Use of Rehabilitated Habitat by Brown Trout and Rainbow Trout in an Ozark Tailwater River

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Abstract.—We evaluated instream and riparian habitat rehabilitation that was completed following catastrophic flooding in the White River, below Beaver Dam, Arkansas. Most rehabilitation structures were designed to stabilize the river banks and increase cover for trout (Salmonidae) during high flows associated with hydroelectric power generation. We quantified trout response to rehabilitation at two spatial scales—microhabitat and river reach. At the microhabitat scale, brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* occupied the deepest habitats available and were randomly associated with cover at low flow (about 1 m³/s). Principal-component scores describing physical characteristics of brown trout and rainbow trout microhabitats were significantly different from available-habitat scores at high flow (about 215 m³/s), when trout were strongly associated with velocity refugia near the river margins—habitats similar to those created by rehabilitation structures. At the reach scale, trout population size and structure were estimated in modified (700-m) and reference (800-m) reaches before and after rehabilitation. Total trout density and biomass in the modified reach increased after rehabilitation relative to that of the reference reach, evidence that the modified reach supported more fish after rehabilitation. Analyses stratified by salmonid species and size indicated that the observed effect was primarily due to rainbow trout and small trout (10.0–19.9 cm) of all species shifting their distributions into the modified reach. Our results suggest that instream and riparian habitat rehabilitation structures commonly applied to small streams are a valid management technique for large tailwater rivers. However, implementation in each system should be carefully evaluated, and management expectations for large trout should be conservative. Because of the observed benefit for small trout, placement of rehabilitation structures near spawning areas should be considered when management for wild trout is a priority. Finally, we suggest integration of instream and riparian habitat rehabilitation into broader management plans when applied to regulated rivers.

In a proposal for a national freshwater research initiative, Naiman et al. (1995) listed ecological restoration and rehabilitation studies as the highest priority, based on “scientific significance, socio-political relevance, and the needs of decision makers.” This priority highlighted a general lack of ecological understanding of aquatic restoration. However, techniques to rehabilitate small streams have been used and studied for more than 50 years

(Reeves et al. 1991), most rehabilitation projects having been undertaken to restore damaged fish habitat resulting from poor stream and watershed management practices. Habitat rehabilitation techniques have been widely applied in small cold-water and warmwater streams throughout the United States (Lyons and Courtney 1990; Orth and White 1993) but infrequently in large rivers (Gore and Shields 1995).

Rehabilitation of trout stream habitat to enhance fisheries has often succeeded (e.g., Hunt 1988, 1992; Thorn 1988; Binns 1994; Riley and Fausch 1995; Gowan and Fausch 1996) but has also frequently failed (Hartzler 1983; Knudson and Dilley 1987; Frissell and Nawa 1992; Kondolf et al. 1996). Minns et al. (1996) suggested that some managers may be reluctant to evaluate rehabilitation efforts to avoid questions about success or failure. Simply determining success or failure of stream rehabilitation does not address important ecological questions about processes and mechanisms altered with habitat manipulations. Quantifying and understanding changes associated with

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rehabilitation as ecological processes and mechanisms that influence individuals and populations should lead to a more unified theory of aquatic restoration and is critical for improving stream and fisheries management.

The White River system of Arkansas and Missouri has been substantially modified by several large dams constructed for flood control and hydroelectric power generation. The resulting cold-water riverine tailwater habitats below these dams have been intensively managed for nonnative trout (*Salmonidae*) to mitigate for the decimation of native warmwater species. White River tailwaters support renowned and popular trout fisheries that have produced world-record size brown trout *Salmo trutta* (Hudy and Rider 1989; Wright 1995).

During the spring of 1990, the U.S. Army Corps of Engineers released 1,416 m³/s of floodwater through the dam's floodgates into the White River below Beaver Dam (Beaver Dam tailwater) for several days. This flooding created a channel that was relatively wide and shallow near the dam and moved gravel from upstream areas, filling downstream pools (L. L. Rider, Arkansas Game and Fish Commission, unpublished data). After the 1990 flooding, habitat rehabilitation was initiated in Beaver Dam tailwater to repair instream and riparian habitat damaged by flooding and enhance the trout fishery. Effort was concentrated on stabilizing low-flow streambanks by installing cedar and rock revetments and log crib structures and by planting vegetation. Such structures were available to fish as cover during high discharges associated with hydroelectric generation. Instream structures, such as boulder clusters and logs, were added to provide habitat for trout at all discharges. This rehabilitation project is unique; we are unaware of other intensive rehabilitation of a tailwater river below a large hydropower dam using techniques developed primarily in small streams (e.g., log cribs, cedar revetments).

This study was designed to evaluate the Beaver Dam tailwater habitat rehabilitation project. Our primary objectives were to (1) determine changes in available habitat after rehabilitation, (2) determine the effectiveness of rehabilitation in creating suitable trout microhabitat, and (3) quantify trout density and biomass before and after rehabilitation to determine changes in the reach-scale distribution of trout. Results of this ecological evaluation may assist stream and fisheries managers in refining techniques for future tailwater rehabilitation and contribute to our understanding of regulated river ecology.

Study Area

Beaver Dam, within the Ozark Mountains in northwestern Arkansas, is the most upstream and recent of the major White River dams. The dam is 70 m high and has two power generation turbines. Discharge in the tailwater changed incrementally during our study from conditions with no generators operating (low flow; 1 m³/s) to one generator operating (medium flow; 129 m³/s), to both generators operating (high flow; 258 m³/s). Beaver Dam tailwater flows for about 13 km before draining into Table Rock Lake, but its length varies as a function of Table Rock Lake water level.

