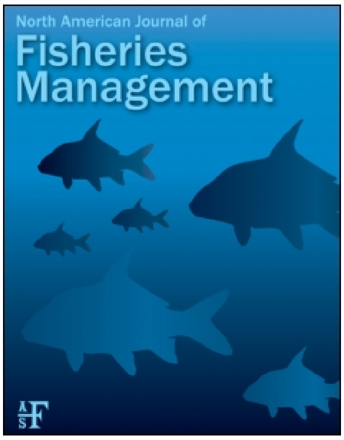

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Seasonal Movement of Brown Trout in the Clinch River, Tennessee

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Abstract.—We used radiotelemetry to monitor the seasonal movements of trophy-size brown trout *Salmo trutta* in the Clinch River below Norris Dam, Tennessee, to determine whether establishing a special-regulation reach to reduce fishing mortality was a viable management option. Fifteen brown trout (size range, 430–573 mm total length) collected from the river were implanted with radio transmitters between November 1997 and May 1998. Forty-seven percent of these fish died or expelled their transmitters within 50 d postsurgery. The range of movement for surviving brown trout was significantly larger in fall (geometric mean range = 5,111 m) than in any other season. Four brown trout that were monitored for more than 1 year exhibited a limited range of movement (<2 km) during the winter, spring, and summer, but they made extensive movements (>5 km) during the fall season, presumably to spawn. Brown trout also moved more during the fall than in any other season. Harvest restrictions applied to a specific reach of the Clinch River would reduce the exploitation of brown trout in that reach for most of the year but not during the fall, when many fish undertake extensive spawning migrations.

Management objectives for trout streams and rivers often include increasing the numbers of large fish and protecting populations from high exploitation. Special-regulation reaches, or ''quality zones,'' are often implemented in an attempt to meet these objectives (e.g., Wright 1992; Gigliotti and Peyton 1993). Special-regulation reaches will not be effective unless adult fish spend most of their lives in a limited river reach. Some researchers have observed this behavior by rainbow trout *Oncorhynchus mykiss* (Cargill 1980) and small brown trout *Salmo trutta* (Schuck 1945; Bachman 1984; Hesthagen 1988). However, recent studies have found that many trout, especially large brown trout, move a great deal throughout the year (Clapp et al. 1990; Meyers et al. 1992; Hudson 1993; Young 1994; Young et al. 1997). The movements of large brown trout (>430 mm) in a large regulated river have not been reported in the literature.

To assess whether establishing a special-regulation reach is a suitable tool for the management of trout in the Clinch River, Tennessee, we sought to determine the seasonal movements of trophy brown trout in the river. If large brown trout in the Clinch River demonstrate restricted ranges, then special-regulation reaches would be a viable management option for reducing exploitation.

Methods

Study area.—The Clinch River below Norris Lake, Tennessee, is a regulated river that supports a popular recreational trout fishery; in 1996, nearly 100,000 h of fishing pressure were directed towards trout species (Bettoli and Bohm 1997). Brown trout and rainbow trout were first stocked in 1950 by the Tennessee Game and Fish Commission (now named the Tennessee Wildlife Resources Agency [TWRA]). Natural reproduction by trout is negligible, and the TWRA maintains this put-and-take and put-grow-and-take fishery by annually stocking several hundred thousand trout fry, fingerlings, and adults. Current fishing regulations allow anglers 7 fish/d with no length or bait restrictions. The Clinch River is known for its production of trophy-size brown trout. The current state record brown trout (13.04 kg) was caught in the Clinch River in 1988, and brown trout exceeding 4 kg are routinely collected in annual electrofishing surveys.

Norris Dam is located on the Clinch River at river kilometer 128 in Anderson County in eastern Tennessee. The dam was constructed by the Tennessee Valley Authority (TVA) in 1936 for flood control and power generation. The tailwater below

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the dam extends 23 km downstream to the headwaters of Melton Hill Reservoir and covers about 251 ha during periods of power generation. The average width of the tailwater is approximately 132 m during power generation and 95 m at base flow. During base flow, the macrohabitat is dominated by long, deep (1–4 m) pools separated by short, shallow (<0.5 m) riffles or shoals. The predominant substrate is bedrock with small patches of cobble and gravel.

