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[Article]

Population Density and Instream Habitat Suitability of the Endangered Cape Fear Shiner

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Abstract.—The Cape Fear shiner *Notropis mekistocholas* is an endangered minnow endemic to the Cape Fear River basin of North Carolina; only five populations remain, all of which are declining. Determining the population densities and habitat requirements of the species is critical to its survival and restoration planning. We conducted population surveys (four sites) and instream microhabitat suitability analyses (six sites) on the Rocky and Deep rivers to (1) estimate the population density of Cape Fear shiners, (2) quantify the use, availability, and suitability of microhabitats, and (3) determine whether physical habitat alterations were a likely cause of local extirpations and whether instream habitat limits the occurrence and density of this species. Density ranged from 795 fish/ha to 1,393 fish/ha (4,768–7,392 fish/km) at three of the sites surveyed and was too low to be estimated at the fourth site. The fish most frequently occupied riffles and velocity breaks at moderate depths over gravel substrates. It occupied microhabitats nonrandomly with respect to availability; the microhabitats occupied were similar between spawning and postspawning seasons but shallower during spawning. Comparisons of suitable habitat among sites where the fish is extant, rare, or extirpated suggest that suitable substrate (gravel) is lacking where the fish is rare and that suitable microhabitat combinations, especially with respect to water velocity, are rare at all sites. Potential reintroduction sites where the species is rare or extirpated were shallower than extant sites, and one site where the fish is extirpated contained suitable physical habitat but lacked adequate water quality. Another site where the species is rare would require substrate alteration to improve conditions. The survival and recovery of the Cape Fear shiner is dependent on the protection of remaining suitable physical habitat with approaches that consider instream habitat, water quality, and biotic interactions as well as human uses and alterations of the river, riparian zone, and watershed.

Freshwater fishes are among the most diverse of vertebrate groups, but they are also one of the most vulnerable due to widespread degradation of aquatic ecosystems (Angermeier 1995; Warren et al. 2000; Duncan and Lockwood 2001). The drainage basins of the southern United States contain the greatest diversity and number of endemic freshwater fishes in North America north of Mexico, and many populations are declining; 28% (187 taxa) are recognized as extinct, endangered, threatened, or vulnerable to extinction (Burr and Mayden 1992; Warren et al. 1997, 2000). The growing imperilment of fishes and other aquatic fauna is predominantly due to human-mediated changes within watersheds including construction of impoundments, water withdrawals, urbanization, land use alterations, and environmental pollution (Moyle and Leidy 1992; Burkhead et al. 1997; Burkhead and Jelks 2001).

Habitat loss and increasing insularization of populations are factors that have been related to species extinction (Angermeier 1995). Cataclysmic loss of diversity via extinction is not the norm (Warren et al. 1997). Instead, regional extirpations generally precede extinction and indicate a population's sensitivity to habitat degradation and insularization (Angermeier 1995). Furthermore, isolated endemics and other geographically restricted species are more vulnerable to catastrophic events, such as droughts, floods, or chemical spills, and localized degradation of physical habitat and water quality, and, therefore, have a greater risk of extirpation and extinction (Warren and Burr

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1994; Burkhead et al. 1997). Information relating to the ecology of rare native fishes, including habitat needs and natural history, is critical to explain reasons for their decline and to guide recovery efforts (Warren et al. 1997).

The Cape Fear shiner *Notropis mekistocholas* is a federally endangered, restricted-range endemic minnow (Cyprinidae) of the Cape Fear River drainage, North Carolina (USFWS 1987). It has the smallest range among the 87 *Notropis* species currently recognized in North America (Page and Burr 1991; Nelson et al. 2004). This species is a relatively recent discovery, having first been collected in the early 1960s and described soon after (Snelson 1971). Since the time of its initial discovery, it has been extirpated from much of its historic range and is currently known from only five remaining populations in the Cape Fear River basin (Pottern and Huish 1985, 1986, 1987; NCWRC 1995, 1996). Recent analyses of the Cape Fear shiner indicate that the species maintains robust genetic diversity and is not genetically impoverished, but genetic consequences of reduced gene flow among local populations were identified (Gold et al. 2004; Saillant et al. 2004).

The Cape Fear shiner is most frequently associated with gravel, cobble, and boulder substrates (Pottern and Huish 1985; USFWS 1988). Adults have been collected in riffles, shallow runs, and slow pools with these substrates, while both juveniles and adults occur in slack water and flooded side-channels with good water quality and relatively low silt loads. Emersed aquatic vegetation, specifically American water willow *Justicia americana*, or conditions associated with such vegetation create highly suitable habitat for the Cape Fear shiner, especially during spawning (USFWS 1988; NCWRC 1995). Primary proximate stressors negatively affecting the Cape Fear shiner may be degraded physical instream habitat or changes in water quality (Pottern and Huish 1985). Pervasive and complex changes to the landscape have led to degraded water quality, habitat loss, and the fragmentation and isolation of Cape Fear shiner populations that currently exist (USFWS 1988). Before this research, no quantitative information on the habitat ecology of the Cape Fear shiner was available.

The direct and indirect effects of dams and associated impoundments are widespread, and they influence the physical habitat and population dynamics of the Cape Fear shiner. They alter instream physical habitat by changing flow patterns and biological and physical characteristics of river channels (Bednarek 2001). Further, they can disrupt population dynamics and limit connectivity and dispersal of individuals (Winston et al. 1991; Schrank et al. 2001). Construction of dams has altered the Cape Fear River ecosystem, fragmenting what was formerly a continuous Cape Fear shiner population into several remnant declining populations (USFWS 1988). Dams on the Cape Fear River system alter the physical surroundings in at least two ways that would affect Cape Fear shiner population dynamics; they impound flowing instream habitat that was previously suitable for Cape Fear shiner occupancy, and they form a barrier to fish migration.

Sediment transport is a natural part of the fluvial process (Waters 1995), but excessive sedimentation from soil erosion and agricultural runoff can threaten aquatic organisms (Pimentel et al. 1995). Sedimentation is among the most widespread causes of stream impairment in the Cape Fear basin (NCDWQ 1996). The Cape Fear shiner is vulnerable to excessive sedimentation because it feeds on benthic algae and spawns over coarse substrate materials (Snelson 1971; Pottern and Huish 1985).

Quantitatively determining specific habitat requirements of this species is critical to its survival and may facilitate protection of existing habitat and guide restoration of degraded habitats as outlined in the Cape Fear shiner recovery plan (USFWS 1988). Thus, we quantified the physical habitat suitability of the Cape Fear shiner and related it to historical and extant locations. Our goals were to assess the habitat quality of potential reintroduction sites to improve our overall understanding of the fish's ecology. Our specific objectives were to (1) estimate Cape Fear shiner population density, (2) quantify its microhabitat use, availability, and suitability in extant habitats during the spring spawning season and summer postspawning season, and (3) compare habitat characteristics among sites to assess whether physical habitat alterations were a contributing cause of extirpation of the species at historical locations, and whether instream habitat is a limiting factor to occurrence and density of the species in extant habitats and potential reintroduction and population augmentation sites.

Methods

Study area.—The Cape Fear River originates in the north central piedmont region of North Carolina and flows southeasterly to the Atlantic Ocean. It comprises a 15,000-km^2 watershed and 9,735 km of freshwater streams and rivers, and supports approximately 22% of the state's human population, including 116 municipalities (NCDWQ 2000). Land use in the Cape Fear basin was 26% agriculture, 59% forest, 6% urban, and 9% other uses during the 1990s and developed land and agricultural land use is increasing (NCDWQ 1996, 2000).

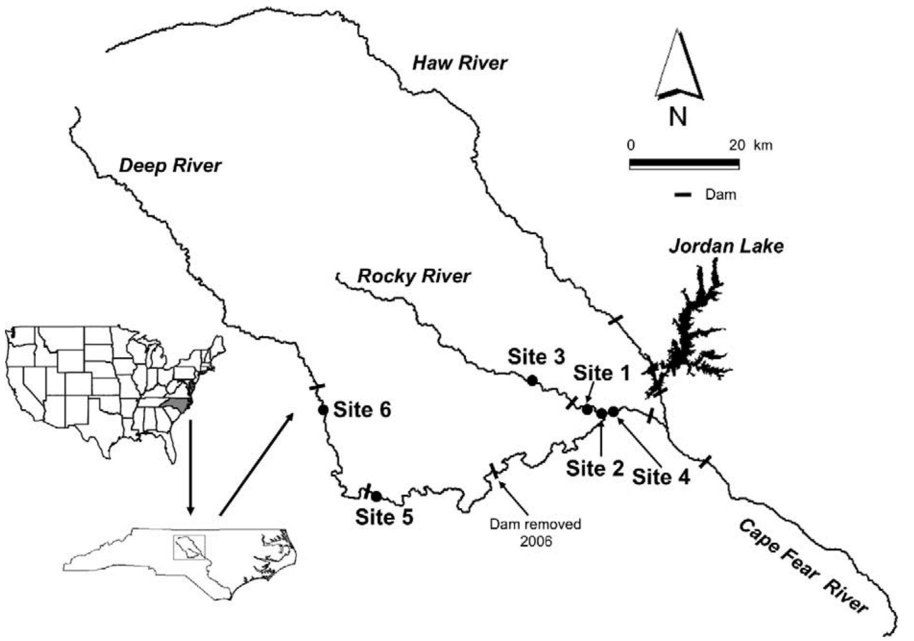

FIGURE 1.—The six primary sites on the Deep and Rocky rivers selected for Cape Fear shiner population density estimates and instream physical habitat analyses. Only the dams that might affect local Cape Fear shiner populations are shown.