Habitat characteristics of the river channel vary greatly and rapidly with hydropower releases from Beaver Dam (Quinn 1998). Maximum depth ranges from about 2 m at low flow to 4.5 m at high flow. Current velocities at low flow are less than 0.10 m/s in 80% of stream habitat. At high flow, more than 90% of measured velocities exceed 0.10 m/s and range up to 2 m/s. The substrate is composed primarily of gravel and bedrock, which is generally covered with filamentous algae during summer months.

We selected two representative reaches for evaluation: a 700-m, modified reach that was to be intensively rehabilitated, and an 800-m, unaltered reference reach (Quinn 1998). The modified reach was 500 m downstream of Beaver Dam, and the reference reach was 1.5 km downstream of the modified reach.

Although not native to the drainage, trout were initially stocked in Beaver Dam tailwater in 1966, and naturally reproducing, or "wild," populations have since become established (Robison and Buchanan 1988; Wright 1995; Pender 1998). Both study reaches received supplemental trout stocking by the Arkansas Game and Fish Commission during our study; stocking was conducted by boat to evenly distribute fish throughout the tailwater. Brown trout (about 10,000/year) and brook trout *Salvelinus fontinalis* (about 15,000/year) were stocked during winter as fingerlings (13–15 cm), but brown trout were not stocked during all years of the study. Catchable cutthroat trout *Oncorhynchus clarki* (23–30 cm; about 30,000 fish/year) were stocked during spring, and rainbow trout *Oncorhynchus mykiss* of varied catchable sizes were stocked throughout the year. Approximately 175,000–230,000 trout were stocked in Beaver Dam tailwater each year of our study. Both study reaches were open to angling and harvest, but restrictive regulations included daily creel limits (six

trout total; two brown trout or cutthroat trout) and size restrictions for brown trout and cutthroat trout (40-cm minimum).

Methods

Habitat availability.—We quantified habitat characteristics at the low-flow streambank along longitudinal transects before (November 1995 and March 1996) and after rehabilitation (September 1997). At the land–water interface along each bank, segments of the transect were classified according to the dominant substrate or bank condition present; categories were fine substrate (sand and silt), coarse substrate (diameter greater than sand), woody structure, or overhanging bank. Pre-rehabilitation data were collected in the modified reach shortly after rehabilitation was initiated when only a negligible number (nine) of new structures had been installed.

Instream habitat characteristics were quantified before (October 1995–January 1996) and after (July–September 1997) rehabilitation at low flow. Within each study reach, 20 cross-sectional transects were delineated at even intervals (modified reach = 35 m; reference reach = 40 m); the position of the first transect was selected randomly. The exact same transects were measured before and after rehabilitation. Along each transect, water depth, mean velocity, distance to the nearest streambank, substrate, and associated cover were measured at 2-m intervals. Additional variables measured during postrehabilitation surveys, but not before rehabilitation, included surface velocity and distance from cover. Depth and mean velocity were measured with a topset wading rod and a model 2000 Marsh–McBirney flowmeter. Mean velocity was measured at 0.6 of total depth from the water surface (depths ≤ 0.76 m) or was calculated as the average of measurements at 0.2 and 0.8 of total depth (depths > 0.76 m). Cover and substrate were categorically determined at each interval point by observing a 1-m² quadrat. Dominant substrate was classified according to a modified Wentworth particle-size classification (Simonson 1993). Cover was defined as physical objects that serve as a velocity refuge or provided overhead cover, and cover categories included none (no cover in the quadrat), woody structure, boulder, macrophyte, riparian vegetation, and undercut bank. Overhead cover was not distinguished from objects that provide a velocity refuge.

Habitat availability variables before and after rehabilitation were compared separately for modified and reference reaches at low flow. Continuous

variables (velocity and depth) were compared with a Kolmogorov–Smirnov (K–S), two-sample test (Sokal and Rohlf 1981), and categorical variables (substrate and cover) were compared with a log-likelihood ratio, *G*-test for independence (Zar 1984). We used a paired *t*-test to separately compare discharge and stream width for each reach before and after rehabilitation because data were collected at the same transects before and after rehabilitation.

Available habitat was quantified after rehabilitation under high flow at a subset of four transects (two per study reach) during March–April 1997. These transects were surveyed during rare periods when two hydroelectric generators were operating for an extended period (e.g., 24-h generation for several days). Transect survey techniques at high flow were similar to those at low flow, but were conducted from a boat attached to a cable stretched across the river; we used a sounding reel and weight (13.6 kg) to measure depth and velocity every 4 m across. If high-flow conditions precluded observation of substrate or cover, those data were collected later under low-flow conditions.

Habitat use.—Trout microhabitats were identified from June 1996 to August 1997 by directly observing individual fish by using snorkeling gear or radiotelemetry. Both methods were used at low flow, but only radiotelemetry was used at high flow. At low flow, a snorkeler visually searched for trout. After locating an undisturbed fish, a weight attached to a numbered float by line was placed at the precise location. While the diver was locating another fish, physical habitat measurements (water depth; mean, surface, and bottom velocity; distance to nearest streambank; distance to cover; and associated cover) were collected at the marked locations by another researcher using methods described above for cross-sectional transects.

Small 48-MHz radio transmitters were surgically implanted into 20 trout captured by boat electrofishing on 6–7 July 1996. Transmitters were implanted into five brown trout and five rainbow trout captured within each reach. Eight of these transmitters were recovered later and reimplanted into other fish on 14–15 July 1997. After capture, trout were anesthetized with 40 mg/L benzocaine for 3–6 min, measured for total length (TL ± 1 mm), weighed (± 1 g), and fitted, using a shielded-needle technique (Ross and Kleiner 1982), with a surgically implanted transmitter. During the 5–9 min surgery, the fish's gills were kept immersed in a 20-mg/L benzocaine solution. Transmitters with

external wire antennas were manufactured by Advanced Telemetry Systems (ATS, Isanti, Minnesota) and had a life expectancy of 175 d, mean displacement of 5.9 cm³ (range, 4.9–7.1 cm³), and mean weight of 10.1 g (range, 9.5–10.7 g). Transmitter weights were less than 4% of fish body weight for all individuals.