Norris Dam operates as a peaking facility, and hypolimnetic discharges through two turbines maintain coldwater habitat in the entire tailwater throughout the year. During summer months (June–September), water temperatures vary between 13°C and 18°C. Maximum discharge through each turbine is approximately 114 m^3/s. Water levels fluctuate about 1.8 m between base flow and maximum turbine discharge.

In 1980, the TVA initiated a program to increase late-summer dissolved oxygen concentrations and to provide minimum flows below TVA dams (Yeager et al. 1987). Dissolved oxygen concentrations below Norris Dam are maintained by an autoventing turbine system designed to keep dissolved oxygen concentrations above 6mg/L. A re-regulation weir, located approximately 3.2 km below the dam, provides a minimum flow of 5.7 m^3/s when the turbines are idle.

Field methods.—Brown trout were captured from throughout the 23-km tailwater by use of boat-mounted DC electrofishing equipment. Eleven brown trout (mean total length [TL] = 486 mm) were implanted with radio transmitters between 13 November and 17 December 1997 (Table 1). Transmitters recovered from four of those fish were implanted in four more brown trout (mean TL = 524 mm) on 19 May 1998.

Brown trout were anesthetized with a 40-mg/L concentration of clove oil (Anderson et al. 1997), and transmitters were inserted through an incision made adjacent to the midventral line and anterior to the pelvic girdle via the shielded-needle technique (Ross and Kleiner 1982). The incision was closed with 3-0 or 4-0 silk nonabsorbable sutures. Fish were placed in a holding tank filled with river water for 4–8 min to recover and were then released near the capture site.

Radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota) were fitted with 20-cm whip antennae, possessed a battery life of at least 310 d, and broadcasted a unique frequency between 30 and 31 MHz. Each transmitter weighed 16 g in air, which was 1.7% of the weight of the

TABLE 1.—Summary of radio-tagged trophy brown trout in the Clinch River, Tennessee, 1997–1998, indicating identification number (ID), sex (F = female, M = male), total length (TL), implantation date, number of days fish were assumed to be alive, and the number of times each transmitter was located. Fate codes are as follows: S = study ended, AD = assumed dead, H = harvested, D = died, RC = transmitter was recovered in the channel, RB = transmitter was recovered on the bank, and NL = never located.

ID	Sex	TL (mm)	Date implanted	Days alive	Locations (*N*)	Fate
10	F	572	Nov 20, 1997	362	29	S
30	M	487	Nov 13, 1997		10	AD
40	F	482	Nov 13, 1997			NL
50	F	430	Dec 17, 1997	156	9	H
70	F	464	Nov 14, 1997	516	33	S
100	M	492	Nov 13, 1997	369	27	S
120	F	510	Dec 17, 1997	177	20	D/RC
140	F	455	Nov 20, 1997	10		H
150	F	495	Dec 16, 1997	109	8	D/RB
170	M	497	Dec 17, 1997	44	23	AD
181	M	461	Nov 20, 1997	511	29	S
1401	F	457	May 19, 1998	9	10	D/RC
1501	F	550	May 19, 1998	23	13	AD
1901	F	555	May 19, 1998	23	13	D/RC
2001	F	535	May 19, 1998	17	10	D/RB

smallest trout tagged and 1% of the weight of the average-size trout tagged. Each tag also had a label with the Tennessee Cooperative Fishery Research Unit phone number and the word ''Reward'' printed on it.

We attempted to locate each transmitter at least once every 2 weeks by traversing the entire tailwater. Approximately once per month, we searched up to 10 km below the tailwater; on two occasions, we also searched Melton Hill Reservoir. During the summer months (May–August), fish were located more frequently and most fish were located at least once per week. Because fish may exhibit erratic behavior after surgery (Pickering et al. 1982; Mesing and Wicker 1986), location data collected within 2 weeks of surgery were eliminated from any analysis.