The extant populations of the Cape Fear shiner are located in the Deep, Haw, and Rocky rivers in Randolph, Moore, Lee, and Chatham counties, North Carolina (USFWS 1988; NCWRC 1996). We selected six study sites to collect data on Cape Fear shiner microhabitat use, availability, and suitability, and to estimate its population density (Figure 1). These included four river reaches where the Cape Fear shiner was extant and common (use, availability, and density data collected; sites 1, 4, and 5), one where the fish was extant, but rare (availability data only; site 6), and one where the fish has been extirpated (availability data only; site 3). Sites 3 and 6 were included as potential reintroduction or augmentation sites. Descriptions of these sites and their water quality characteristics were detailed by Howard (2003) and Hewitt et al. (2006).

Cape Fear shiner population density.—Cape Fear shiner population density was estimated using the strip-transect method (Buckland et al. 2001), that is, by snorkeling through a measured strip transect and visually counting all individuals in the transect. Populations were estimated at two sites in the Deep River and one in the Rocky River (sites 1, 4, and 5) during summer 2002. Surveying was also attempted at another site where the Cape Fear shiner is considered extant, but rare, in the Deep River (site 6), but no Cape Fear shiners were detected at this site.

Ten strip transects were surveyed to estimate population density at each site (sites 1, 4, and 5) using systematic random sampling. The first transect was chosen randomly, and the following nine transects were spaced 50 m apart in an upstream direction. The width of each transect was based on the underwater visibility at the time of sampling. The length of each transect varied based on how far snorkeling was possible without obstruction (i.e., large boulders or woody debris). To reduce bias associated with the visual assessment of strip width, we used weights attached to flagging tape and a float to mark the boundary of the strip being surveyed. Cape Fear shiners are often found in groups. To account for this clumped distribution, we included all fish counted in a cluster if more than 50% of the individuals were within the strip boundary, and conversely, did not include individuals in the cluster if more than 50% were outside the strip boundary (Buckland et al. 2001). The width and length of each transect and number of Cape Fear shiners in each was recorded to approximate Cape Fear shiner density (fish/ha). The number of fish per area was converted to number of fish per linear kilometer by dividing by the mean stream width. We estimated Cape Fear shiner mean density for each site and associated confidence intervals among the 10 transects. These estimates represent minimum densities due to the possibility that some fish within the strip boundaries were not detected. We did not use distance sampling (Buckland et al. 2001) because of relatively turbid sampling conditions that required narrow strip transects for accurate counts.

Microhabitat use, availability, and suitability.— From 29 July to 5 October 2001 and from 29 April to 5 June 2002, we observed Cape Fear shiners instream and quantified their microhabitat characteristics for summer–fall postspawning (2001) and spring spawning (2002) periods at sites 1, 2, and 5. At each site on multiple occasions, we snorkeled 50-m sections in an upstream direction to locate fish with minimal disturbance. When an individual or group of Cape Fear shiners was observed, we marked the precise location of the fish with a colored weight and immediately measured and recorded focal depth and focal velocity, which are the distance between the fish's snout and the substrate, and the velocity at the fish's snout, respectively. For a group of Cape Fear shiners, we estimated the average focal depth and focal velocity of the group. Distance to cover was also recorded at each Cape Fear shiner location. After thoroughly searching a section, we returned to each marked location and measured additional physical habitat characteristics. Water depth, mean column velocity, focal velocity, focal depth, substrate composition, and associated physical cover were measured at 99 (2001) and 66 (2002) precise Cape Fear shiner locations (totals for three sites). The spring 2002 microhabitat data were collected during the spawning period for this species. Although spawning-related activities were observed, our data are intended to represent general microhabitat use during the spawning season, rather than precise spawning measurements.

Water depth was measured with a top-set wading rod (nearest centimeter), and velocity was measured with a Marsh–McBirney model 2000 portable flowmeter. Mean velocity was measured at 0.6 of total depth from the water surface (depths less than 0.76 m) or was calculated as the average of measurements at 0.2 and 0.8 of total depth (depths greater than or equal to 0.76 m; McMahon et al. 1996). The predominant substrate was classified according to a modified Wentworth particle size scale. Categories used in the analysis for substrate were silt (<0.62 mm diameter), sand (0.62–2.0 mm), gravel (3–64 mm), cobble (65–250 mm), small boulder (251–2,000 mm), large boulder (2,001–4,000 mm), and mammoth boulder (>4,000 mm). Associated physical cover categories were algae, American water willow, other aquatic macrophytes, rock overhang, roots, terrestrial vegetation, and woody debris.

During August through September 2001, coinciding with the postspawning period during which we gathered fish microhabitat-use data, we also conducted microhabitat surveys at all sites to characterize available habitat. We used the transect and point-intercept method to quantify available microhabitat under typical base flow conditions (Simonson et al. 1994). At each site, we took 15 measurements of stream width to obtain a mean stream width (MSW), which we used to determine the appropriate length of the reach and distance between transects to be sampled (Simonson et al. 1994). The location of the first transect was selected randomly, and a minimum of 10 equally spaced transects were sampled within the reach. A minimum of 10 regularly spaced points were sampled along each transect; thus, at least 100 points were measured per reach. Data collected at points sampled along each transect included all variables quantified for fish microhabitat use.

During May–June 2002, coinciding with the spawning period during which we collected microhabitat-use data, we repeated microhabitat transect surveys at the three sites with extant Cape Fear shiner populations (sites 1, 2, and 5). In these surveys, data were collected for the same physical variables and following the same transect selection procedure as described previously in this section, but only five transects were sampled at each site. We justified measuring fewer transects by taking a stratified random subsample from the transects sampled in 2001 and testing for differences in the distribution of continuous habitat variables between the subsample and full sample using a Kolmogorov–Smirnov (K–S) two-sample test for depth, mean column velocity, and substrate, and a chi-square test on categorical cover data. All tests yielded P-values greater than 0.05.

Postspawning (summer–fall 2001) and spawning (spring 2002) seasonal microhabitat data were analyzed separately. We used principal component analysis (PCA) on habitat availability data for continuous variables (depth, mean column velocity, and substrate) to quantify habitat characteristics with fewer parameters. Categorical cover data were omitted from this analysis. A PCA was performed separately for habitat availability data by river and period (spawning, postspawning) for a total of four analyses. The PCA extracted linear combinations from a correlation matrix of the original untransformed variables that explained the maximum amount of variation in the data without axis rotation. Components with an eigenvalue greater than 0.90 were retained as a practical break point explaining over 70% of the variance in each data set examined (Stevens 2002; Kwak and Peterson 2007). Microhabitat-use component scores were then calculated from the scoring coefficients of the corresponding linear function generated by the habitat-available PCA, stratified by river and period. Comparing microhabitat-

TABLE 1.—Cape Fear shiner population density estimates and associated statistics from three reaches of the Rocky and Deep rivers during summer 2002. The data are means and measures of variance among 10 transects surveyed at each site. No Cape Fear shiners were detected at site 6 (Deep River).

Variable statistic	Site 1 (Rocky River)	Site 4 (Deep River)	Site 5 (Deep River)
Number observed			
Mean	19.2	6.4	10.1
SD	27.4	9.3	12.6
Range	0–82	0–26	0–32
Area surveyed (ha)			
Mean	0.0120	0.0084	0.0079
SD	0.0030	0.0025	0.0028
Range	0.0064–0.0162	0.0056–0.012	0.006–0.015
Mean stream width (m)	45	60	70
Density (fish/ha)			
Mean	1,393	795	1,056
95% confidence interval	97–2,690	0–1,773	179–1,933
Range	0–5,062	0–4,333	0–3,333
Density (fish/km)			
Mean	6,270	4,768	7,392
95% confidence interval	437–12,104	0–10,642	1,254–13,529
Range	0–22,778	0–26,000	0–23,333

use and availability component scores with a K–S two-sample test (Sokal and Rohlf 1981) tested for nonrandom habitat use. To further elucidate which variables were responsible for differences in microhabitat use and availability component scores, we performed K–S two-sample tests on univariate distributions of microhabitat use and availability for water depth, mean column velocity, and substrate composition. A chi-square test was performed on cover data to test for nonrandom cover use. All statistical analyses were performed using PC SAS version 8.1 (1999–2000).