Radio-tagged trout were located by triangulation using an ATS model R2000 receiver and a hand-held loop antenna. Physical characteristics were measured, as described above for cross-sectional transects, at each site where a trout was located. To increase independence of observations (White and Garrott 1990), individual fish were usually not located more than once within a 7-d period, and never more than once within a 24-h period. Precision of the location was improved by repetitive triangulation and by employing a short-range omnidirectional antenna. Niemela et al. (1993) used a similar procedure in a tailwater environment during high flow; their estimated mean error was 2.9 m of radius with a 95% confidence interval of 6.4 m.

Habitat selectivity.—Habitats used selectively (nonrandomly) by trout were identified by separately comparing microhabitat use to availability for low- and high-flow data. Categorical variables (substrate and cover) were tested for nonrandom microhabitat use by *G*-tests for independence. When availability frequencies were less than five for several categories, we eliminated or combined categories and recalculated results as reduced tests.

For the analysis of continuous microhabitat variables at low flow (depth; mean, surface, and bottom velocity; distance to bank; distance to cover), we used a multivariate approach. This reduced the number of variables and significance tests required to test the effects of species (brown trout versus rainbow trout), reach (modified versus reference), and location method (snorkeling versus telemetry) on habitat use, and to subsequently compare habitat use to availability. We performed principal-components analysis (PCA) on the correlation matrix of the postrehabilitation habitat availability data from both reaches (40 transects, 831 observations). The PCA extracted linear combinations of the original variables that explained the maximum amount of variation in the data; this enabled components to be interpreted as axes describing available habitat characteristics. Components with an eigenvalue greater than 1.0 were retained (Stevens 1996). Component scores for available habitat were calculated separately by reach. Micro-

habitat-use component scores were calculated using the scoring coefficients generated by the available-habitat PCA, stratified by species, reach, and location method. A multivariate analysis of variance (MANOVA) was used to test the effects of species, reach, and location method on trout microhabitat use (component scores). This analysis determined whether microhabitat use and availability comparisons should be stratified by such effects. Nonrandom microhabitat use was tested by comparing use and availability component scores with K-S two-sample tests by using the stratification scheme developed from the MANOVA.

For high-flow continuous variables (depth; mean, surface, and bottom velocity; distance to bank; distance to cover), transect data from both reaches (4 transects, 85 observations) were pooled into one PCA on availability data. Component scores were calculated from output scoring coefficients for available habitat, brown trout microhabitat use, and rainbow trout microhabitat use. Nonrandom microhabitat use was tested with a separate K-S two-sample test for each species. Unlike the low-flow analysis, a MANOVA on high-flow microhabitat-use scores was not performed because data were collected by only one location method (telemetry) and sample sizes were insufficient to stratify by reach.

Trout abundance.—During nighttime hours, trout were sampled at low flow with a boom-type, boat-mounted electrofisher. A 3,500-W generator supplied 220-V AC to a Smith-Root, Type VI-A, variable-voltage pulsator to convert AC to pulsed DC. Trout collected on a marking date were measured (TL $\pm$ 1 mm), given a partial caudal fin clip, and released. Trout sampled during a recapture date (2–8 d following marking) were measured for (TL $\pm$ 1 mm) and observed for a fin clip. Weights ($\pm$ 1 g) of up to 20 fish for each 1-cm length-group were collected to estimate biomass.

Before and after rehabilitation at both study reaches, trout population density and biomass and approximate 95% confidence intervals ($\pm$ 2 SE) were estimated using a Petersen single-census, mark-recapture method (Ricker 1975; Bohlin et al. 1989; Kwak 1992). Trout population estimates were stratified into 2-cm length groups to correct for possible size bias associated with electrofishing. Successive size groups were occasionally combined because of low sample sizes. Prerehabilitation estimates were completed during fall 1995 (September–October) and postrehabilitation

during fall 1996 (October), spring 1997 (June), and fall 1997 (October).

Because trout were intensively stocked and fished in Beaver Dam tailwater, changes in the absolute abundance of trout were not of primary interest. Instead, we quantified the change in relative distribution of trout between the modified and reference reaches over time. We assumed that trout were free to migrate and occupy the reach with the most suitable habitat or that they would exhibit higher survival in that reach. We assumed that trout distribution would shift into the modified reach if the supportive capacity of that reach was increased by rehabilitation. The ratio of trout abundance in the modified reach, relative to that of the reference reach (hereafter modified: reference ratio, or MR ratio), was quantified as an index of relative distribution between the reaches, whereby an increase in the MR ratio after rehabilitation would indicate that the supportive capacity of the modified reach had increased.

Results

Habitat Availability

Fine sediments on the riverbank were replaced by woody structure after rehabilitation in the modified reach (Table 1). In both reaches, the left bank was highly armored with bedrock, boulder, and cobble, and no rehabilitation structures were installed on this bank. The right bank was composed of easily eroded fine substrates (fines), and it was intensively rehabilitated in the modified reach. The proportion (by length) of the right bank with woody structure (e.g., logs, downed trees, cedar revetment, and log cribs) increased from 10% to 27% after rehabilitation. Percent fines in the modified reach decreased from 18% to less than 1% of the right bank after rehabilitation. Minor decreases in percent fines and increases in percent coarse substrate were measured in the reference reach.

