reservoirs, we studied 77 piers located on forty-seven, 100-m transects that were modified using plastic ''fish hab'' modules augmented with brush (brushed habs), hab modules alone (habs), or left unaltered for reference purposes. We sampled fish from all piers and transects during April, July, and October 2001 using a boat-mounted electrofisher. With few exceptions, catch rates were higher at brushed-hab piers and piers with habs than at reference piers during all seasons. Similarly, during spring and summer, fish abundance was generally higher on transects containing natural woody debris, brushed habs, and habs than on reference-developed transects; however, during fall, there were exceptions. Therefore, fish abundance associated with shorelines in these reservoirs appears to be related to the structural complexity of available habitat rather than structure composition. One year after installation, 92% of pier owners responding to a mail survey expressed satisfaction with pier modifications. Supplementing piers with habitat structures is recommended to enhance littoral habitat complexity for fishes in residentially developed reservoirs.

The importance of structural cover as a component of fish habitat has been well documented. Fish often avoid predation by occupying structurally complex areas where predators cannot forage efficiently (Glass 1971; Savino and Stein 1982) or to utilize advantageous foraging areas (Werner et al. 1983). Complex habitats that provide abundant cover are important for many species as nursery areas and for survival and growth. Although beneficial, structural cover is usually scarce in southeastern United States reservoirs due to basin-clearing practices and to the disruptive nature of water level fluctuations and purposeful removal of woody debris and vegetation (Jenkins 1970; Meals and Miranda 1991; Bryan and Scarnecchia 1992; Christensen et al. 1996).

This strong reliance and association of fish with natural structural cover suggests that fish would associate in a similar fashion with artificial cover, such as fish attractors. Most studies evaluating fish attractors constructed from stake beds (Johnson and Lynch 1992), plastic structures (Herrig and Miller 1985; Rold et al. 1996), brushed structures (Pierce and Hooper 1979; Johnson and Lynch 1992), tire reefs (Paxton and Stevenson 1979; Prince et al. 1979), evergreen trees (Johnson and Lynch 1992; Rold et al. 1996), plywood (Lawson 1981), and other synthetic materials (Rogers and Bergersen 1999) concluded that fish abundance was higher in areas modified with complex structure.

Landowners are developing shorelines of many southeastern U.S. reservoirs at a rapid rate, and natural structures are often removed to provide

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increased lake access for recreation, pier construction, and installation of erosion-control devices such as rock revetment (riprap). Incremental impacts of shoreline development often include cumulative losses of lake-wide habitat diversity and sometimes habitat complexity, particularly when retaining walls are constructed as erosion-control devices (Jennings et al. 1999). Given the tendency of shoreline residential and commercial landowners to remove woody debris, a habitat management response should be considered and evaluated. One technique, the addition of complex structure under piers on residentially developed shorelines, may be an approach that can improve shoreline habitat and meet the needs of reservoir managers, anglers, and shoreline landowners.

The objectives of our study were to (1) evaluate fish abundance among artificial-habitat modifications under piers, (2) evaluate this technique as a habitat management response to the loss of natural woody debris in reservoirs with residential shoreline development, (3) quantify natural woody-debris characteristics and compare them with those of artificial-habitat modules, and (4) determine pier owner satisfaction with this type of management approach. Our evaluation approach was to apply one of two modifications to piers in two reservoirs and compare fish abundance associated with the modified piers to fish abundance among untreated reference piers, as well as among shorelines containing natural woody debris.

Methods

Study areas.—We conducted our research at two Catawba River reservoirs in the Piedmont region: Fishing Creek Reservoir in South Carolina and Lake Hickory in North Carolina. Fishing Creek Reservoir, a 1,364-ha eutrophic reservoir located near Great Falls, South Carolina, was built to support hydroelectric generation and water supply (Duke Power 1999). Shoreline use on Fishing Creek Reservoir is 7% residential and commercial, 18% undeveloped with natural woody debris, and 75% otherwise undeveloped (Duke Power, unpublished data). Fishing Creek Reservoir has a full-pool elevation of 127 m above sea level, contains a total water volume of 74 million m^3, and has a mean depth of 5.4 m. Maximum depth is 27.3 m and mean retention time is 6 d (Duke Power, unpublished data).

Lake Hickory, a 1,660-ha mesotrophic reservoir located near Hickory, North Carolina, was also constructed for hydroelectric generation and water supply (Duke Power 1999). Shoreline use on Lake Hickory is 52% residential and commercial, 2% undeveloped with natural woody debris, and 46% otherwise undeveloped (Duke Power, unpublished data). Lake Hickory has a full-pool elevation of 285 m above sea level, contains a total volume of 157.3 million m^3, and has a mean depth of 9.5 m. Maximum depth of Lake Hickory exceeds 25 m and mean retention time is 33 d (Duke Power, unpublished data).

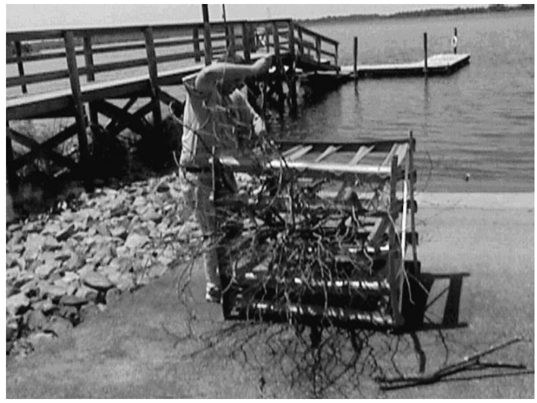

FIGURE 1.—Modification structure used in an effort to enhance piers on Fishing Creek Reservoir and Lake Hickory.

Pier modifications.—To enhance piers, the Berkley Fish Hab, a 1.2-m^3, pallet-type structure constructed from recycled plastic, was used as a basic assembly (Figure 1). This assembly was only deployed under walkways supported by pilings that were not subject to vertical fluctuation related to the reservoir pool elevation (stationary components) of 7 piers on Fishing Creek Reservoir and 14 piers on Lake Hickory. Habitat structures were not deployed under sections of piers that were supported by flotation (floating components) and subject to vertical fluctuation.

To increase structural complexity of the plastic module, small saplings and branches (brush) were incorporated into the basic assembly that were comparable in species composition to natural woody debris found along other shorelines of these reservoirs. This combination of plastic modules and brush was deployed under stationary-pier components of 8 piers on Fishing Creek Reservoir and 15 piers on Lake Hickory. Fifteen piers on Fishing Creek Reservoir and 18 piers on Lake Hickory remained unaltered to serve as reference units. The number of plastic modules installed under individual study piers varied from 0.8 to 9.2 according to pier length. In most cases, the heights of structures nearest the shore were modified to

TABLE 1.—Experimental design and sample sizes of pier and transect habitat treatments evaluated separately by reservoir and season (spring, summer, and fall) within each scale of evaluation. Treatments are defined as follows: Hab = addition of the Berkley Fish Hab, a 1.2-m^3 pallet-type structure made of recycled plastic; brushed hab = addition of the Berkley Fish Hab with small saplings and branches embedded in it; woody debris = natural woody debris present; and reference = unmodified (no woody debris).