Microhabitat suitability was quantified as microhabitat use divided by availability. This parameter expresses the relative importance of microhabitats based on the intensity of use relative to the amount available (Bovee 1986). Suitability was calculated for ranges or categories of each variable (depth, mean velocity, substrate composition, and cover), according to river (Rocky River sites combined). Results for each variable were standardized to a maximum of 1.0, with a value of 1.0 designating the most suitable range or categories, with suitability of other ranges or categories decreasing to zero. To determine overall microhabitat suitability for the species, suitability values for each range or category of a variable in the two rivers were summed, and those results were standardized to 1.0 again. This analysis was performed separately for data from each period (spawning, postspawning).

Results

Population Density

Cape Fear shiner population density estimates characterize three local populations where fish were numerous enough to estimate as locally abundant with widely varying densities among transects. Density was equivalently high at sites 1 and 5, somewhat lower at site 4, and no Cape Fear shiners were detected at site 6 (Table 1). Mean density during summer 2002 varied from 795 to 1,393 fish/ha and from 4,768 to 7,392 fish/km. Upper 95% confidence limits of density means averaged 2.0 times the mean, and maximum density estimates among transects averaged 4.1 times the mean. The mean number of fish observed per transect ranged from 6.4 to 19.2 fish, but the number observed within a single transect ranged up to 82 fish. Transect area means were equivalent at Deep River sites (0.0084 and 0.0079 ha) and larger at the Rocky River site (0.0120 ha), and stream width varied from 45 to 70 m.

Postspawning Habitat

Principal component analysis allowed descriptions of gradients among instream macrohabitats, from riffle to pool and from bank to thalweg. Available habitat in the Rocky River (sites 1 and 2, Figure 1) during the postspawning season (summer 2001) was described by gradients from riffle to pool (component 1) and from bank to thalweg (component 2; Table 2; Figure 2a). That structure was reversed for Deep River habitat with gradients from bank to thalweg in component 1 and from pool to riffle in component 2 (Table 2; Figure 2b). The first two principal components explained a combined 77% of the variance in the available habitat in the Rocky River and 73% of that in the Deep River (Table 2). Rocky River component 1 (riffle–pool) was interpreted as describing a gradient from riffle to pool because it was positively loaded on depth and substrate, and negatively loaded on velocity (Figure 2a). Pools in the Rocky River were deep, with lower

TABLE 2.—Component loadings (correlation coefficients) from the two retained principal components (PC) for Rocky and Deep river habitat measurements during Cape Fear shiner postspawning (summer 2001) and spawning (spring 2002) seasons.

	Postspawning				Spawning			
	Rocky River (N = 516)		Deep River (N = 118)		Rocky River (N = 161)		Deep River (N = 101)	
Variable and statistic	PC 1	PC 2	PC 1	PC 2	PC 1	PC 2	PC 1	PC 2
Depth	0.71	0.01	0.55	−0.65	0.73	0.04	0.58	0.58
Mean velocity	−0.25	0.94	0.67	−0.03	−0.56	0.59	−0.53	0.80
Substrate	0.66	0.33	0.50	0.76	0.38	0.80	0.62	0.13
Eigenvalue	1.32	1.00	1.23	0.96	1.12	1.02	1.30	0.90
Variance explained (%)	44	33	41	32	37	34	43	30

velocities and coarser substrate (i.e., boulder or bedrock) relative to riffles that were shallow with higher velocities and finer substrates (i.e., gravel or cobble). Component 2 (bank–thalweg) was interpreted as describing a gradient from near-bank to midchannel areas because it was positively loaded on substrate and mean velocity (Figure 2a). Near-bank areas in the Rocky River had fine substrates (i.e., silt and sand) and lower velocities compared with midchannel areas (thalweg) that had higher velocities and coarse substrates. Component 1 in the Deep River (bank–thalweg) was interpreted as describing areas from near-bank to the thalweg because it was positively loaded on depth, mean velocity, and substrate (Figure 2b). Bank areas in the Deep River have fine substrates (i.e., silt and sand) relative to the thalweg, which was deep with the highest velocities and coarse substrates (i.e., boulder or bedrock). The Deep River component 2 (pool–riffle) was interpreted as describing the gradient from pool to riffle because it was negatively loaded on depth and positively loaded on substrate (Figure 2b). Pools in the Deep River had finer substrates, such as silt and sand, compared with pools in the Rocky River, which had coarser substrates, and riffles in the Deep River had coarse substrates such as gravel, cobble, and boulders (Figure 2a, b).

Cape Fear shiner postspawning microhabitat use varied slightly between the two study rivers. Cape Fear shiners occupied microhabitats in both rivers during the postspawning season that were most often associated with riffle habitat (Figure 2a). They were most frequently associated with moderate depths (40–49 cm), water velocity breaks (i.e., areas of swift water adjacent to slow water), and cobble substrates, which are all characteristics associated with riffles (see Howard 2003 for frequency distributions of univariate microhabitat use and availability). Cape Fear shiners in both rivers were not associated with physical cover at a majority of locations, but when they associated with cover, it was most commonly emersed stands of American water willow.

Comparisons of Cape Fear shiner microhabitat use to that available generally indicated nonrandom habitat selection during the postspawning season. Two-sample K–S comparisons between PCA scores of microhabitat availability and Cape Fear shiner microhabitat use in the Rocky River indicate that Cape Fear shiners occupied microhabitats in a nonrandom manner with respect to component 1 (riffle–pool) ($P = 0.003$; Table 3). In contrast, distributions of component 2 (bank–thalweg) scores of microhabitat availability and use were not significantly different ($P = 0.65$; Table 3), indicating random habitat use with respect to near-bank or midchannel attributes of the Rocky River. Their habitat use with respect to riffle–pool and bank–thalweg gradients in the Deep River was nonrandom as indicated by distributions of component 1 ($P = 0.033$) and component 2 ($P = 0.022$) scores for microhabitat use and availability (Table 3).

The nonrandom habitat use revealed by multivariate comparisons was confirmed by univariate comparisons. Univariate frequency distributions of postspawning microhabitat use were significantly different than those corresponding distributions of microhabitat availability for all four variables in the Rocky River (depth, velocity, substrate, and cover; $P < 0.05$; Table 3). Mean depth varied moderately between those for Rocky River fish habitat use and availability (37.5 versus 43.0 cm; Table 4), as did means of use and availability for mean velocity (0.037 versus 0.031 m/s). In the Deep River, frequency distributions of microhabitat use and availability for depth and cover were also significantly different (Table 3), and the use and availability means for depth differed moderately (41.2 versus 35.3 cm; Table 4), similar to those in the Rocky River. However, mean velocity distributions were not significantly different in the Deep River ($P = 0.25$; Table 3) even though a substantial difference in mean values occurred (0.048 versus 0.106 m/s; Table 4), and the comparison for substrate composition was only marginally significant ($P = 0.065$; Table 3), suggesting that Cape Fear shiners occupied microhabitats ran-