After rehabilitation, depth and stream width were unchanged in both reaches. Mean velocity was higher in both reaches, boulders were fewer and fine substrates were greater in the reference reach, and woody structures were greater in the modified reach. Distributions of depth were similar before and after rehabilitation within the modified ($D = 0.041$, $P = 0.8934$) and reference reaches ($D = 0.032$, $P = 0.9769$). Stream width did not change after rehabilitation in either the modified reach ($t = -1.301$, $df = 19$, $P = 0.209$) or the reference reach ($t = 1.571$, $df = 19$, $P = 0.133$). The distribution of mean velocities was signifi-

TABLE 1.—Longitudinal transect survey results for each riverbank of modified and reference reaches of Beaver Dam tailwater before and after rehabilitation.

Bank and time	Percent of total bank length			
	Fine sub-strates	Coarse sub-strates	Over-head bank cover	Woody structure
Modified reach				
Left bank				
Before	0	95	5	0
After	0	92	8	0
Right bank				
Before	18	72	0	10 ^a
After	0	73	0	27
Combined				
Before	9	84	2	5 ^a
After	0	82	3	15
Reference reach				
Left bank				
Before	16	83	1	0
After	7	89	4	0
Right bank				
Before	21	70	2	7
After	19	73	1	7
Combined				
Before	18	77	1	4
After	13	81	3	3

^a Rehabilitation structures accounted for 96% of the total prerehabilitation woody structure (i.e., 10% of right bank total and 5% of reach total).

cantly higher after rehabilitation in both the modified ($D = 0.145$, $P = 0.0005$) and reference reaches ($D = 0.095$, $P = 0.0405$). Discharge increased in the modified reach (1995 mean $\pm$ SD: 1.439 ± 0.133 m³/s; 1997: 1.762 ± 0.273 m³/s; $t = 4.999$, $df = 19$, $P < 0.0001$) but not in the reference reach (1995: 1.725 ± 0.315 ; 1997: 1.847 ± 0.379 ; $t = 1.255$, $df = 18$, $P = 0.2247$). Less boulder and greater quantities of fines in the reference reach were observed after rehabilitation ($G = 14.696$, $df = 4$, $P = 0.005$), but substrate distribution did not change in the modified reach ($G = 8.343$, $df = 4$, $P = 0.080$). Cover was unchanged in the reference reach ($G = 5.419$, $df = 3$, $P = 0.144$), but more woody structure was measured in the modified reach ($G = 8.634$, $df = 2$, $P = 0.013$). Instream woody structure was absent from the modified reach before rehabilitation and comprised 6 of 400 total observations after rehabilitation.

Habitat Selectivity

Low flow.—Available habitat was described by riffle-to-pool dimensions (component 1) and near-to-mid channel (component 2) variation at low flow (Table 2). The PCA on the combined-reach,

TABLE 2.—Principal-component loadings and variance explained by each component for low-flow and high-flow habitat availability data at Beaver Dam tailwater.

Variable and statistic	Low flow		High flow, component 1
	Component 1	Component 2	
Mean velocity	0.93	0.05	0.93
Depth	-0.22	0.73	0.60
Surface velocity	0.94	0.03	0.94
Bottom velocity	0.87	-0.10	0.88
Distance to cover	0.51	0.21	0.81
Distance to bank	0.08	0.85	0.79
Eigenvalue	2.83	1.32	4.14
Variance explained %	47	22	69

low-flow habitat availability data extracted two components that together explained 69% of the variance in the data. Component 1 (hereafter velocity-cover component) described a gradient from riffles to pools because it was positively loaded on velocity variables and distance to cover. Riffles were characterized by high velocities and sparse cover, whereas pools had low velocities with more proximate cover. Component 2 (hereafter depth-bank component) described nearshore to midchannel areas because it was positively loaded on depth and distance to bank.

Species (brown trout versus rainbow trout) and reach (reference versus modified) had a significant influence on trout microhabitat use at low flow, but snorkeling and radiotelemetry were not statistically distinguishable location methods (Table 3). The lack of a significant difference between methods justified treating telemetry locations as replicates and pooling snorkeling and telemetry data. Both trout species used relatively deeper microhabitats that were farther from the bank in the reference reach, compared with those occupied in the modified reach (Figures 1, 2). Within reaches,

rainbow trout occupied microhabitats that were faster, deeper, and farther from cover and the streambank than those by brown trout. These results suggested that trout microhabitat selectivity should be examined separately for each species-reach combination (Table 3).

Brown trout and rainbow trout disproportionately occupied microhabitats that were relatively deep and distant from the streambank in both reaches at low flow (Figures 1, 2). For all species-reach combinations, trout occupied microhabitats in a nonrandom manner on the depth-bank component (Table 4). Rainbow trout used microhabitat nonrandomly in the modified reach for the velocity-cover component and selected microhabitats that had high velocities away from cover (Table 4). Rainbow trout used microhabitat randomly for the velocity-cover component in the reference reach, and brown trout used microhabitats randomly for the velocity-cover component in both reaches (Table 4).

Bedrock and boulder substrates were favored by brown trout and rainbow trout at low flow, but cover was used randomly (Table 4). Rainbow trout in the reference reach disproportionately selected bedrock and boulder substrates, but in the modified reach rainbow trout selected gravel and bedrock. Cover was occupied randomly by rainbow and brown trout in all four comparisons at low flow (Table 4).

High flow.—At high flow, available habitat was described as a gradient from the channel margin to mid-channel. One principal component was sufficient to quantify high-flow habitat availability; it explained 69% of the variance in physical characteristics (Table 2). No other components were retained because they did not substantially increase explained variance.

The retained component quantified a habitat gra-

TABLE 3.—Multivariate analysis of variance for low-flow habitat use principal component scores from data collected at Beaver Dam tailwater. Species included brown trout and rainbow trout, reach included modified and reference reaches, and location method included radiotelemetry and snorkeling.