During periods of power generation, brown trout were located from a 4.3-m boat in the daytime by use of a scanning receiver, loop antenna, and omnidirectional whip antenna (i.e., a bare piece of coaxial cable). Precise locations during power generation were determined by following the technique of Niemela et al. (1993). Once a strong signal was achieved with the whip antenna, which had a limited range (10–15 m), the location of the fish was recorded in a global positioning system (GPS) receiver. The GPS receiver locations were differentially corrected by use of Pathfinder Office software (Trimble Navigation, Limited, Sunnyvale, California), and were plotted on a digitized map (U.S. Geological Survey; 1:24,000 scale) of the river by use of Arc/View software (version 3.0, 1992).

We assumed that a fish had died when a transmitter was recovered or when a fish did not move after several locations. However, we continued to note the position of every fish during each tracking event, regardless of our assumptions. Location data were grouped by season for analysis of movements and activity. Seasonal periods for this study were defined as winter (1 January–31 March), spring (1 April–30 June), summer (1 July–30 September), and fall (1 October–31 December). The delineation of seasons was not arbitrary, but based on subsequent field observations.

Data analysis.—Range was defined as the distance (m) between the extreme upstream and extreme downstream positions of an individual fish. The range for brown trout in the Clinch River was calculated to the nearest meter by use of ArcView software. Ranges were calculated for each fish tracked each season. Total range was the range of a fish for the entire study period. Only data from fish that were located at least three times within a given season were analyzed. Range values were $\log_{10}$ transformed to normalize data, and differences in seasonal range were investigated with analysis of variance (ANOVA). Multiple comparisons were performed with Tukey's test. Regression analysis was used to determine if fish size had an influence on range during any of the four seasons.

Activity was defined as the distance (m) between consecutive locations of individual fish and was calculated in ArcView. Mean activity was determined for each fish during every season it was tracked. Activity data were $\log_{10}$ transformed to normalize data and stabilize variances. Mean activity data were grouped by season, and ANOVA was used to determine if activity differed seasonally. Locations often spanned adjacent seasons; in these instances, distance values were coded for the previous season. Multiple comparisons were evaluated by use of Tukey's test. Because not every fish was located during every location attempt, regression analysis was used to determine if days between locations had an effect on distance traveled (i.e., activity).

Regression analysis was used to determine whether activity varied with water temperature and discharge. Activity values for brown trout tracked for at least two seasons were pooled and grouped by month. Mean monthly brown trout activity was

TABLE 2.—Geometric mean seasonal range (distance between the extreme upstream and extreme downstream locations) and associated 95% confidence limits (CL) for radio-tagged brown trout tracked in the Clinch River, Tennessee, during 1997 and 1998. Means with the same letter were not significantly different (Tukey's multiple comparison test; $P > 0.05$).

Season	*N*	Range (m)	95% CL (m)
Winter	6	350 z	141–718
Spring	6	652 z	339–1,714
Summer	4	402 z	176–1,057
Fall	4	5,111 y	3,550–11,643

$\log_{10}$ transformed to normalize the data. Water temperature was measured by an Onset StowAway temperature logger. Mean monthly discharge values for Norris Dam were obtained from the TVA.

Analysis of variance, regression analysis, Tukey's multiple comparisons, confidence limits, and measures of central tendency were calculated in SAS (SAS Institute 1989). Tests were considered statistically significant if the probability of a type I error was less than 0.05.

Results

Forty-seven percent of brown trout died or expelled their transmitters within 50 d postsurgery (Table 1). Brown trout implanted during the fall survived better than brown trout implanted during the spring. Four of the 11 brown trout implanted during the fall of 1997 were alive at the conclusion of the study (Table 1). Two of the 11 brown trout were harvested (at 11 and 157 d postsurgery), one fish was never located, and four fish died or expelled their transmitters between 0 and 177 d postsurgery. Sixty-four percent (7 of 11) of brown trout implanted in the fall survived for more than 100 d.

None of the brown trout implanted on 19 May 1998 survived more than 23 d; two transmitters were recovered in the river, one transmitter was recovered on the bank, and one fish was assumed to have died.