Scale of evaluation	Treatment	Sample size: Fishing Creek Reservoir	Sample size: Lake Hickory
Pier	Brushed hab	8	15
	Hab	7	14
	Reference	15	18
Transect	Woody debris	8	8
	Brushed hab	4	5
	Hab	3	7
	Reference	5	7

enhance shallow water while remaining submersed during normal water levels. Thus, fractions of complete structures were deployed under most piers to maximize the extent of augmentation. Treatments were not assigned randomly to piers, but were selected without regard to shoreline slope, water depth, substrate, existing habitat, or location within the reservoirs. Willingness of pier owners to allow modification of their pier was a primary criterion in treatment assignment and was not systematically correlated with physical habitat features. Habitat structures were installed under piers during the winter of 2000–2001, prior to the initiation of fish sampling in April 2001.

Field and analytical procedures.—We sampled fish communities from forty-seven, 100-m shoreline transects (31 residentially developed with piers and 16 undeveloped containing natural woody debris) on Fishing Creek Reservoir and Lake Hickory during April, July, and October 2001. Residentially developed transects contained a total of 77 piers—either unmodified or modified with brushed habs or habs only.

We evaluated fish abundance at two spatial scales: among piers and among transects. Three treatments were compared at the pier scale and consisted of piers augmented with (1) brushed habs, (2) habs (without brush), and (3) reference (unmodified) piers. Four treatments were compared at the transect scale and included (1) woody-debris transects, (2) transects containing piers modified with brushed habs, (3) transects containing habs, and (4) transects containing reference piers (Table 1). Transects containing piers were partitioned into three components; a stationary-pier component (where the treatment, if used, was applied), a floating-pier component (if present), and a shoreline component between adjacent piers. Fish catch was quantified according to transect component to evaluate the effect of pier modifications at the pier scale and transect scale.

We collected fish using a boat-mounted, Smith-Root model 5.0 GPP electrofisher powered by pulsed DC at a frequency of 120 pulses/s at a voltage sufficient to draw 4–6 A. All fish collected were identified to species, enumerated according to transect component, and individually measured (± 1 mm; total length [TL]), and weighed (± 1 g). In cases where numerous individuals of a species were collected, total number and biomass were recorded for that species, a random subsample of at least 30 fish was selected from the component catch, and each individual of the subsample was measured and weighed.

Surface area of stationary components of all piers was measured using a distance-measuring wheel, and catch rates from stationary components were expressed as number (n) of fish collected per 100 m^2 of pier area (n/100 m^2) and biomass of fish collected per 100 m^2 of pier area (kg/100 m^2). Transect catch rates were expressed as number of fish collected per 100 m of shoreline (n/100 m) and biomass of fish collected per 100 m of shoreline (kg/100 m).

Because no difference was observed in fish catchability among pier treatments through depletion or scuba techniques (Barwick 2002), actual catch rates for stationary components of piers were calculated and compared among treatments as an index of associated fish density and biomass. Catch rates of all species (total catch) and of largemouth bass *Micropterus salmoides* and bluegills *Lepomis macrochirus* (two principal sport fishes) were calculated for each stationary-pier component, and each stationary-pier component of the same treatment served as a replicate for statistical analysis. Similarly, fish abundance from transects included fish collected from all components of piers and shoreline between piers and was calculated for all species (total catch) and individually for largemouth bass and bluegills using each transect of the same treatment as a replicate for analysis. Mean length of largemouth bass and bluegills was calculated for each stationary-pier component and for each transect and compared among treatments at each scale of analysis. We employed a Kruskal–Wallis nonparametric test, followed by pair-wise comparisons of mean ranks, to detect if differences existed in catch (by number and biomass) and in mean length among treatments at the pier scale and transect scale within each reservoir. All tests established $\alpha = 0.05$ as the level of statistical significance.

Woody-debris survey.—The criterion for selecting natural woody-debris transects was that fallen trees (>25 cm diameter at breast height) constituted at least 80% coverage by shoreline area and distance. To determine the diameter-size distribution of this type of structure, nine quadrats (10 m in shoreline length extending to the 1.2-m depth contour) from three of the woody-debris transects on each reservoir were randomly selected; diameter ($\pm$ 1 cm) of all woody structure within each quadrat was measured. Size distribution of brush incorporated into hab modules under study piers was also estimated. We measured ($\pm$ 1 cm) all brush, small saplings, and tree limbs incorporated into one hab module to a density similar to that of brushed-hab modules installed under study piers. This resulting size distribution of brush was then compared to that of natural woody structure found on woody-debris transects.

Pier owner mail survey.—Permission to modify pier habitat was sought by project personnel and granted voluntarily by pier owners. During November 2001, shortly after completion of fish sampling and approximately 1 year after installation of treatments, all pier owners whose piers received treatment were mailed surveys. The survey was mailed to 43 pier owners and return by mail was requested. The survey posed 10 questions regarding overall satisfaction with modification structures, pier use by owners, regularity of fishing from the pier, fishing success, observations of fish and wildlife around the pier, effect of the modification on property aesthetics, and general opinions of the modification structures. Pier owners were presented a combination of yes or no questions, categorical questions, and open-ended questions to allow pier owners to offer comments. Survey responses from both reservoirs were pooled and compiled separately for pier owners receiving the brushed-hab treatment and the hab treatment. These data represent a qualitative measure of pier owner opinion.

Results

Pier-Scale Fish Abundance

For comparison of fish assemblages associated with treatments at the pier scale, we sampled 30 piers on Fishing Creek Reservoir and 47 piers on Lake Hickory. Total catch from piers for all seasons combined on Fishing Creek Reservoir totaled 1,430 fish representing 20 species, and that from Lake Hickory totaled 6,396 fish representing 14 species (see Barwick 2002 for species list).

Fishing Creek Reservoir.—Total catch by number on Fishing Creek Reservoir from brushed-hab piers was significantly higher than at reference piers during all seasons (Figure 2). During summer, largemouth bass catch rate was higher at brushed-hab piers than at piers modified with hab modules alone, and during fall, catch rate of largemouth bass was higher at brushed-hab piers than at reference piers. Similarly, bluegill catch rate was higher at brushed-hab piers than at reference piers during spring and fall. No species was consistently more abundant at reference piers than at modified piers.