Factor	Levels	Wilks' lambda	F	Degrees of freedom		P
				Numerator	Denominator	
Species	2	0.946	3.37	2	119	0.038
Reach	2	0.930	4.51	2	119	0.013
Species × reach		0.998	0.10	2	119	0.906
Method	2	0.973	1.67	2	119	0.193
Species × method		0.979	1.28	2	119	0.282
Reach × method		0.988	0.70	2	119	0.499
Species × reach × method		0.985	0.89	2	119	0.413

FIGURE 1.—Principal-component scores of brown trout microhabitat use and habitat available in reference (top) and modified (bottom) reaches of the Beaver Dam tailwater at low flow. Component loadings appear in Table 2.

dient from channel margins (low scores; shallow depth, low velocity, and close to cover and the riverbank) to mid-channel habitats (high scores; deeper and faster water, farther from cover and the bank).

Brown trout and rainbow trout were associated with characteristics of velocity refugia at high flow (Figure 3). The distribution of component scores for available habitat was significantly different than that of brown trout (K-S two-sample test, $D = 0.396$, $P = 0.0004$) and rainbow trout microhabitat use ($D = 0.536$, $P = 0.0003$) at high flow. Both species appeared to select microhabitats with low velocities, close proximity to cover and the riverbank, and shallow water, relative to those available. Conversely, extremely shallow and slow microhabitats very close to the riverbank and cover appeared to be avoided at high flow.

Cover and substrate were used randomly by trout at high flow, except that rainbow trout selected fines and bedrock substrates with greater frequency than available. Brown trout used substrate randomly during high flow ($G = 6.09$, $df = 4$, $P = 0.185$). Rainbow trout selected substrates of fines and bedrock and avoided gravel ($G = 14.30$, $df = 4$, $P = 0.006$). During snorkeling surveys, trout were frequently observed using crevices in the bedrock substrate as velocity refugia during high flow. Cover was used randomly by brown trout ($G = 5.20$, $df = 4$, $P = 0.267$) and rainbow trout ($G = 8.77$, $df = 4$, $P = 0.067$) at high flow.

Trout Abundance

We captured 10,860 trout during population sampling of four species: brown trout, rainbow

FIGURE 2.—Principal-component scores of rainbow trout microhabitat use and habitat available in reference (top) and modified (bottom) reaches of the Beaver Dam tailwater at low flow. Component loadings appear in Table 2.

TABLE 4.—Low-flow comparisons of brown trout ($N = 27, 26$) and rainbow trout ($N = 36, 37$) habitat use to habitat available ($N = 431, 400$) for continuous (Kolmogorov–Smirnov two-sample tests) and categorical (G -tests) variables in reference and modified reaches of Beaver Dam tailwater. Degrees of freedom are in parentheses for G -tests.

Variable	Brown trout		Rainbow trout	
	Statistic	<i>P</i>	Statistic	<i>P</i>
Reference reach				
Component 1 scores	$D = 0.206$	0.2287	$D = 0.148$	0.4329
Component 2 scores	$D = 0.344$	0.0049	$D = 0.380$	0.0001
Substrate	$G = 38.27 (4)$	0.001	$G = 25.17 (4)$	0.001
Cover	$G = 4.85 (3)$	0.183	$G = 2.65 (3)$	0.448
Modified reach				
Component 1 scores	$D = 0.123$	0.8534	$D = 0.324$	0.0016
Component 2 scores	$D = 0.332$	0.0090	$D = 0.520$	0.0001
Substrate	$G = 11.09 (4)$	0.026	$G = 22.73 (4)$	0.001
Cover	$G = 0.66 (2)$	0.719	$G = 1.73 (2)$	0.420

FIGURE 3.—Distributions of principal-component scores for habitat available versus used by brown trout and rainbow trout in the Beaver Dam tailwater at high flow. Component loadings appear in Table 2.

trout, brook trout, and cutthroat trout. Rainbow trout and brown trout accounted for most of the total trout density (87%) and biomass (97%) in the reference reach and modified reach (76% density, 90% biomass; Table 5). Mean total trout density for all sampling dates was 463 fish/ha (103 kg/ha) in the reference reach and 1,854 fish/ha (252 kg/ha) in the modified reach. The lowest estimated total trout density for any date was 307 fish/ha (75

kg/ha), and the highest was 2,738 fish/ha (342 kg/ha).

Total trout density and biomass in the modified reach, relative to that of the reference reach, increased after rehabilitation—evidence that the modified reach supported more fish after rehabilitation (Figure 4). Before rehabilitation in October 1995, there were 3.1 fish/ha in the modified reach for every 1 fish/ha in the reference reach. After

TABLE 5.—Mean, standard deviation, and minimum–maximum (min–max) population estimates of density and biomass for four trout species and combined trout species at two reaches of Beaver Dam tailwater based on four sample dates from September 1995 to October 1997.