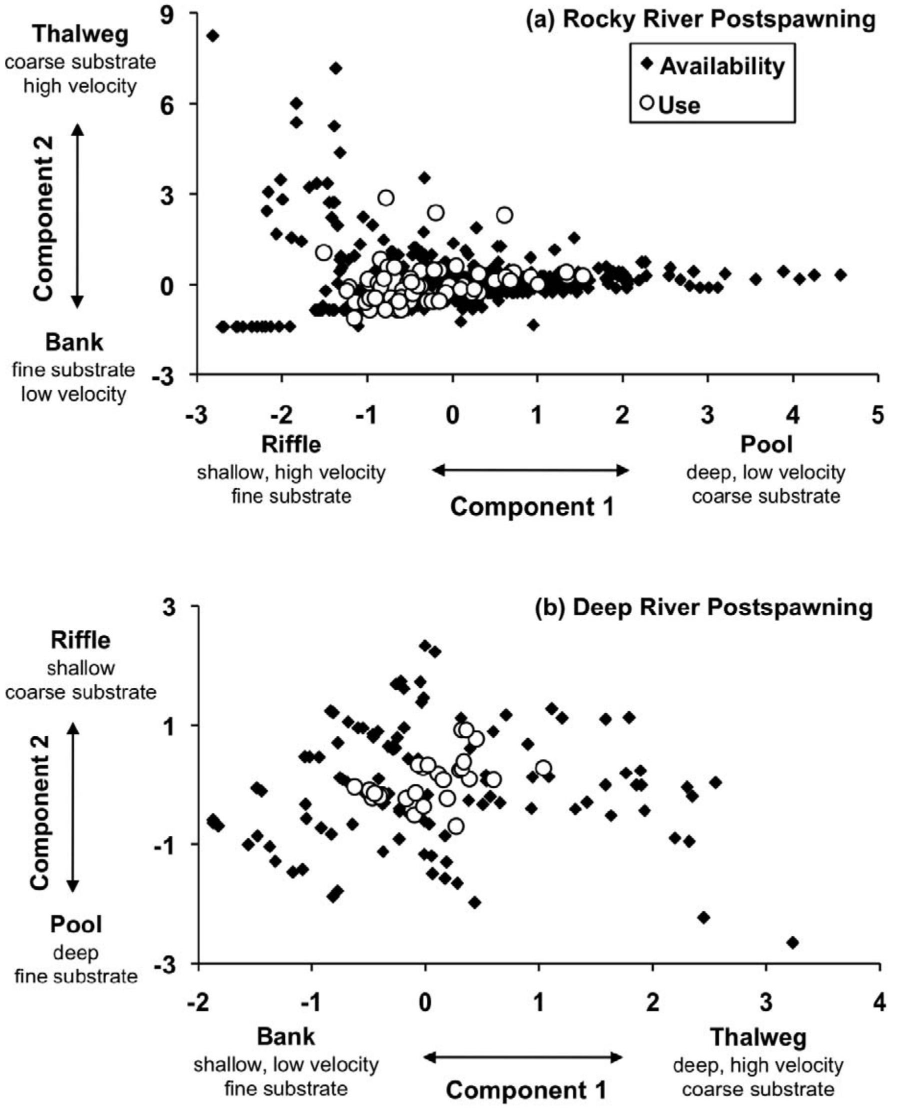

FIGURE 2.—Plots of Cape Fear shiner microhabitat use and habitat availability component scores in **(a)** the Rocky River and **(b)** the Deep River during postspawning (summer 2001). The principal component loadings and sample sizes are given in Table 2 and statistical comparisons in Table 3.

domly with respect to velocity and substrate in the Deep River.

Cape Fear shiners occupied similar focal depths and focal velocities in the Rocky and Deep rivers during the postspawning season. In the Rocky River, mean focal depth was 11.9 cm, and mean focal velocity was 0.026 m/s (Table 4). Mean focal depth in the Deep River was 10.4 cm and mean focal velocity was 0.022 m/s (Table 4). Cape Fear shiners were most frequently located at focal depths of 10–15 cm and focal velocities of 0–0.02 m/s in both rivers (Figure 3). Mean focal depth in both rivers was one-third or less than mean total depth, as expected for an epibenthic species. Mean focal velocities were lower than mean column velocities of Cape Fear shiner locations in both rivers (Table 4).

Cape Fear shiners were more frequently located farther from cover in the Deep River than in the Rocky

TABLE 3.—Statistical comparisons of Cape Fear shiner microhabitat use and availability for continuous (Kolmogorov–Smirnov two-sample (D) test; all variables except cover) and categorical (chi-square test; cover) variables in the Rocky and Deep rivers during the postspawning (summer 2001) and spawning (spring 2002) seasons. Sample sizes are given in Table 2.

	Postspawning		Spawning	
River and variable	Statistic	*P*	Statistic	*P*
Rocky River				
Component 1 scores	0.230	0.003	0.509	0.0001
Component 2 scores	0.094	0.65	0.339	0.0012
Depth	0.296	0.0001	0.298	0.0068
Mean velocity	0.244	0.0013	0.396	0.0001
Substrate	0.217	0.0062	0.383	0.0002
Cover	48.127	0.0001	24.374	0.0002
Deep River				
Component 1 scores	0.297	0.033	0.528	0.0001
Component 2 scores	0.312	0.022	0.248	0.16
Depth	0.509	0.0001	0.308	0.0395
Mean velocity	0.211	0.2527	0.349	0.0131
Substrate	0.271	0.0652	0.481	0.0001
Cover	20.619	0.001	12.492	0.0286

River during the postspawning season. Cape Fear shiners were located within 25 cm of cover at 70% of locations in the Rocky River (Figure 4a). In contrast, only 24% of locations in the Deep River during the postspawning season were within 25 cm of cover, and 66% of locations were greater than 50 cm from cover (Figure 4b). Cover was available in the Rocky and Deep rivers at 45% and 52% of the points surveyed, respectively, with similar proportions of available American water willow in both rivers.

Cape Fear shiners disproportionately occupied certain microhabitats relative to their availability (nonrandom or selective habitat use) during the postspawning season, resulting in identification of most suitable microhabitats that differed in some characteristics from those most frequently occupied by the fish. The most suitable microhabitats had similar depth, higher mean velocity, similar substrate, and a greater cover association with the aquatic macrophyte American water willow than those most frequently occupied (Figure 5a–d). The most suitable postspawning Cape Fear shiner habitat, based on relative proportions of microhabitat use and availability from both rivers (three sites total) was 40–49 cm deep, with mean water velocity of 0.16–0.19 m/s, over gravel substrate, and associated with beds of American water willow (Figure 5a–d).

Microhabitat Comparison among Sites

Comparisons of mean values of physical variables describing use and availability among river reaches during the postspawning season where the Cape Fear shiner was extant, rare, or extirpated revealed shallower mean water depths at rare or extirpated sites, relative to those extant, and mean velocities that were similar among sites. Mean depth of the reach sampled in the

TABLE 4.—Cape Fear shiner microhabitat use and availability statistics for reaches of the Rocky and Deep rivers during the postspawning season (summer 2001).

Variable	*N*	Mean	SE	Range
Rocky River				
Microhabitat use[a]				
Depth (cm)	70	37.5	1.07	10–51
Mean velocity (m/s)	70	0.037	0.006	0–0.25
Focal depth (cm)	70	11.9	1.0	1–30
Focal velocity (m/s)	70	0.026	0.007	1–0.26
Microhabitat availability (extant sites)[a]				
Depth (cm)	516	43.0	1.51	1–225
Mean velocity (m/s)	516	0.031	0.003	0–0.70
Microhabitat availability (extirpated site)				
Depth (cm)	285	27.0	1.14	1–91
Mean velocity (m/s)	285	0.034	0.005	0–0.550
Deep River				
Microhabitat use				
Depth (cm)	29	41.2	1.07	32–57
Mean velocity (m/s)	29	0.048	0.011	0–0.26
Focal depth (cm)	29	10.4	1.34	1–25
Focal velocity (m/s)	29	0.022	0.006	0–0.12
Microhabitat availability (extant site)				
Depth (cm)	118	35.3	2.31	2–139
Mean velocity (m/s)	118	0.106	0.015	0–0.720
Microhabitat availability (rare site)				
Depth (cm)	169	27.5	1.32	2–86
Mean velocity (m/s)	169	0.068	0.010	0–0.850

[a] Two sites.

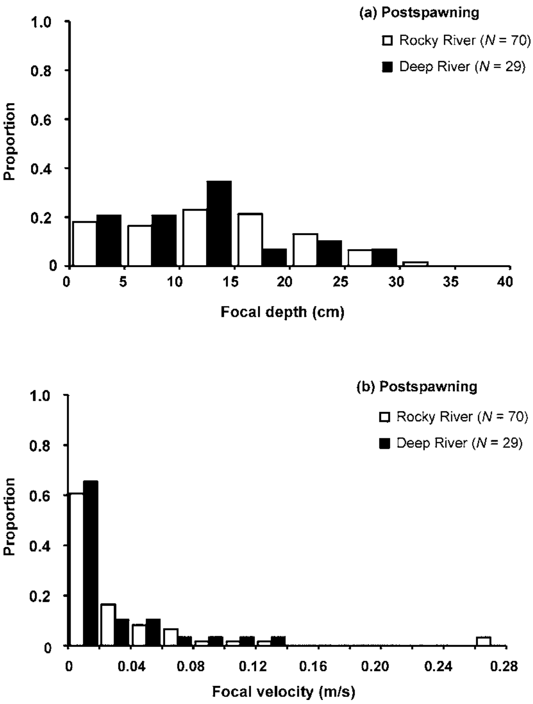

FIGURE 3.—Frequency distributions of **(a)** focal depth and **(b)** focal velocity for Cape Fear shiner microhabitats in the Rocky and Deep rivers during postspawning (summer 2001).