Biomass followed similar trends as those of numerical catch rates (Figure 2). Total fish biomass was significantly higher at brushed-hab piers than at reference piers during all seasons. Biomass of largemouth bass and bluegills followed similar trends as those of total fish biomass. During spring and fall, biomass of largemouth bass and bluegills was higher at brushed-hab piers than at reference piers. During summer, largemouth bass biomass was significantly higher at brushed-hab piers than at piers with habs or reference piers. No significant trend in mean length was observed for largemouth bass or bluegills among pier treatments within any season (Figure 3).

Lake Hickory.—Numerical catch rates from Lake Hickory piers were similar to those observed on Fishing Creek Reservoir (Figure 4). Total numerical catch rate from brushed-hab piers was higher than at reference piers during all seasons. During summer and fall, total catch of all species was significantly higher both at brushed-hab piers and at piers modified with habs relative to that at reference piers. Largemouth bass catch rate was higher at brushed-hab piers than at reference piers during spring and summer, but during summer, both brushed-hab piers and piers with habs held more largemouth bass than reference piers. During spring and summer, bluegill catch rate was significantly higher at brushed-hab piers than at piers modified with hab modules or reference piers, and during fall, bluegill catch rate was significantly higher at both types of modified piers than at reference piers.

Biomass of fish collected from piers on Lake Hickory followed the same general trend as that of numerical catch rate (Figure 4). Within each season, brushed-hab piers and piers with habs held

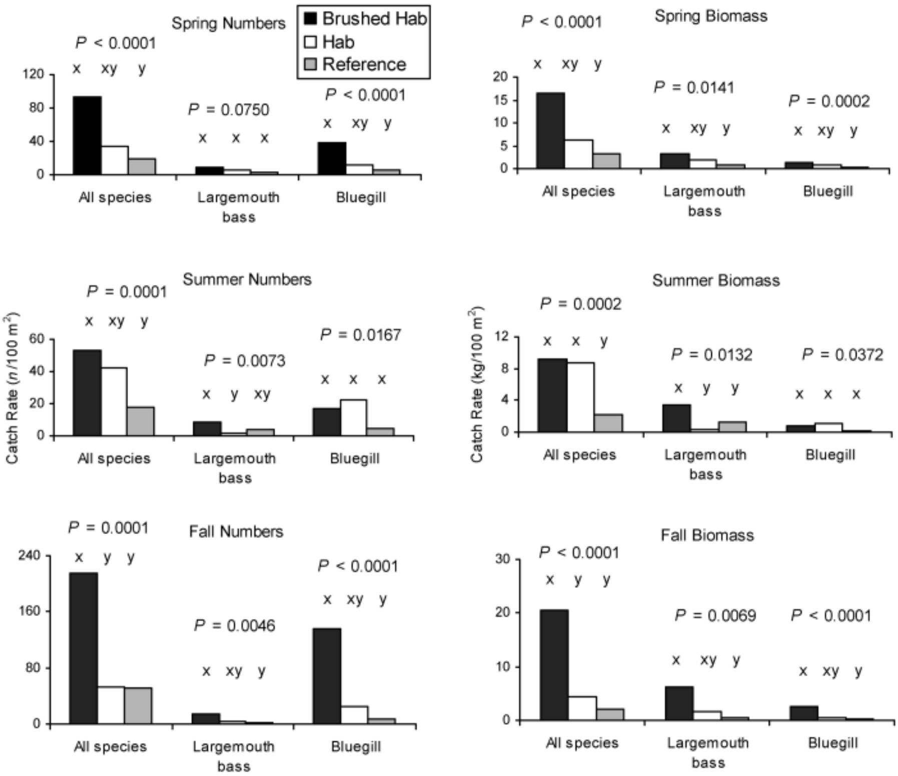

FIGURE 2.—Mean catch rate by number (n/100 m^2) and biomass (kg/100 m^2) for all species, largemouth bass, and bluegills collected from brushed-hab piers (N = 8), piers with habs (N = 7), and reference piers (N = 15) during spring, summer, and fall on Fishing Creek Reservoir, 2001. P-values refer to Kruskal–Wallis tests of significance while common letters within a chart indicate treatments that are not significantly different within each season and species (or total).

more total fish biomass than reference piers. Largemouth bass biomass followed this trend during all seasons, as total fish biomass was composed largely of largemouth bass. Bluegill biomass was significantly higher during spring at brushed-hab piers than at reference piers and at those with habs, whereas during summer and fall, bluegill biomass was significantly higher at both types of modified piers. Difference in mean length of largemouth bass or bluegills was not detected among most pier-treatment comparisons, with the exception of largemouth bass during fall and bluegills during summer (Figure 3). During fall, largemouth bass mean length was greater at brushed-hab piers and at piers with habs, while during summer, bluegills were significantly larger at piers with habs.

Transect-Scale Fish Abundance

For transect-level comparison of fishes associated with residentially developed shorelines with pier treatments (brushed habs, habs only, and reference piers) and undeveloped shorelines with natural woody debris, we sampled 20 transects on Fishing Creek Reservoir and 27 transects on Lake Hickory. Total catch for all seasons combined from transects on Fishing Creek Reservoir was 6,375 fish representing 25 species and that from Lake Hickory was 12,767 fish representing 22 species (Barwick 2002).

Fishing Creek Reservoir.—Total catch rate of all species was significantly different among transect treatments within each season on Fishing Creek Reservoir according to the overall Kruskal–Wallis analysis, but multiple-comparison tests failed to elucidate which treatments differed (Figure 5). Although largemouth bass catch rate did not differ significantly among transect treatments during any season, numerical catch rate of bluegills differed among transect treatments in Fishing Creek Reservoir. During spring, catch rate for bluegills was significantly higher at natural woody-debris transects than at transects with habs and reference-