Species and statistic	Reference reach		Modified reach	
	Mean (SD)	Min–max	Mean (SD)	Min–max
Brown trout				
Density (fish/ha)	117 (75)	66–229	446 (260)	165–765
Biomass (kg/ha)	43.2 (31.8)	14.8–88.9	73.6 (54.3)	43.8–154.8
Rainbow trout				
Density (fish/ha)	286 (177)	146–543	966 (604)	286–1,712
Biomass (kg/ha)	56.4 (39.1)	31.4–114.5	151.6 (89.5)	62.0–270.9
Brook trout				
Density (fish/ha)	10 (15)	1–32	384 (469)	110–1,086
Biomass (kg/ha)	0.6 (0.6)	0.1–1.4	23.6 (14.9)	13.7–45.7
Cutthroat trout				
Density (fish/ha)	50 (89)	<1–184	58 (99)	<1–206
Biomass (kg/ha)	2.9 (3.5)	0.1–7.5	2.8 (3.0)	0.1–7.0
Combined trout				
Density (fish/ha)	463 (145)	307–615	1,854 (855)	1,076–2,738
Biomass (kg/ha)	103.1 (26.4)	74.5–129.9	251.6 (70.4)	173.0–342.3

FIGURE 4.—Total trout density (top) and biomass (bottom) estimates (± 2 SE) in modified and reference reaches and modified: reference ratios (mod/ref) for the Beaver Dam tailwater before (October 1995) and after (October 1996, June 1997, and October 1997) habitat rehabilitation.

rehabilitation, the MR ratio for trout density successively increased to 3.5 in October 1996, 4.0 in June 1997, and 4.9 in October 1997. The MR ratio for total trout biomass followed a similar pattern, increasing from 1.9 before rehabilitation in October 1995 to 2.3 in October 1996, 2.6 in June 1997, and 3.0 in October 1997.

Reach-scale distribution of rainbow trout shifted into the modified reach; brown trout showed no consistent change, and brook trout and cutthroat trout patterns were difficult to interpret (Figure 5). The relative distribution shift by rainbow trout was clear and consistent, as indexed by increased MR ratios in all postrehabilitation estimates. Brown trout showed no consistent shift in distribution following rehabilitation, except for an increase during June 1997, which followed a stocking of small brown trout (about 15 cm TL). Brook trout density and biomass were always much higher in the mod-

ified than in the reference reach, before and after rehabilitation (Table 5; Figure 5). Brook trout and cutthroat trout distribution may have shifted out of the modified reach after rehabilitation, as indicated by reduced MR ratios. However, their low prerehabilitation density and biomass in the reference reach limited our interpretation of rehabilitation effects on these species (Figure 5).

The observed distribution shift following rehabilitation among different sizes of fish was greatest for small trout in Beaver Dam tailwater (Figure 6). Because stockings of small trout throughout the tailwater during the study appeared to influence relative distribution of trout on specific sampling dates, we stratified total trout density estimates into fish length groups (10.0–19.9 cm, 20.0–29.9 cm, 30.0–39.9 cm, >40.0 cm) that we subsequently examined. The total density of trout 10.0–19.9 cm successively increased every sampling period, the relative distribution of this size-group appearing to shift into the modified reach after rehabilitation (Figure 6). Relative distribution did not change substantially or consistently for larger trout sizes. Density MR ratios for the 20.0–29.9-cm group were 4.7 before rehabilitation and 4.5, 4.5, 5.7 after rehabilitation; were 1.2 before and 1.0, 1.0, and 1.3 after rehabilitation for the 30.0–39-cm group; and were 0.32 before and 0.44, 0.33, and 0.11 after rehabilitation for the group 40 cm or larger.

Discussion

Rehabilitation of Beaver Dam tailwater stabilized the river banks and stemmed the widening of the river channel observed after flooding. Our streambank measurements indicated that fine substrates were stabilized by rehabilitation structures, primarily cedar revetments and log cribs. Our in-stream habitat surveys indicated that the river channel was no longer becoming wider or shallower after rehabilitation. Bank stabilization structures were available as overhead cover and velocity refugia for trout during frequent hydropower generation periods and when Table Rock Lake inundated Beaver Dam tailwater.

Our microhabitat-scale results indicated that brown trout and rainbow trout were strongly associated with velocity refugia at high flow. In addition, we frequently observed trout in large groups near the lateral margins of the river or individually resting on or within bedrock substrate during high flow. We hypothesize that increased abundance of velocity refugia available during high flow in the rehabilitated reach was the pri-

mary cause for the observed reach-scale trout distribution shifts in Beaver Dam tailwater. The addition of velocity refugia may have exerted the greatest effect on small trout and recently stocked rainbow trout because those fish may be least able to locate and maintain energetically profitable positions. Adding velocity refugia may increase the likelihood that small trout and rainbow trout find suitable habitat at high flow, which may limit poststocking emigration or mortality.

At high flow, brown trout and rainbow trout were not highly selective of any of the cover types available in Beaver Dam tailwater. We suggest that other site-specific factors, such as velocity profile, were more important than structure type in determining trout microhabitat use. Placement of a structure in habitats with different velocity profiles may produce varying numbers and quality of positions that may be occupied by trout. This hypothesis was supported by our observation that trout spatial distributions at high flow were highly clumped in some lateral habitats, but more dispersed in others. Future research on tailwater trout habitat rehabilitation at the microhabitat scale should examine site-specific factors—both near and distant from cover—that influence the density of trout at high flow.

Although snorkeling and telemetry have been criticized as variably biased fish location methods (Heggenes 1988; Pert et al. 1997), we did not detect a difference between trout microhabitat-use data collected with either method; however, telemetry locations were slightly less precise than those identified by snorkeling. Because microhabitat data were usually collected weekly with radiotelemetry at times when daily discharge fluctuated, observations were treated as independent replicates for statistical analyses. However, considering telemetry locations as replicates may be a form of pseudoreplication (Hurlbert 1984; Winter 1996), and treating telemetry locations as replicates caused variance loss (Quinn 1998). Nonetheless, concerns about replication and independence of telemetry observations appeared ecologically unimportant because snorkeling and telemetry observations were statistically indistinguishable.