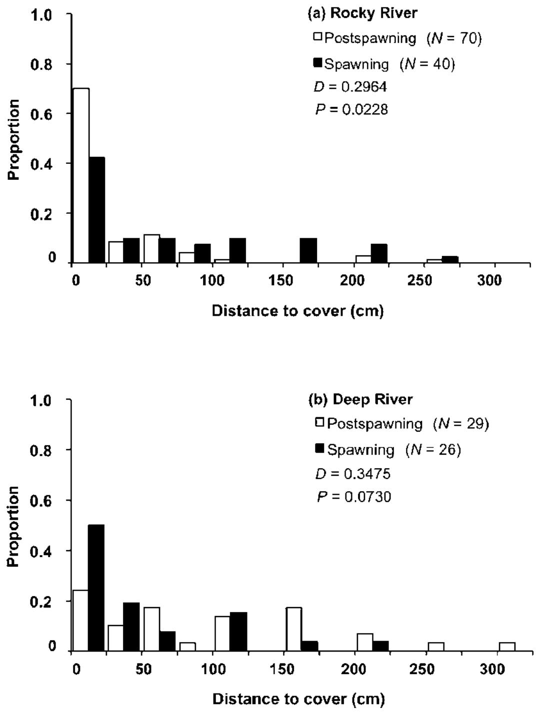

FIGURE 4.—Frequency distributions of Cape Fear shiner distance to cover in the **(a)** Rocky River and **(b)** Deep River during the postspawning (summer 2001) and spawning (spring 2002) seasons. The distributions were tested with Kolmogorov–Smirnov two-sample tests (D).

Rocky River where the Cape Fear shiner has been extirpated (site 3) was 16 cm (37%) lower than that of two reaches where the Cape Fear shiner is extant (sites 1 and 2) and 10.5 cm (28%) lower than mean depth of microhabitats occupied by the fish in that river (Table 4). The same trend occurred in the Deep River where the mean depth of a reach where the Cape Fear shiner is extant, but rare (site 6), was 7.8 cm (22%) shallower than that of a site where the fish is extant and common (site 5) and 13.7 cm (33%) shallower than occupied microhabitats in that river (Table 4). Mean depths of extirpated and rare sites on these rivers were below the most suitable range for Cape Fear shiners (40–49 cm), as was the mean depth at the Deep River extant site; however, mean depth of Rocky River extant sites fell within the suitable range of depths (Table 4; Figure 5a). Mean velocities of reaches in the Rocky River where the Cape Fear shiner is extant and extirpated were both similar to that of microhabitats occupied by the fish, and while mean velocity of the Deep River reach where the fish is rare was lower than that of the extant reach, both were greater than that of occupied microhabitats (Table 4).

Comparing proportions of suitable postspawning microhabitat availability among river reaches where the Cape Fear shiner is extant, rare, or extirpated suggests that habitat similar to extant sites is available at rare or extirpated sites in both rivers, with the exception of a lack of suitable substrate at the rare site in the Deep River. In the Rocky River, the site where the fish is extirpated contained proportions of suitable microhabitats for depth (40–49 cm, 11.2% versus 12.4%), mean velocity (0.16–0.19 m/s, 0.7% versus 0.8%), substrate (gravel, 14.4% versus 11.6%), and cover (American water willow, 23.9% versus 13.2%) that were equivalent or exceeded those proportions of extant sites (Table 5). Similarly at Deep River sites, the proportion of suitable depth (40–49 cm, 17.8% versus 13.6%), mean velocity (0.16–0.19 m/s, 4.1% versus 1.7%), and cover (American water willow, 17.2% versus 9.3%) at the rare site exceeded those corresponding proportions at the extant site. Conversely, there was a much lower percentage of suitable substrate (gravel, 4.7% versus 26.3%) at the rare site versus the extant site of the Deep River (Table 5). The low proportion of gravel substrate available at the Deep River site where the Cape Fear shiner is rare (site 6) is not likely due to embeddedness

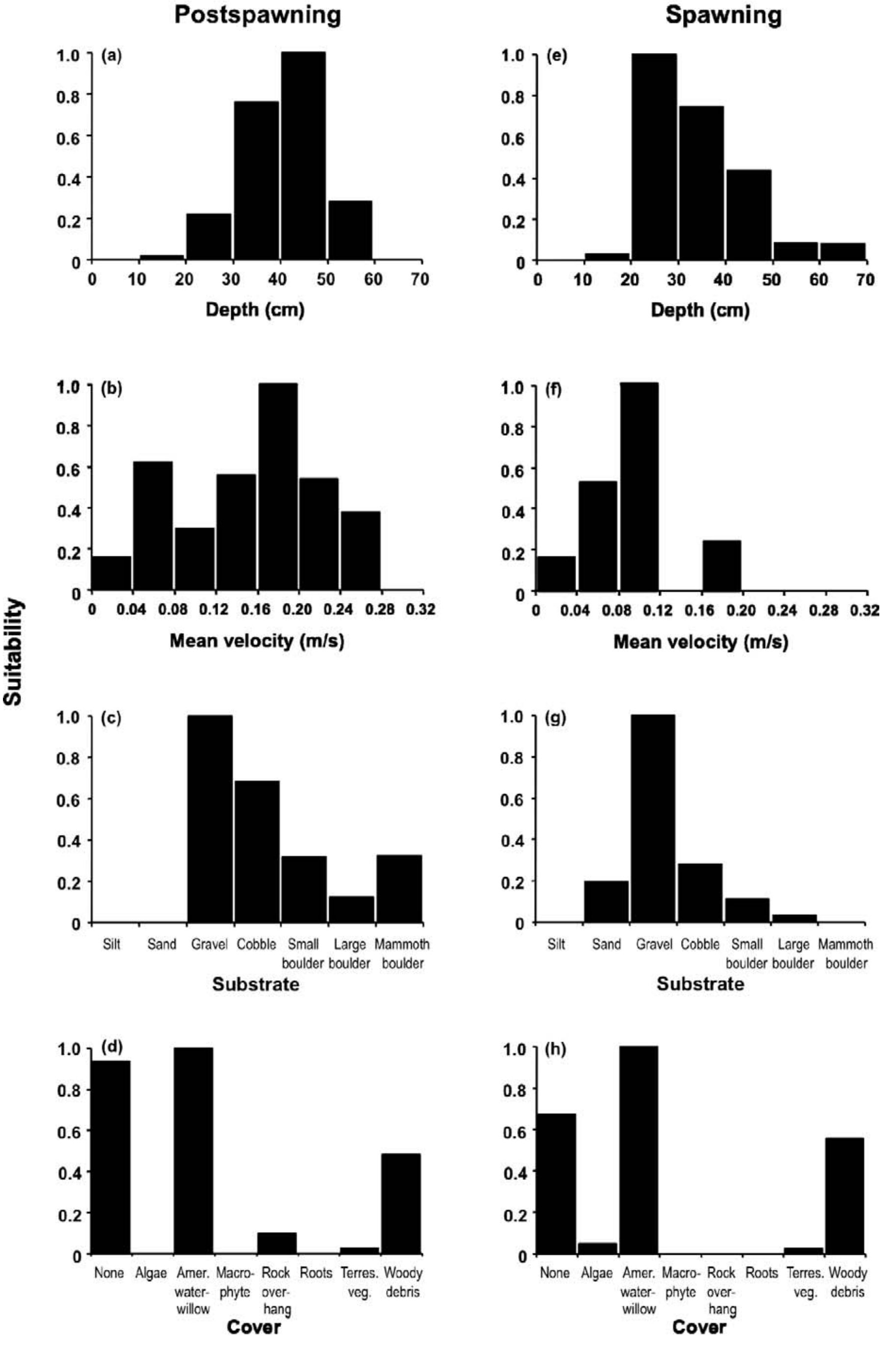

FIGURE 5.—Microhabitat suitability distributions for Cape Fear shiners based on combined data from the Rocky and Deep rivers during the **(a–d)** postspawning (summer 2001) and **(e–h)** spawning (spring 2002) seasons.

by fine sediments (i.e., silt and sand), as only 5% of the substrate at the rare site was composed of fine sediment, while 32% of the substrate at the extant site (site 5) was fine particles.

Suitable microhabitats comprised 26.3% or less of the total available habitat for all postspawning variables examined, and suitable velocities were available at no more than 1.7% of any extant site, which suggests that

TABLE 5.—Comparison of suitable microhabitat availability for the Cape Fear shiner among sites of the Rocky and Deep rivers during summer 2001, where the species is extant, rare, or extirpated. Percentages pertain to the area of habitat within the suitable range or category.

		Rocky River		Deep River	
Variable	Suitable category	Sites 1 and 2 (Extant)	Site 3 (Extirpated)	Site 5 (Extant)	Site 6 (Rare)
Depth	40–49 cm	12.4%	11.2%	13.6%	17.8%
Mean velocity	0.16–0.19 m/s	0.8%	0.7%	1.7%	4.1%
Substrate	Gravel	11.6%	14.4%	26.3%	4.7%
Cover	American water willow	13.2%	23.9%	9.3%	17.2%

suitable Cape Fear shiner habitat may be scarce, even at sites where the fish is common. The proportion of suitable microhabitat among extant or rare sites ranged from 0.8% for suitable mean velocity at the extant site of the Rocky River to 26.3% for suitable substrate at the extant site on the Deep River (Table 5).