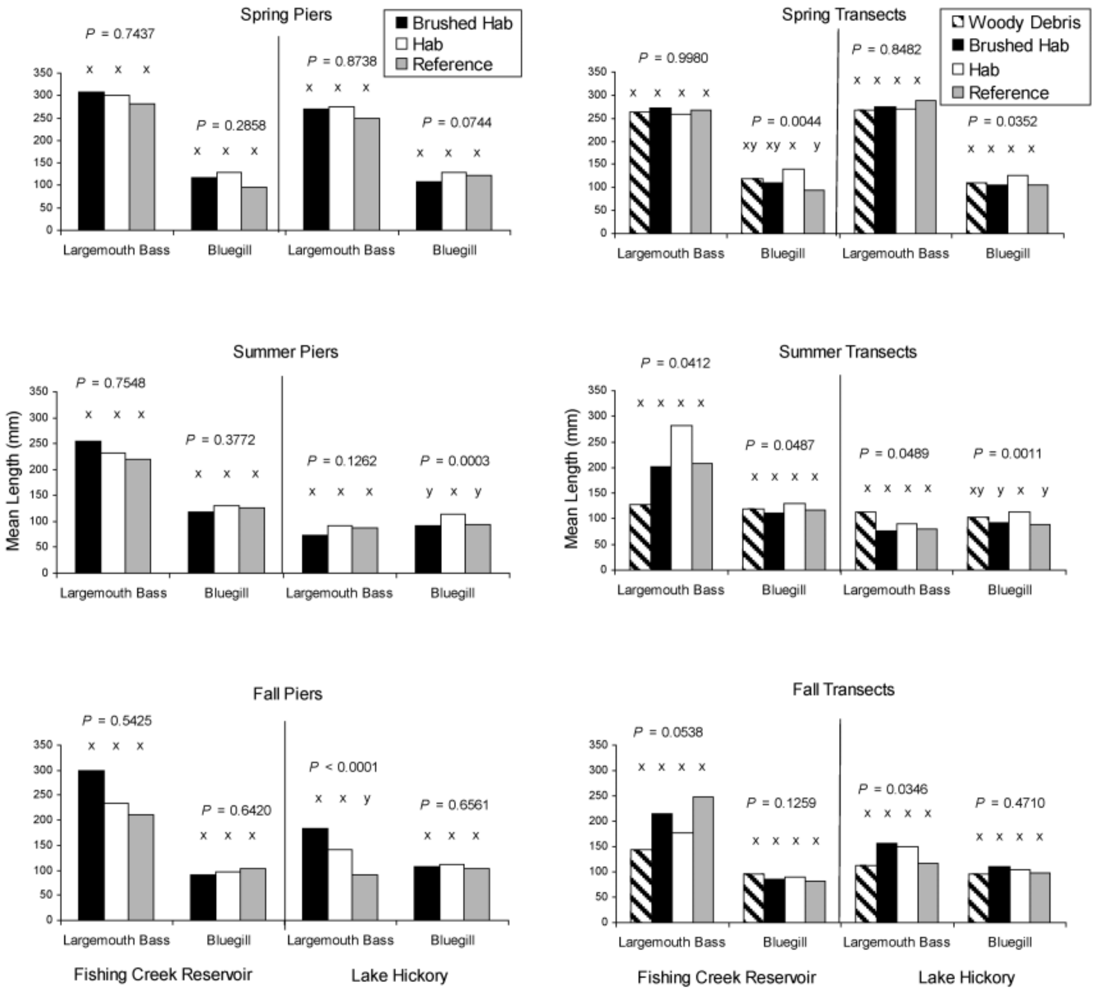

FIGURE 3.—Mean lengths (mm) of largemouth bass and bluegills collected from brushed-hab piers, piers with habs, reference piers, natural woody-debris transects, brushed-hab transects, transects with habs, and reference-developed transects during spring, summer, and fall on Fishing Creek Reservoir and Lake Hickory, 2001. *P*-values refer to Kruskal–Wallis tests of significance while common letters within a chart indicate treatments that are not significantly different within each season and species (or total). Treatment sample sizes appear in Figures 2, 4, 5, and 6.

developed transects. During fall, bluegill catch rate was significantly higher at brushed-hab transects than at transects with habs or reference-developed transects.

Biomass of fish collected from transects on Fishing Creek Reservoir followed similar trends as those for numerical catch rate (Figure 5). Total fish biomass was significantly different among transect treatments during summer and fall as determined by the Kruskal–Wallis analysis. However, during summer, multiple-comparison tests failed to detect which treatments differed. During fall, total biomass was higher at brushed-hab transects than at reference-developed transects. As with numerical catch rate, biomass of largemouth bass did not differ significantly among transect treatments within any season, but differences in bluegill biomass were apparent. During spring, bluegill biomass was significantly higher at natural woody-debris transects than at reference-developed transects. During summer, bluegill biomass was higher at transects with habs than at reference-developed transects, and during fall, bluegill biomass was significantly higher at brushed-hab transects than at reference-developed transects.

Similar to pier-scale results, few differences in

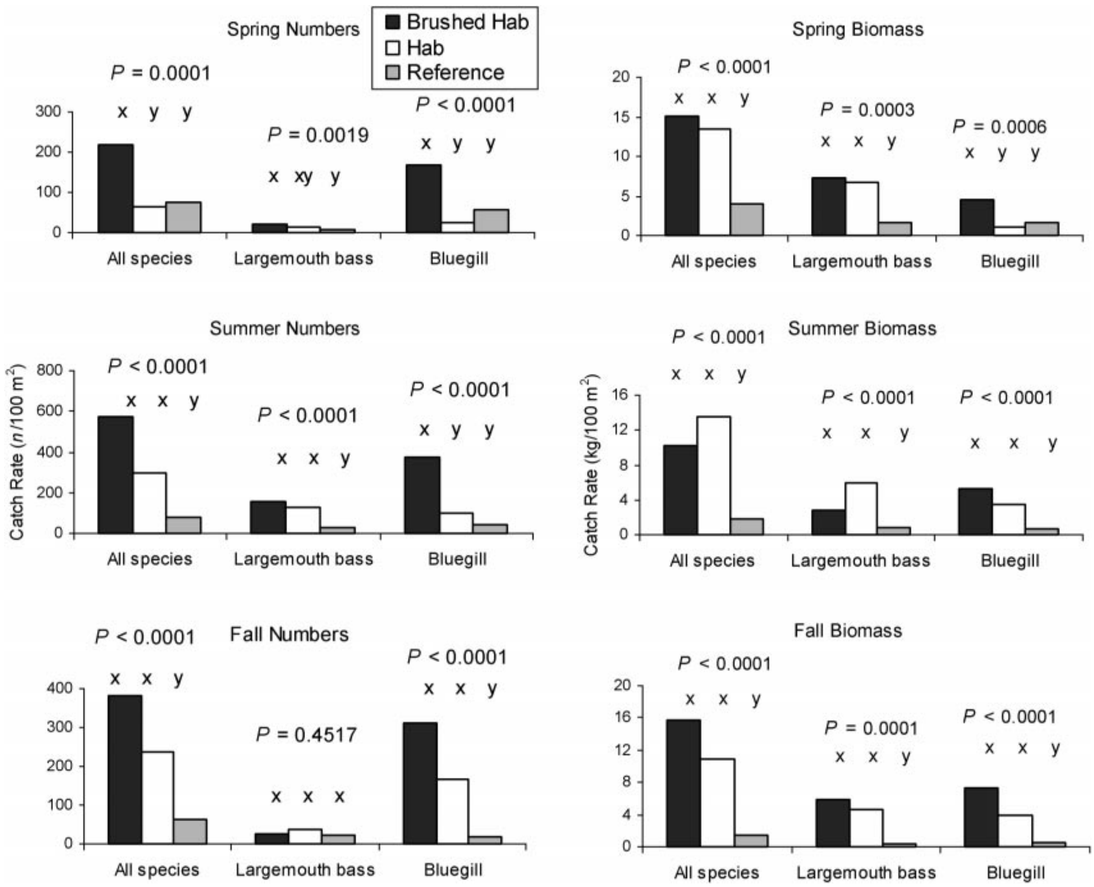

FIGURE 4.—Mean catch rate by number (n/100 m^2) and biomass (kg/100 m^2) of all species, largemouth bass, and bluegills collected from brushed-hab piers ($N = 15$), piers with habs ($N = 14$), and reference piers ($N = 18$) during spring, summer, and fall on Lake Hickory, 2001. P-values refer to Kruskal–Wallis tests of significance while common letters within a chart indicate treatments that are not significantly different within each season and species (or total).