The reach-scale trout distribution changes that we documented suggest that addition of cover (rehabilitation structures) to the modified reach resulted in greater supportive capacity for trout. Increased relative supportive capacity may be a conceptually vague management goal for a system supporting a fishery because anglers may ultimately desire increased absolute fish density or

biomass. Our reach-scale results are consistent with the finding of Gowan and Fausch (1996) that increases in trout abundance associated with habitat manipulation were primarily due to diffuse immigration to modified habitats. However, the relationship of increased relative supportive capacity to fish residence time, or the time required to reach a quality size, remains unresolved for our study because the temporal scope did not allow fish growth to larger sizes. Long-term research would be required to resolve relationships related to fish growth, survival, and recruitment.

Our reach-scale analyses would have been strengthened by replication, but this was not logistically possible. Other investigators have suggested that, to evaluate habitat alterations, study reaches be divided into short, alternating, modified, and reference reaches (e.g., Cederholm et al. 1997). In our case, we believe that such an approach in a single river would not allow extending results to other tailwater rivers because broadly generalized hypotheses would require spatial replication among tailwaters. In addition, fragmenting our large study reaches into smaller ones could confound or mask any rehabilitation effects because trout may easily migrate between short reaches during discharge fluctuations. We agree with the pragmatic view of Kingsolving and Bain (1993), who noted that it may be impossible to perform truly controlled, replicated, large-scale experiments in rivers. Additional prerehabilitation habitat surveys and fish population estimates would have provided useful baseline data to better assess natural variation and rehabilitation-induced changes, but additional surveys were beyond the logistic limits of this study.

Trout stocking, harvest, and Table Rock Lake water level were potential confounding factors that we believe did not influence our conclusions. Large stockings (>5,000) of trout were evenly distributed by boat throughout the tailwater. Angling pressure and trout harvest generally increase following stream habitat modifications (Hunt 1988), and if this occurred in the modified reach of our study, the reach-scale trout distribution changes measured were conservative. Table Rock Lake impounded water as far upstream as Beaver Dam on several occasions during our study, but all fall trout population estimates were conducted when Table Rock Lake had not, for an extended period, influenced the hydrology of Beaver Dam tailwater. Furthermore, radio-tagged trout did not notably shift their reach-scale distribution with changes in the water level of Table Rock Lake. Thus, we conclude

Brown Trout

Rainbow Trout

Brook Trout

Cutthroat Trout

FIGURE 6.—Length-stratified (10.0–19.9 cm) total trout density estimates (± 2 SE) in modified and reference reaches and modified : reference ratios (mod/ref) for the Beaver Dam tailwater before (October 1995) and after (October 1996, June 1997, and October 1997) habitat rehabilitation.

that these factors were of minimal influence on our findings.

Management Implications

Rehabilitation of tailwater rivers, with focus on bank stabilization practices, may create velocity refugia during hydroelectric generation and increase supportive capacity of trout. However, managers must be realistic in their goals and expectations for rehabilitation influences on trout density, biomass, and size structure in tailwater reaches. Dramatic increases in absolute density and biomass of trout may be unrealistic because absolute changes may be strongly tied to stocking, angling harvest, and natural recruitment and mortality—all processes that require long durations to detect. Furthermore, water fertility may set an upper limit on trout production in streams (Kwak and Waters 1997); differences in water fertility and invertebrate density among tailwater reaches of the White River influence trout reproductive success, condition, and supportive capacity (Pender 1998). Managers expecting rehabilitation-induced increases in density of large trout and biomass may be disappointed. For example, we found no shift in spatial distribution of large trout in this study,

and food availability and residence time may greatly influence density of large trout in tailwaters (Weiland and Hayward 1997).

A goal of tailwater trout management may be to increase the numbers of wild trout. If rearing habitat for fry and juveniles has been documented to be limiting in a tailwater, placement of structures near spawning areas may increase the supportive capacity for juvenile, wild trout—provided bioenergetic conditions are favorable. Because rehabilitation structures appeared to function most effectively in supporting small-sized trout, it is possible that placement of structures downstream of known spawning areas might enhance juvenile survival and wild trout production.

Although our results suggest that habitat rehabilitation may increase trout supportive capacity and may be considered a valid management technique in tailwater rivers, we emphasize that it would be unwise to presume similar results in other tailwater systems without confirmation. Further, habitat modifications should be considered only a single component of tailwater fishery management. We suggest that higher base flow release rates should be considered as a future management strategy to increase suitable trout microhabitat in Beaver Dam tailwater and other similar systems. Increased minimum flows would create more deep water and higher velocities, which are habitat characteristics disproportionately selected by brown trout and rainbow trout at low flow. Increased minimum flow would also increase the number of rehabilitation structures inundated and available to trout as cover at low flow. Thus, we conclude by suggesting that all aspects of habitat management be considered together when objectives are to enhance tailwater fisheries, and we look forward to future evaluations to clarify the applicability of our results to other regulated rivers.

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FIGURE 5.—Trout density and biomass estimates (± 2 SE) by species in modified and reference reaches and modified : reference ratios (mod/ref) for the Beaver Dam tailwater before (October 1995) and after (October 1996, June 1997, and October 1997) habitat rehabilitation.