Spawning Habitat

Available habitat in both rivers during the spawning season (spring 2002) was described by gradients from riffle to pool (component 1) and from bank to thalweg (component 2) with varying component structures between the rivers (Table 2; Figure 6). Two principal components explained a combined 71% of the variance in Rocky River data and 73% of that in the Deep River (Table 2). The interpretation of the axes from the PCA on available habitat from the Rocky River during summer 2001 and spring 2002 are identical (see previous section on postspawning habitat). The Deep River component 1 (riffle–pool) was interpreted as describing the gradient from riffle to pool because it was positively loaded on depth and substrate, and negatively loaded on mean velocity (Figure 6b). Pools in the Deep River were deep with coarse substrate and slower velocities. Deep River component 2 (bank–thalweg) described a gradient between near-bank areas and the thalweg, as it was positively loaded on substrate and mean velocity (Figure 6b). Near-bank areas in the Deep River had fine substrates (i.e., silt and sand), whereas the thalweg had higher velocities and coarser substrates.

Cape Fear shiners occupied similar microhabitats during the spawning season (spring 2002) between rivers that were shallower, but similar to postspawning microhabitats. During the spawning season, they occupied microhabitats in the Rocky River that were associated with riffle habitat (Figure 6a). Cape Fear shiners in the Rocky River were most frequently associated with shallower depths during the spawning season (20–29 versus 40–49 cm), but the distributions of available depths during the postspawning and spawning seasons were not significantly different ($P > 0.72$) in a K–S two-sample test. In the Deep River during the spawning season, Cape Fear shiners were most frequently associated with shallower depths (30–39 cm versus 40–49 cm) than during the postspawning season, and the distributions of available depth during the postspawning and spawning seasons were not significantly different ($P > 0.20$). However, Cape Fear shiners in both rivers during the spawning season were similarly associated with low velocities (0–0.03 m/s), velocity breaks, and gravel substrate, and when cover was used, American water willow was most frequently used. With the exception of mean velocity, all most-frequently used categories are characteristics of riffles, as found during the postspawning season. Higher velocities were rare in both rivers during the spring (Tables 4, 6), due to drought conditions that may have influenced habitat availability.

Cape Fear shiner microhabitats that were occupied, compared with those available, generally indicated a nonrandom habitat selection during the spawning season, similar to those findings for postspawning. Two-sample K–S comparisons between Rocky River microhabitat use and availability scores for principal component (PC) 1 and PC 2 were both significantly different ($P = 0.0001$ and $P = 0.0012$, respectively; Table 3). Deep River distributions of component 1 scores for microhabitat use and availability were significantly different ($P < 0.0001$), but those of component 2 scores were not significantly different ($P = 0.16$). These results indicate that Cape Fear shiners typically occupied microhabitats nonrandomly or selectively. Faster velocities were in short supply (Table 6; Figure 6), and Cape Fear shiner microhabitat use scores are clustered toward the riffle end of the component-1 axis in both rivers. Deeper water was available with coarse substrates (i.e., boulders), but Cape Fear shiners appeared to select microhabitats with substrates smaller than boulders (i.e., gravel and cobble) with shallower depth in or near moderate velocities (i.e., velocity breaks). Cape Fear shiners occupied microhabitats that were relatively shallow with higher velocities than those habitats available, and

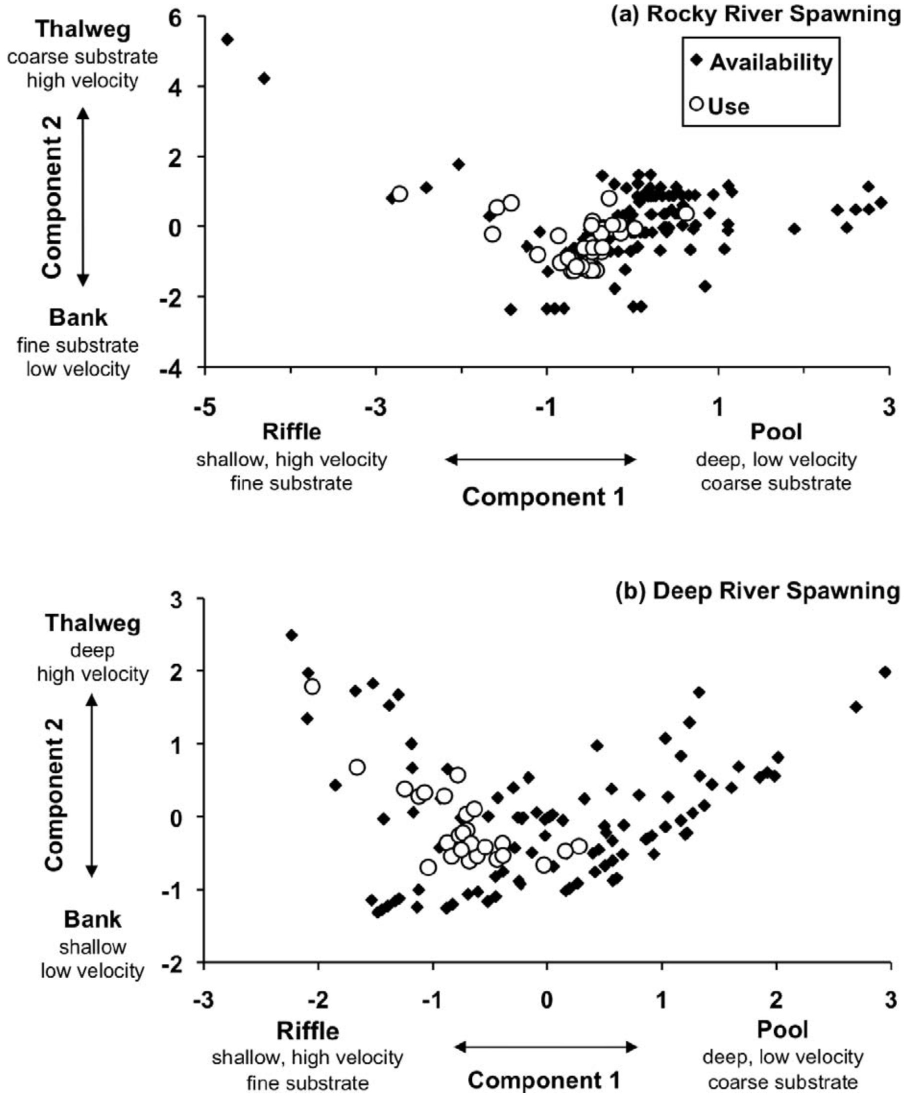

FIGURE 6.—Cape Fear shiner microhabitat use and habitat availability component scores in **(a)** the Rocky River and **(b)** the Deep River during spawning (spring 2002). The principal component loadings and sample sizes are given in Table 2, statistical comparisons in Table 3.

this result is consistent for all principal component analyses (Figures 2, 6).

Univariate comparisons of microhabitat use and available frequency distributions were significantly different for all four variables in both rivers ($P <$ 0.05; Table 3), confirming nonrandom habitat use during the spawning season. In both rivers, mean values of depth varied substantially between those for microhabitat use and availability (32.5 versus 47.7 cm in Rocky River and 34.6 versus 43.9 cm in Deep River; Table 6), as did mean values for velocity that were higher in the Deep River (0.026 versus 0.016 m/s in Rocky River and 0.035 versus 0.046 m/s in Deep River). Gravel was the most frequently encountered substrate at Cape Fear shiner locations in both rivers. In both rivers, Cape Fear shiners occupied similar microhabitats during the spawning season relative to those during the postspawning season, with the exception that depths in the spawning season were shallower.

Cape Fear shiners occupied similar focal depths in both rivers during the spawning season, but mean focal velocity occupied was greater in the Deep River. Mean focal depth of Cape Fear shiners in the Rocky River

TABLE 6.—Cape Fear shiner microhabitat use and availability statistics for reaches of the Rocky and Deep rivers during the spawning season (spring 2002).

Variable	N	Mean	SE	Range
Rocky River				
Microhabiat use[a]				
Depth (cm)	40	32.5	1.47	12–60
Mean velocity (m/s)	40	0.026	0.006	0–0.19
Focal depth (cm)	40	13.0	0.90	3–25
Focal velocity (m/s)	40	0.016	0.003	0–0.07
Microhabitat availability (extant sites)[a]				
Depth (cm)	161	47.7	3.77	2–250
Mean velocity (m/s)	161	0.016	0.004	0–0.43
Deep River				
Microhabitat use				
Depth (cm)	26	34.6	1.27	23–50
Mean velocity (m/s)	26	0.046	0.008	0–0.19
Focal depth (cm)	26	13.4	1.01	5–25
Focal velocity (m/s)	26	0.035	0.007	0–0.14
Microhabitat availability (extant site)				
Depth (cm)	101	43.9	3.37	3–165
Mean velocity (m/s)	101	0.035	0.006	0–0.35

[a] Two sites.