largemouth bass and bluegill mean length were detected among transect treatments during each season (Figure 3). However, differences in bluegill mean length among treatments were detected during spring by both the overall Kruskal–Wallis analysis and multiple-comparison procedure. During spring in Fishing Creek Reservoir, bluegill mean length was significantly larger at developed transects with habs than at reference-developed transects. Significant among-treatment differences in mean length were detected by the overall Kruskal–Wallis analysis of largemouth bass and bluegills during summer, but multiple comparisons failed to identify among which treatments they occurred.

Lake Hickory.—Transect catch rate by number for all species combined was significantly different among treatments during spring and summer according to results of the overall Kruskal–Wallis analysis, but multiple comparisons among treatments failed to detect those differences during spring (Figure 6). During summer, total species catch rate was significantly higher at brushed-hab transects than at reference-developed transects. Largemouth bass catch rate followed trends slightly different from those observed for total combined species, as overall significant differences in largemouth bass catch rates were detected during summer and fall by the Kruskal–Wallis analysis, but none were detected using multiple comparisons. During summer, largemouth bass catch rate was higher at natural woody-debris transects than at reference-developed transects. For numerical bluegill catch rate, significant differences were detected among transect treatments during all seasons by the Kruskal–Wallis analysis, but multiple-comparison analysis detected significant trends

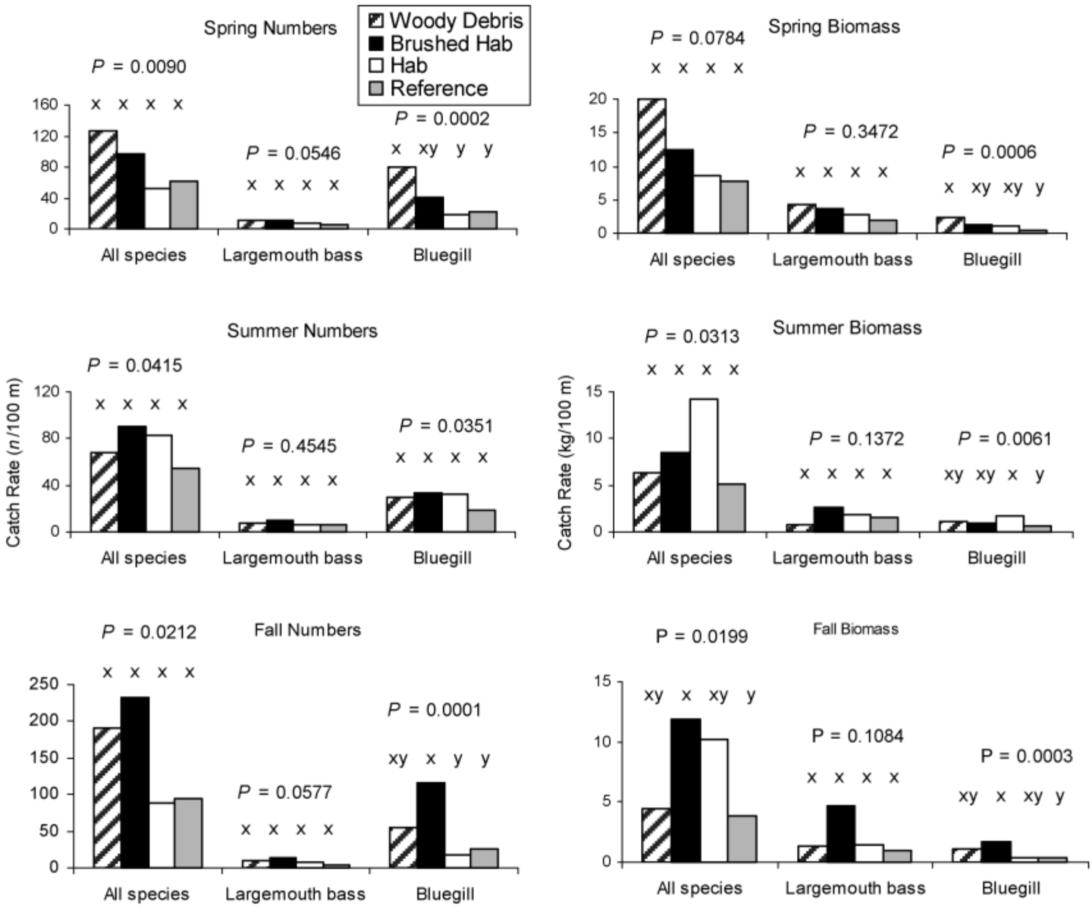

FIGURE 5.—Mean catch rate by number (n/100 m) and biomass (kg/100 m) of all species, largemouth bass, and bluegills from natural woody-debris transects (N = 8), brushed-hab transects (N = 4), transects with habs (N = 3), and reference-developed transects (N = 5) during spring, summer, and fall on Fishing Creek Reservoir, 2001. P-values refer to Kruskal–Wallis tests of significance while common letters within a chart indicate treatments that are not significantly different within each season and species (or total).

among treatments only during spring and fall. During spring, bluegill catch rates were significantly higher at natural woody-debris transects and brushed-hab transects than at transects with habs. During fall, brushed-hab transects yielded significantly higher bluegill catch rates than reference-developed transects.

Trends in biomass among transect treatments on Lake Hickory generally resembled those observed for numerical catch rate (Figure 6). Total fish biomass was not significantly different among transect treatments during spring and fall, but significant trends were detected during summer. During summer, total fish biomass was significantly higher at transects with habs than that at reference-developed transects. Although no significant difference was observed for largemouth bass biomass, transect differences in bluegill biomass were detected during all seasons. During spring, bluegill biomass was significantly higher at brushed-hab transects than at reference-developed transects or transects with habs. During summer and fall, bluegill biomass was significantly higher at brushed-hab transects than at reference-developed transects.