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References

- Binns, N. A. 1994. Long-term responses of trout and macrohabitats to habitat management in a Wyoming headwater stream. *North American Journal of Fisheries Management* 14:87-98.
- Bohlin, T., S. Hamrin, T. G. Heggberget, G. Rasmussen, and S. J. Saltveit. 1989. Electrofishing—theory and practice with special emphasis on salmonids. *Hydrobiologia* 173:9-43.
- Cederholm, C. J., R. E. Bilby, P. A. Bisson, T. W. Bumstead, B. R. Fransen, W. J. Scarlett, and J. W. Ward. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. *North American Journal of Fisheries Management* 17:947-963.
- Frissell, C. A., and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. *North American Journal of Fisheries Management* 12:182-197.
- Gore, J. A., and F. D. Shields, Jr. 1995. Can large rivers be restored? *BioScience* 45:142-152.
- Gowan, C., and K. D. Fausch. 1996. Long-term demographic responses of trout populations to habitat manipulation in six Colorado streams. *Ecological Applications* 6:931-946.
- Hartzler, J. R. 1983. The effects of half-log covers on angler harvest and standing crop of brown trout in McMichael Creek, Pennsylvania. *North American Journal of Fisheries Management* 3:228-238.
- Heggenes, J. 1988. Effect of experimentally increased intraspecific competition on sedentary adult brown trout (*Salmo trutta*) movement and stream habitat choice. *Canadian Journal of Fish and Aquatic Sciences* 45:1163-1172.
- Hudy, M., and L. L. Rider. 1989. Brown trout management in the natural state. Pages 67-70 in F. Richardson and R. H. Hamre, editors. *Wild trout IV*. Trout Unlimited, Arlington, Virginia.
- Hunt, R. L. 1988. A compendium of 45 trout stream habitat development evaluations in Wisconsin during 1953-1985. Wisconsin Department of Natural Resources, Technical Bulletin 162, Madison.
- Hunt, R. L. 1992. Evaluation of trout habitat improvement structures in three high-gradient streams in Wisconsin. Wisconsin Department of Natural Resources, Technical Bulletin 179, Madison.
- Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54:187-211.
- Kingsolving, A. D., and M. B. Bain. 1993. Fish assemblage recovery along a riverine disturbance gradient. *Ecological Applications* 3:531-544.
- Knudson, E. E., and S. J. Dille. 1987. Effects of riprap bank reinforcement on juvenile salmonids in four western Washington streams. *North American Journal of Fisheries Management* 7:351-356.
- Kondolf, G. M., J. C. Vick, and T. M. Ramirez. 1996. Salmon spawning habitat rehabilitation on the Merced River, California: an evaluation of project planning and performance. *Transactions of the American Fisheries Society* 125:899-912.
- Kwak, T. J. 1992. Modular microcomputer software to estimate fish population parameters, production rates and associated variance. *Ecology of Freshwater Fish* 1:73-75.
- Kwak, T. J., and T. F. Waters. 1997. Trout production dynamics and water quality in Minnesota streams. *Transactions of the American Fisheries Society* 126:35-48.
- Lyons, J., and C. C. Courtney. 1990. A review of fisheries habitat improvement projects in warmwater streams, with recommendations for Wisconsin. Wisconsin Department of Natural Resources, Technical Bulletin 169, Madison.
- Minns, C. K., J. R. M. Kelso, and R. G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Supplement 1):403-414.
- Naiman, R. J., J. J. Magnuson, D. M. McKnight, J. A. Stanford, and J. R. Karr. 1995. Freshwater ecosystems and their management: a national initiative. *Science* 270:584-585.
- Niemela, S. L., J. B. Layzer, and J. A. Gore. 1993. An improved radiotelemetry method for determining use of microhabitats by fishes. *Rivers* 4:30-35.
- Orth, D. J., and R. J. White. 1993. Stream habitat management. Pages 205-230 in C. C. Kohler and W. A. Hubert, editors. *Inland fisheries management in North America*. American Fisheries Society, Bethesda, Maryland.
- Pender, D. R. 1998. Factors influencing brown trout reproductive success in Ozark tailwater rivers. Master's thesis. University of Arkansas, Fayetteville.
- Pert, E. J., J. M. Deinstadt, and D. C. Erman. 1997. Evidence of differential detectability of lotic adult rainbow and brown trout: implications for habitat use inference from direct-underwater observation. *Journal of Freshwater Ecology* 12:359-365.
- Quinn, J. W. 1998. Fish populations and trout microhabitat use of rehabilitated habitat in an Ozark tailwater river. Master's thesis. University of Arkansas, Fayetteville.
- Reeves, G. H., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. 1991. Rehabilitating and modifying stream habitats. Pages 519-557 in W. R. Mee-

- han, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.
- Riley, S. C., and K. D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. *Canadian Journal of Fisheries and Aquatic Sciences* 52:34-53.
- Robison, H. W., and T. M. Buchanan. 1988. *Fishes of Arkansas*. University of Arkansas Press, Fayetteville.
- Ross, M. J., and C. F. Kleiner. 1982. Shielded-needle technique for surgically implanting radio-frequency transmitters in fish. *Progressive Fish-Culturist* 44: 41-43.
- Simonson, T. D. 1993. Correspondence and relative precision of stream habitat features estimated at two spatial scales. *Journal of Freshwater Ecology* 8: 363-373.
- Sokal, R. R., and F. J. Rohlf. 1981. *Biometry*, 2nd edition. Freeman, New York.
- Stevens, J. 1996. *Applied multivariate statistics for the social sciences*, 3rd edition. Lawrence Erlbaum Associates, Mahwah, New Jersey.
- Thorn, W. C. 1988. Evaluation of habitat improvement for brown trout in agriculturally damaged streams of southeastern Minnesota. Minnesota Department of Natural Resources Section of Fisheries Investigational Report 394.
- Weiland, M. A., and R. S. Hayward. 1997. Cause for the decline of large rainbow trout in a tailwater fishery: too much putting or too much taking? *Transactions of the American Fisheries Society* 126: 758-773.
- White, G. C., and R. A. Garrott. 1990. *Analysis of wildlife radio-tracking data*. Academic Press, San Diego, California.
- Winter, J. 1996. Advances in underwater biotelemetry. Pages 555-590 in B. R. Murphy and D. W. Willis, editors. *Fisheries techniques*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Wright, S. A. 1995. *Ozark trout tales*. White River Chronicle, Fayetteville, Arkansas.
- Zar, J. H. 1984. *Biostatistical analysis*, 2nd edition. Prentice Hall, Englewood Cliffs, New Jersey.