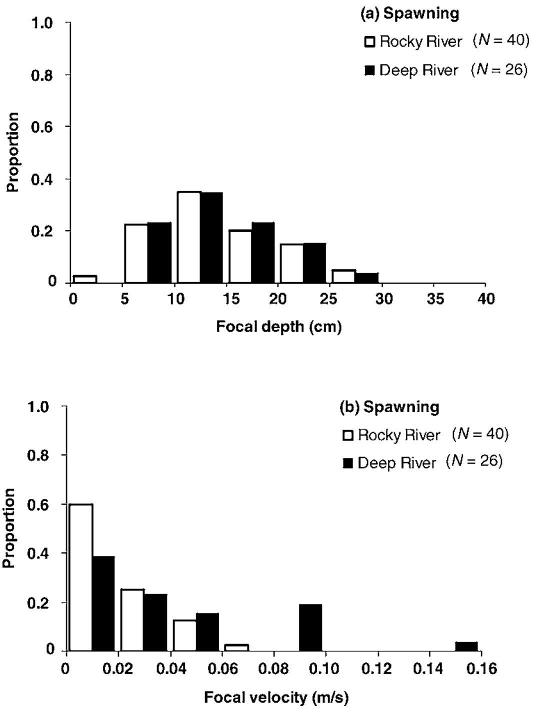

FIGURE 7.—Frequency distributions of **(a)** focal depth and **(b)** focal velocity for Cape Fear shiner microhabitats in the Rocky and Deep rivers during spawning (spring 2002).

was 13.0 cm and was 13.4 cm in the Deep River (Table 6). Mean focal velocity in the Rocky River was 0.016 m/s and in the Deep River was 0.035 m/s. Cape Fear shiners most frequently occupied focal depths of 10–15 cm and focal velocities of 0–0.02 m/s in both rivers during the spawning season (Figure 7), which was the same result as during the postspawning season. Mean focal depths occupied in both rivers during the spawning season were slightly greater than those occupied during postspawning; however, mean focal velocity in the Deep River during the spawning season was slightly greater than that during the postspawning season (Tables 4, 6). Mean focal velocity in the Rocky River during the spawning season was slightly less than that occupied during the postspawning season.

Cape Fear shiners were found near cover more frequently in the Deep River than in the Rocky River during the spawning season, and they were most frequently found within 25 cm of cover in both rivers during both seasons (Figure 4). Cape Fear shiners associated with American water willow in greater frequency than the plant's availability, and it was the most common cover structure available in both rivers. As noted for cover association during the postspawning season, Cape Fear shiners closely associated with characteristics of habitat that also support stands of American water willow, and while these areas of vegetation may provide optimal habitat, it appears that with the appropriate combination of depth, velocity, and substrate, Cape Fear shiners may occupy microhabitats without cover. This is supported by the occurrence of fish as far away as 275 cm from a cover object (Figure 4a).

The Cape Fear shiner's distance to cover varied between rivers and between seasons. They occupied microhabitats closer to cover objects during the postspawning season than during the spawning season in the Rocky River (Figure 4a). The frequency distributions of distance to cover in the Rocky River between seasons were significantly different (P = 0.0228; Figure 4a). The opposite result was found in the Deep River, where Cape Fear shiners were more closely associated with cover objects during the spawning season than during the postspawning season (Figure 4b). However, the frequency distributions of distance to cover in the Deep River between seasons were marginally different with regard to significance (P = 0.0730), suggesting that the association with cover was similar between seasons.

The most suitable microhabitats based on relative proportions of microhabitat use and availability during the spawning season differed in some characteristics from those during the postspawning season. The most suitable microhabitats during the spawning season had shallower depth, higher mean velocity, similar substrate, and a similar association with American water willow than those most frequently occupied during that season (Figure 5e–h). Thus, the most suitable Cape Fear shiner habitat during the spawning season from both rivers (three sites total) was 20–29 cm deep with mean velocity of 0.08–0.11 m/s, over gravel substrate, and associated with beds of American water willow (Figure 5e–h). Suitable depth was shallower during the spawning season, relative to the postspawning season (20–29 versus 40–49 cm), and suitable velocity was slower during the spawning season (0.16–0.19 versus 0.08–0.11 m/s; Figure 5).

Microhabitat Summary

Cape Fear shiners occupied riffle-type habitat, as interpreted from the PCA, and occupied microhabitats selectively during spawning and postspawning seasons. Microhabitat use was similar between rivers during both seasons, and differed between seasons with respect to depth and mean velocity occupied. Cape Fear shiners occupied microhabitats with shallower depths and slower velocity in both rivers during the spawning season, relative to those in the postspawning season. Cape Fear shiners were not associated with cover at the majority of locations, but when associated with cover, it was most frequently American water willow. Among seasons and rivers, the Cape Fear shiner was most closely associated with American water willow during the postspawning season in the Rocky River; however, a closer association with cover, relative to the postspawning season, was only marginally significant during the spawning season in the Deep River. Among-site microhabitat comparisons revealed that suitable substrate is lacking at a site where the fish is rare, and that suitable microhabitat combinations, especially for water velocity, are rare at all sites.

Discussion

We estimated Cape Fear shiner population density and quantified its microhabitat use, availability, and suitability at sites where the fish is extant and applied these results to assess habitat quality at sites where the species is rare or extirpated. Our results represent the first quantitative descriptions of the fish's density and habitat and have direct implications for understanding the ecology and guiding management of the species.

Population Density

We found the strip-transect method (Buckland et al. 2001) to be an effective approach to estimate the population density of the Cape Fear shiner. While success in applying this method to benthic fish species, such as darters (Percidae), has been limited (Ensign et al. 1995), most cyprinids, like the Cape Fear shiner, are considered water-column-dwelling species, and are good candidates for use of this method. Comparisons of underwater observation and more typical parameter-estimating methods (i.e., removal or mark–recapture) have shown that underwater observations estimate abundance as well or better than the traditional methods for some species (Hankin and Reeves 1988). We employed the strip-transect method rather than distance sampling, which can estimate the number of undetected individuals (Buckland et al. 2001), because visibility was relatively low in our study rivers. We surveyed narrow transects to maximize the likelihood of detecting all or most Cape Fear shiners within a strip transect. However, our density estimates should be considered as minima, as some undetected individuals are a possibility. Further, we randomly selected strip transects within a larger river reach that included riffle, pool, and run macrohabitats, rather than using a representative-reach approach, which can give highly biased and misleading estimates of fish density (Hankin and Reeves 1988).

Our strip-transect sampling results suggest some conclusions about the distribution of Cape Fear shiners. First, we surveyed the upper Deep River thoroughly at two sites where the Cape Fear shiner was previously collected, and it was either not detected (at site 6) or only two individuals were observed (at State Route 1456; Howard 2003) after a large area was searched. This species is relatively abundant at the three other extant sites where we estimated density (sites 1, 4, and 5), and it appears that there is a discrepancy between the density in the upstream reaches of the Deep River compared with those reaches downstream in the Deep River and the lower Rocky River. Second, Cape Fear shiners are clumped in distribution and can be found in large groups (up to 82 individuals observed; Table 1) within limited sampling areas. A clumped distribution that varies greatly depending on available habitat makes extrapolation of densities to larger reaches of river problematic. Finally, a review of the literature revealed that Cape Fear shiner population density in the Rocky and Deep rivers is moderate to high when compared with the density of other minnows in the genera *Notropis*, *Cyprinella*, *Luxilus*, and *Lythrurus* in warmwater streams of the United States (Lotrich 1973; Vadas and Orth 1993; Vadas 1994; Rambo 1998; Radwell 2000). This confirms that Cape Fear shiners may be locally abundant in remaining suitable habitats, but are geographically restricted with respect to the overall area occupied by the species.

Microhabitat Suitability

Our multivariate analyses on microhabitat use and availability indicate that Cape Fear shiners were associated with riffle habitat in the majority of observations and occupy microhabitats selectively. Our univariate microhabitat results are useful in understanding dynamics of specific variables of Cape Fear shiner habitat and for serving as microhabitat suitability criteria for instream flow models to support flow regulation decisions (Annear et al. 2004). In general, univariate analyses of microhabitat variables (depth, mean velocity, substrate, and cover) were significantly different for use and availability in both rivers and both seasons, with the exception of the Deep River during the postspawning season. Depth, velocity, and substrate composition are highly correlated variables in rivers; therefore, it is not unusual that all three paired distributions for use and availability would be different in comparisons between use and availability when a species shows a high degree of habitat specificity. If the Cape Fear shiner selects microhabitats based on one particular variable, such as substrate, it follows that the depth and mean velocity associated with substrate will be related for most observations. Other studies have shown strong interactions between depth, velocity, and substrate for riffle–run guilds of fishes, making it difficult to discern whether the fishes are selective for a specific variable (Vadas and Orth 2001). Cape Fear shiners show clear habitat specificity on a broad scale (i.e., lentic versus lotic habitats), and on a finer scale within the riffle–pool sequence by being selective for specific combinations of depth, velocity, and substrate.