Few significant trends in mean length of largemouth bass and bluegills were observed from transects in Lake Hickory (Figure 3). Bluegill mean length was significantly different among transect treatments during spring and summer, as indicated by Kruskal–Wallis results, but multiple comparisons were significant only for summer data. During summer, bluegill mean length was significantly larger at transects with habs than at either transects

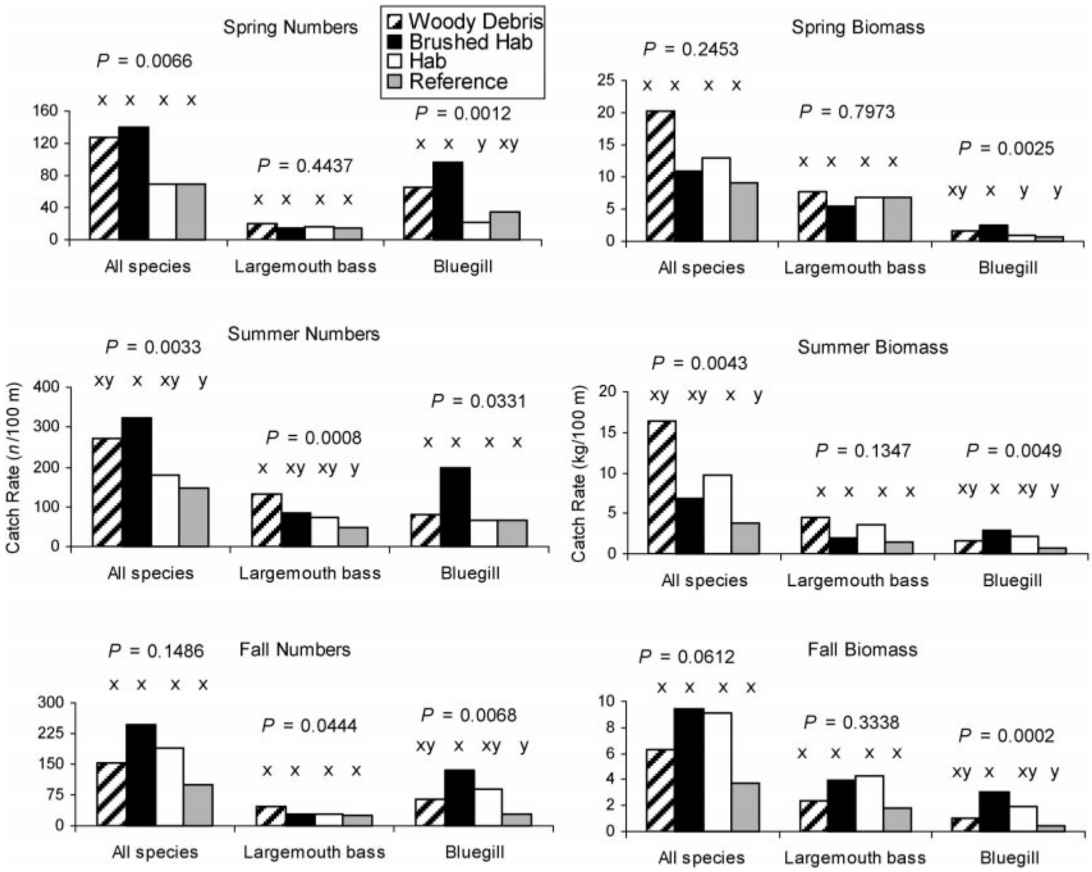

FIGURE 6.—Mean catch rate by number (n/100 m) and biomass (kg/100 m) of all species, largemouth bass, and bluegills from natural woody-debris transects ($N = 8$), brushed-hab transects ($N = 5$), transects with habs ($N = 7$), and reference-developed transects ($N = 7$) during spring, summer, and fall on Lake Hickory, 2001. P-values refer to Kruskal–Wallis tests of significance while common letters within a chart indicate treatments that are not significantly different within each season and species (or total).

with brushed habs or reference-developed transects. Largemouth bass mean length was significantly different among transect treatments during summer and fall according to Kruskal–Wallis results, but no multiple comparisons were significant.

Woody-Debris Survey

Mean diameter of natural woody debris incorporated into hab modules used to modify piers with the brushed-hab treatment differed in size from that found on study transects of Fishing Creek Reservoir and Lake Hickory (Table 2). In Fishing

TABLE 2.—Diameter size distribution (percent) of natural woody debris sampled from study transects on Fishing Creek Reservoir and Lake Hickory during summer 2001 compared with brush incorporated into hab modules deployed under piers on both reservoirs. See Table 1 for a description of the hab module.

	Diameter (cm)					
Woody debris source	0–9	10–19	20–29	30–39	40–49	≥50
Fishing Creek Reservoir	92.1	5.5	0.3	1.5	0.3	0.3
Lake Hickory	95.7	3.5	0.8	0	0	0
Brushed hab module	100.0	0	0	0	0	0

TABLE 3.—Survey responses (percent) to a questionnaire distributed to pier owners on Fishing Creek Reservoir and Lake Hickory whose piers received brushed-hab (N = 23; 17 surveys returned) or hab module treatments (N = 20; 14 surveys returned). See Table 1 for treatment descriptions.

Survey question	Piers with brushed hab		Piers with hab	
	Yes	No	Yes	No
Are you satisfied with the enhancement structures?	94	6	93	7
Have you experienced problems with the structures?	18	82	14	86
Have the structures caused damage to your pier?	0	100	0	100
Does your household fish from the pier?	100	0	100	0
Have you noticed better fishing success since enhancement?	76	24	57	43
Have you noticed an increase in other anglers fishing from your pier?	41	59	21	79
Have you observed more fish around your pier since enhancement?	91	9	80	20
Have you observed more or different wildlife since enhancement?	59	41	21	79
Has the pier enhancement altered the aesthetics of your property?	18	82	36	64
Would you suggest this type of enhancement of others?	100	0	93	7

Creek Reservoir, diameter of natural woody debris ranged from 1 to 52 cm with an average diameter of 4.3 cm. Approximately 92% of natural woody debris located on Fishing Creek Reservoir study transects was less than 10 cm in diameter. Diameter of natural woody debris on Lake Hickory study transects was slightly different from that on Fishing Creek Reservoir. On Lake Hickory, natural woody-debris diameter ranged from 1 to 26 cm with an average diameter of 3.2 cm. More than 95% of natural woody debris sampled from transects in Lake Hickory were less than 10 cm in diameter. Diameter of brush incorporated into hab modules was smaller and less variable than that of natural woody debris found on transects of both reservoirs. Diameter of brush in hab modules ranged from 1 to 3 cm with an average of 1.3 cm.

Pier Owner Mail Survey

Of 43 surveys mailed to pier owners receiving brushed habs or hab modules, 31 surveys were completed and returned for a response rate of 72%. Reported pier uses included boat access, fishing, and swimming. Ninety-two percent of pier owners whose piers received treatment expressed satisfaction with the modification one year after installation (Table 3). However, pier owners receiving the brushed-hab treatment conveyed concerns with brush extending beyond the perimeter of the pier. They noted the potential for injury to children jumping off of the pier and interference with swimming in the vicinity of the pier. Concerns about brushed-hab modules moving from under the piers during storms were also expressed. Pier owners receiving the hab module treatment had concerns with fishing from the pier. They noted that lure snags were more common because of hab modules and that hab modules had also been blown from under the pier during storm events (a problem that we recognized during the study and immediately addressed by securing structures to pier pilings). None of the respondents indicated that either type of structure caused any pier damage, and most perceived better fishing success after modification with either type of structure.

Although pier owners perceived increased fishing success, the majority of respondents did not notice increased fishing pressure by other anglers. Pier owners receiving either modification not only perceived more fish around their pier but also additional wildlife, such as ducks, geese, turtles, and snakes. While no pier owner receiving brushed habs or hab modules felt that the structures diminished aesthetics of their properties, 30% felt that by modifying their pier, they increased the aesthetic value of their property. All pier owners receiving the brushed habs and 93% of pier owners receiving hab modules indicated that they would recommend this type of modification to others. The majority of pier owners agreed to retain the structures under their piers.

Discussion

Fish Utilization of Piers

In most cases, total catch rate by number and biomass was three to four times higher at brushed-hab piers or piers with habs than catch rate from reference piers during spring, summer, and fall. However, the addition of brush appears to further improve the habitat over that provided by the plastic modules alone, as fish abundance associated with brushed-hab piers was consistently (but not always significantly) higher than that associated with piers modified with hab modules alone. Apparently, fish receive some type of ecological or energetic benefit by occupying these areas; however, such benefit may be species- or life stage-specific. Increased structural complexity has been suggested to allow coexistence of predators and prey by creating more microhabitat types (Crowder and Cooper 1982). Inherently, increasing habitat complexity may influence predator efficiency by providing small fish with partial or complete refuges from predation at high-structure densities (Hall and Werner 1977; Werner et al. 1983). Piers enhanced with brushed habs may provide this type of refuge, thus attracting prey fish species and resulting in our high electrofishing catch rates of bluegills that may be utilizing structure to avoid predation. While small bluegills (<100 mm) may occupy these complex habitats in an attempt to avoid predation, larger bluegills that are less vulnerable to predation may use these habitats to a greater extent to forage for invertebrates.

Structural cover, such as modified piers, may provide important habitat for aquatic invertebrates (Nilsen and Larimore 1973; Benke et al. 1984), thus further increasing the suitability of complex pier habitats to bluegills relying on invertebrate food resources during a portion of their life history (Schneider 1999). However, fish habitat use may be more closely related to the advantages of camouflage (Angermeier and Karr 1984). Likewise, structure may serve as habitat for prey resources of largemouth bass, thus increasing foraging efficiency up to some threshold of structure density.

Overall, it appears that fish respond to complexities created by any structure (natural or artificial) to a greater extent than to the composition of that structure. We demonstrated several trends where catch by number and biomass generally increased with habitat complexity. Although this appears to be true for numerical catch rates and biomass, mean length within a species was not affected to the same extent.

Fish Utilization of Transects

The effects of pier treatments on fish abundance were less evident at the transect scale of analysis compared with the clear results at the pier scale. While we detected significant differences in 8 of 12 multisample comparisons (Kruskal–Wallis) of total fish abundance among treatments at the transect scale, only 3 of those could be elucidated by multiple comparisons (Figures 5 and 6). Such ambiguous results reflect that the Kruskal–Wallis procedure is more powerful than multiple-comparison tests; increased sample sizes would likely identify differences among individual transect treatments in our research (Zar 1996). The variation in results between scales of our analysis may simply be due to differing sizes of experimental units, demonstrating unequivocal effects of pier modifications at the finer scale of evaluation. These results also suggest that, in general, with broader scales of application and evaluation (e.g., basin or lake), effects of habitat manipulations on fish populations are likely to be more difficult to detect. Miranda et al. (1996) drew similar conclusions regarding size of experimental units as measured by sampling duration for largemouth bass in reservoirs.

Shoreline habitat composition between piers in residentially developed transects may offer a partial, ecological explanation for our variable between-scale findings. At the transect scale, the effect of shoreline habitat adjacent to and between piers may have contributed to the rate and size composition of our catches in addition to pier treatment effects. Such an effect was apparent from the high number of species collected from transects of each reservoir relative to that collected from piers. This adjacent shoreline in residentially developed transects was usually composed of riprap that provides additional habitat complexity and abundant interstitial spaces for fish to occupy. Shoreline bulkheads and unstructured clay banks were encountered less frequently in developed transects and would provide little in the way of habitat complexity. Although completely different in material and structural composition, artificial riprap may function as fish habitat on residentially developed shorelines in a fashion similar to that of natural woody debris on undeveloped shorelines.

Examination of experiment-wide trends in fish abundance among the four treatments at the transect scale provides additional insight on the effectiveness of the two artificial-pier treatments relative to natural woody debris. Among the 12 multisample comparisons for total fish abundance, the mean number or biomass of fish was consistently greater on natural woody-debris transects relative to that on untreated, reference-pier transects (Figures 5 and 6). Similarly, in all 12 comparisons of total fish abundance, transects treated with brushed habs supported greater mean fish abundance than that at untreated reference transects, whereas mean abundance at transects with piers modified with habs only was greater than that at reference transects in 10 of 12 comparisons. Corresponding transect-level results according to species (bluegills and largemouth bass) showed a similar trend. These relative, experiment-wide comparisons are consistent with a hypothesis that on average, fish abundance is lower at developed, untreated reference transects relative to that of natural shorelines. However, artificial-pier modifications may increase fish abundance to a level approaching that of natural habitats even though differences in structure composition and size distribution exist (Table 2). Such comparisons provide less rigorous inference than significant statistical results for specific lakes and seasons. However, given our ambiguous multiple-comparison results, such consistent trends over seasons, lakes, and species suggest ecological effects that we were unable to clearly elucidate at the transect scale with our experimental design.

While largemouth bass abundance rarely differed among transect treatment comparisons, significant differences in bluegill abundance were revealed in all comparisons. Bluegills were generally more abundant in habitats with woody structure. Bluegill catch rates from brushed-hab transects and natural woody-debris transects were higher than catch rates from transects without woody structure (reference-developed and transects with habs). This observed trend might be explained by the presence of woody structure that provides habitat for invertebrate production (Angermeier and Karr 1984) and, thus, a food resource for bluegills (Schneider 1999).

Conclusions and Management Implications

Modifying pier habitat in this fashion provided a clear benefit to fishes in these reservoirs. This benefit is manifested in higher abundances in enhanced areas, as reflected in increased electrofishing catch rates of all species, largemouth bass, and bluegills at both study scales (pier and transect). Such habitat enhancement techniques may be applied toward management objectives. They may be implemented to direct or increase angler catch rates in locations that ordinarily would provide little success, or they may be applied to reservoirs that have experienced habitat loss over time. However, by implementing such techniques intensively within a portion of a reservoir, fish abundance for certain species may be increased at a larger scale. Although total catch rates and abundance of largemouth bass and bluegills were significantly higher at modified piers and consistently higher at modified and natural woody-debris transects, statistical comparisons at the transect scale were ambiguous compared to those of piers, rendering broad-scale conclusions unresolved.