Microhabitat characteristics most suitable for the Cape Fear shiner were waters of moderate depth and velocity over gravel substrate associated with American water willow, which are general characteristics of riffles in this system. Suitable categories of depth and velocity during the spawning season were shallower and slower, compared with those characteristics postspawning (Figure 5). This may be partially explained by including microhabitat measurements during the spawning season that were not directly related to spawning behaviors. Cape Fear shiners may occupy deeper water when not directly engaged in reproductive behavior. Distributions of available depth were not significantly different in comparisons between seasons for each river, indicating a real shift in Cape Fear shiner habitat suitability (shallower depths) during the spawning season.

Cape Fear shiners were not observed directly in cover at a majority of the microhabitat locations in either river or season; however, they were usually observed within 50 cm of cover (i.e., American water willow), especially during the spawning season, and this may be owing to the similarity between areas of habitat where American water willow occurs and the optimal habitat of this fish, rather than a direct dependence on the plant. Others have suggested that American water willow is essential spawning habitat for the Cape Fear shiner (NCWRC 1995). Yet in captivity, Cape Fear shiners have spawned in tanks with artificial cover (cotton mops) and gravel substrate or in tanks with no physical structure (J. Groves, North Carolina Zoological Park, Asheboro, North Carolina, personal communication; P. Rakes, Conservation Fisheries, Inc., Knoxville, Tennessee, personal communication). While American water willow (or other available cover) may not be a requirement for successful spawning, the presence of this plant in the field may serve other important functions beneficial to the Cape Fear shiner (e.g., velocity or predator refuge for eggs or other life stages).

Results of our habitat availability analysis among extant, rare, and extirpated Cape Fear shiner sites support a number of ecological conclusions. First, not one of these microhabitat suitability criteria was abundant within river reaches, and the specific combination of these four factors that would constitute optimal Cape Fear shiner habitat was rare. In particular, during the postspawning season, the most suitable range of mean water velocity was extremely rare, occurring in only 0.8% of the area of extant sites on the Rocky River and 1.7% of the extant Deep River site (Table 5). Cape Fear shiners were associated with velocity breaks, where swift water joins slow water, which may partially explain the bimodal distribution of mean velocity suitability during the postspawning season (Figure 5b). Comparisons of the availability during summer 2001 of suitable depth among sites where the Cape Fear shiner is extant and where it is rare or extirpated revealed that similar proportions of suitable depths were available, but mean depth was shallower in reaches where the species is rare or extirpated (Tables 4, 5). The reduced mean depth may be ecologically relevant to this species, as depth has been considered the most important factor in stream fish habitat selection (Vadas and Orth 2001). Our comparisons between habitats where the Cape Fear shiner is rare and extant in the Deep River suggest that the scarcity of suitable substrate in the upper Deep River, which is important for feeding and spawning habitat functions, may have contributed to localized decimation of the species and could limit its ecological success where it is extant.

Ecological and Management Implications

Our findings, related to habitat suitability and availability, have implications related to human uses and alterations of the upper Cape Fear River basin. Lower mean water depth at sites where the Cape Fear shiner is rare or extirpated and an extreme scarcity of suitable water velocity at all sites may be related to the presence and operation of dams, changes in hydrology, and changes associated with riparian and watershed land use. The construction of small dams and impoundments on rivers and streams has been hypothesized as the reason for decline of other *Notropis* species. Schrank et al. (2001) found that the number of small impoundments within a watershed was an important factor in the extirpation of the Topeka shiner *N. topeka* in much of its range. Other studies have found that damming has led to the extirpation of obligate riverine cyprinids above dams (Winston et al. 1991) and reduced species richness and diversity below impoundments (Quinn and Kwak 2003). Dams alter the flow of rivers and fragment species' home ranges, impoundments can act as a source of predators, and both can prevent dispersal of individuals, causing local extirpations (Winston et al. 1991; Schrank et al. 2001). Cape Fear shiners are not found in impounded river reaches upstream from dams in the upper Cape Fear River system (T. Kwak, unpublished data), further restricting fish movement between fragmented local populations. These aspects should be carefully considered in efforts to facilitate survival of the Cape Fear shiner and before further alteration of the river takes place or restoration or reintroduction is considered at extirpated locations.

Sedimentation is the greatest source of pollution in the Cape Fear drainage (NCDWQ 2000) and can greatly affect fishes that use benthic resources. Burkhead and Jelks (2001) found that a benthic-spawning *Cyprinella* species reduced its reproductive output with increasing concentrations of suspended sediment in laboratory experiments. Cape Fear shiners probably deposit their eggs in sand and gravel (Pottern and Huish 1985), and may be affected by sediment directly (i.e., reduced egg or juvenile survival) or behaviorally affected by the presence of excessive sedimentation. Both effects are sublethal to adults, but can affect overall population stability and longevity (Burkhead and Jelks 2001).

Considering the two potential Cape Fear shiner reintroduction sites we studied (sites 3 and 6), the Rocky River site (site 3) where the fish has been extirpated contains more suitable physical habitat (Tables 4, 5). This conclusion is primarily based on substrate availability, as this river reach contains a relative abundance of gravel substrate similar to the two sites on that river where the fish is extant. The site on the Deep River where the species persists but is rare (site 6) is also a candidate reach for habitat restoration toward increasing mean water depth and substrate alteration to improve conditions for Cape Fear shiner population growth. Excessive sedimentation is a common detriment to habitat quality and ecological function of many river systems (Waters 1995), and such is the case for the Cape Fear River system (NCDWQ 2000), but dams also act as sediment traps, and may deprive downstream reaches of transported sediment and organic matter (Gordon et al. 1992). Site 6 is located proximately downstream from Coleridge Dam, which may explain the lack of fine sediments (5% by area) and gravel (5%) at that site. The lack of gravel substrate, as well as the lack of suitable depths, are probably related to the presence and operation of the dam and may be addressed to improve habitat suitability for the Cape Fear shiner.

It is critical that both adequate water quality and suitable instream habitat be considered in maintenance and recovery of the Cape Fear shiner throughout its range (Hewitt et al. 2006). Such approaches that integrate knowledge among scientific disciplines (e.g., conservation and toxicology) are needed to facilitate long-term viability of ecosystems (Hansen and Johnson 1999). Our results and interpretation presented here on physical habitat suitability must be considered along with those from Hewitt et al. (2006) on water quality and contaminants for recovery of the Cape Fear shiner. For example, except for reduced mean depth at site 3, management agencies might proceed with an experimental reintroduction of the species, as this site contained all components of suitable instream physical habitat; however, survival of Cape Fear shiners in exposures of caged fish in situ by Hewitt et al. (2006) was significantly reduced at that site (53%), and contaminants accumulated in surviving fish indicated a water quality problem exists there. Thus, until water quality and hydrology are improved, this site remains unsuitable for potential reintroduction of the Cape Fear shiner.

Biotic interactions cannot be ignored in restoration planning for the Cape Fear shiner. Exotic and introduced species have been cited as a major factor in the decline of native fishes, and it has been listed it as the second most common factor, following habitat alteration and preceding pollution (Lassuy 1995). Although the presence of introduced species was not a factor in the federal endangered listing of the Cape Fear shiner in 1987, the flathead catfish *Pylodictis olivaris*, an obligate carnivorous apex predator, has been introduced into the upper Cape Fear River in reaches with extant Cape Fear shiner populations. Although recent studies of this sympatry in the Deep River suggest minimal direct habitat overlap and trophic interactions between the species (Malindzak 2006; Brewster 2007), the effect of this exotic predator may be subtle (e.g., seasonal predation) and indirect (e.g., food-web interactions), but severe (Pine et al. 2007). Introduced populations of the Roanoke bass

Ambloplites cavifrons, a predaceous centrarchid sunfish, also occur in the upper Cape Fear basin, which may pose an additional direct threat to the Cape Fear shiner.

The survival and recovery of the Cape Fear shiner depend on the successful preservation and enhancement of remaining suitable physical habitat and water quality. This task will require a broad-scale approach that incorporates considerations of physical instream habitat, water quality and contaminants, biotic interactions with other organisms, as well as differences in land-use patterns and human activities that may contribute to habitat loss. Our research has provided insight into environmental interactions that have led to Cape Fear shiner extirpations, and it should prove useful toward the strategic planning and management necessary to ensure the long-term survival of this species.

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