In reservoirs that differ in location and trophic status, fish may respond to the complexity of the habitat rather than to the type of structure creating those complexities (Jennings et al. 1999). Thus, complex structure such as riprap found on residentially developed shorelines may provide suitable habitat for fishes, thus resulting in fewer differences than expected between reference-developed transects and natural woody-debris transects. Artificial-habitat enhancement also provides additional suitable structure and appears to be a feasible habitat management response to the lack of structure in reservoirs that can provide overall benefits for fish. Modifying piers by these techniques was well received by lakeshore homeowners. Furthermore, if a habitat management plan includes this method of modifying littoral habitat in residentially developed reservoirs, cooperative pier owners should not be difficult to locate.

Limitations exist in this management approach. Although habitat modules persisted throughout the study period, future maintenance may be necessary and should be included in planning. Despite plastic hab modules being nonbiodegradable, brush incorporated into these structures will need to be replaced periodically due to the decomposition of wood, especially if water levels fluctuate. Other maintenance may include resetting of modification structures displaced by wave and wind action during storms if not anchored securely.

It is also unclear whether modified piers simply attract fish or actually increase local fish production. In these reservoirs, it is probable that habitat for structure-oriented fish is limited. If physical habitat limits fish production, this approach could increase production by enhancing the foraging habitat of fish, increasing nesting habitat for adult fishes, and providing refuges for young fish from predation (Grossman et al. 1997). Fish abundance in Fishing Creek Reservoir and Lake Hickory was consistently higher at modified piers. Additionally, as significantly smaller Lake Hickory bluegills were collected during summer from brushed-hab piers and transects relative to those collected from piers or transects augmented with habs (Figure 3), complex habitats such as those provided by brushed habs may be of importance as nursery areas for young of year bluegills. Thus, if modified piers create habitat that is conducive to foraging, spawning, and as refugia, a production response may be observed. However, few studies have been conducted that unambiguously demonstrate that, rather than simply attracting fishes, increased structure results in increased production.

Likewise, few studies have examined other ecological functions of physical structure in aquatic environments, in addition to support of fishes. Our research demonstrates the efficacy of these habitat modifications in terms of fish-support functions, but their effect in terms of limnology, primary production, and invertebrate support remains largely unknown. More detailed investigations with an emphasis on processes and mechanisms may yield important results that are useful in fully understanding the effect of such habitat modifications and improving their application in fisheries management.

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References

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

Barwick, R. D. 2002. Fish populations associated with habitat-modified piers and natural woody debris in Piedmont Carolina reservoirs. Master's thesis. North Carolina State University, Raleigh.

Benke, A. C., T. C. Van Ardsall, Jr., 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.

Bryan, M. D., and D. L. Scarnecchia. 1992. Species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of a glacial Iowa lake. Environmental Biology of Fishes 35:329–341.

Christensen, D. L., B. R. Herwig, D. E. Schindler, and S. R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications 6: 1143–1149.

Crowder, L. B., and W. E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802–1813.

Duke Power. 1999. Access. Your guide for locating public recreation resources on Duke Power lakes. Duke Power Company, Charlotte, North Carolina.

Glass, N. R. 1971. Computer analysis of predator energetics in the largemouth bass. Pages 325–363 *in* B. C. Patten, editor. Systems analysis and simulation in ecology, volume I. Academic Press, New York.

Grossman, G. D., G. P. Jones, and W. J. Seaman, Jr. 1997. Do artificial reefs increase regional fish production? A review of existing data. Fisheries 22(4): 17–23.

Hall, D. J., and E. E. Werner. 1977. Seasonal distribution of fishes in the littoral zone of a Michigan lake. Transactions of the American Fisheries Society 106: 545–555.

Herrig, D. J., and L. R. Miller. 1985. Comparison of Berkley fish hab and stakebeds in two small western Iowa impoundments. Fisheries Management Investigations, Iowa Department of Natural Resources, Des Moines.

Jenkins, R. M. 1970. Reservoir fish management. Pages 173–182 *in* N. G. Benson, editor. A century of fisheries in North America. American Fisheries Society, Special Publication 7, Bethesda, Maryland.

Jennings, M. J., M. A. Bozek, G. R. Hatzenbeler, E. E. Emmons, and M. D. Staggs. 1999. Cumulative effects of incremental shoreline habitat modification on fish assemblages in north temperate lakes. North American Journal of Fisheries Management 19:18–27.

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.

Lawson, C. S. 1981. Fish utilization of midwater and bottom fish attractors in a fertilized community fishing lake. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 35(1981):372–375.

Meals, K. O., and L. E. Miranda. 1991. Variability in abundance of age-0 centrarchids among littoral habitats of flood control reservoirs in Mississippi. North American Journal of Fisheries Management 11: 298–304.

Miranda, L. E., W. D. Hubbard, S. Sangare, and T. Holman. 1996. Optimizing electrofishing sample duration for estimating relative abundance of largemouth bass in reservoirs. North American Journal of Fisheries Management 16:324–331.

Nilsen, H. C., and R. W. Larimore. 1973. Establishment of invertebrate communities on log substrates in the Kaskaskia River, Illinois. Ecology 54:366–374.

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

Pierce, B. E., and G. R. Hooper. 1979. Fish standing crop comparisons of tire and brush fish attractors in Barkley Lake, Kentucky. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 33(1979):688–691.

Prince, E. D., O. E. Maughan, D. H. Bennett, G. M. Simmons, Jr., J. Stauffer, Jr., and R. J. Strange. 1979. Trophic dynamics of a freshwater artificial tire reef. Pages 459−473 *in* R. H. Stroud and H. Clepper, editors. Predator–prey systems in fisheries management. Sport Fishing Institute, Washington, DC.

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.

Rold, R. E., T. S. McComish, and D. E. Van Meter. 1996. A comparison of cedar trees and fabricated polypropylene modules as fish attractors in a strip mine impoundment. North American Journal of Fisheries Management 16:223–227.

Savino, J. F., and R. A. Stein. 1982. Predator–prey interaction between largemouth bass and bluegills as influenced by simulated, submerged vegetation. Transactions of the American Fisheries Society 111: 255–266.

Schneider, J. C. 1999. Dynamics of quality bluegill populations in two Michigan lakes with dense vegetation. North American Journal of Fisheries Management 19:97–109.

Werner, E. E., J. F. Gilliam, D. J. Hall, and G. G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540−1548.

Zar, J. H. 1996. Biostatistical analysis, 3rd edition. Prentice Hall, Upper Saddle River, New Jersey.