Most of our observations of brown trout movement were recorded in calendar year 1998, which was an average water year for the watershed. The amount of water released through Norris Dam in 1998 (4.317×10^9 m^3) was within 8% of the average amount of water released annually between 1990 and 1999 (3.984×10^9 m^3). During 1998, water temperatures ranged from 5°C to 19°C.

The range of brown trout varied seasonally (ANOVA: $F = 14.59$; df = 3, 16; $P = 0.0001$) and was larger in the fall (geometric mean = 5,111 m) than in any other season (Table 2). The mean range

TABLE 3.—Geometric mean seasonal activity (distance between consecutive locations) and associated 95% confidence limits (CL) for radio-tagged brown trout tracked in the Clinch River, Tennessee, during 1997 and 1998. Means with the same letter were not significantly different (Tukey's multiple comparison test; $P > 0.05$).

Season	*N*	Activity (m)	95% CL (m)
Winter	7	88 z	37–211
Spring	6	253 z	109–586
Summer	4	144 z	68–304
Fall	4	2,983 y	1,013–8,785

of brown trout movement did not differ significantly between spring, summer, or winter, and was not significantly related to brown trout TL.

Brown trout were significantly more active during the fall (geometric mean = 2,983 m) than in any other season (Table 3). The mean activity of brown trout did not differ significantly between spring, summer, or winter. Distance traveled was significantly related to days between locations ($F = 5.53$; df = 1, 105; $P = 0.02$); however, the relationship was very weak ($r^2 = 0.05$). Mean monthly discharge was unrelated to mean monthly activity of brown trout ($r^2 = 0.13$; $F = 1.55$; df = 1, 10; $P = 0.24$). Mean monthly water temperature was positively related to mean monthly activity ($r^2 = 0.51$; $F = 9.38$; df = 1, 9; $P = 0.014$); however, when months associated with fall spawning movements (October and November) were eliminated from the analysis, fish activity was not significantly related to water temperature ($r^2 = 0.23$; $F = 2.07$; df = 1, 7; $P = 0.19$).

The movements of the four brown trout monitored for an entire year were similar. Those four fish moved little during the winter, spring, and summer seasons. During fall, all four fish moved extensively, presumably to spawn. Three of these fish (fish numbers 10, 100, and 181; Table 1) moved into the same area above the weir dam. Fish number 10 made an upstream movement of 3.6 km sometime between 9 and 29 October 1998 and returned back to its home area before 17 November 1998. Fish number 181 moved more than 11 km upstream in October 1998 and returned to its home area by mid-November. Fish number 100 moved upstream 4 km to the weir dam in November 1998, but was not located again. During the fall of 1997 and 1998, fish number 70 made movements in excess of 4 km downstream of its home area.

Discussion

Forty percent of brown trout lost their transmitters in the river channel or were assumed to have expired. Although we assumed that these fish died, it is likely that some fish expelled their transmitters. Comparable rates of transmitter loss in brown trout (23–50%) have been observed in similar studies (Meyers et al. 1992; Hudson 1993; Burrell et al. 2000). In a laboratory study, 59% of radio-implanted rainbow trout expelled their transmitters within 175 d postimplantation (Chisholm and Hubert 1985). The high rates of transmitter expulsion or fish mortality may be attributed to the time of tagging. Most of our fish were tagged in the fall, and many of those fish were gravid. The implantation of transmitters during the spawning season may have increased fish mortality (Winter 1983) or transmitter expulsion. Others have suggested that incision sites may become infected when water temperatures equal or exceed 20°C (Knights and Lasee 1996), but water temperatures in the Clinch River during tagging never exceeded 17°C. Five brown trout were implanted in May 1998, when water temperatures were cool (10°C), and all of those fish expelled their transmitters or died within 23 d of transmitter implantation.

The range of movements for trophy brown trout in the Clinch River was similar to the seasonal ranges documented in other telemetry studies of large brown trout. In the South Branch Au Sable River, Michigan, Clapp et al. (1990) found a mean spring–summer range of 4,935 m and a mean fall–winter range of 11,902 m. Brown trout in the mainstem Au Sable River also moved more in fall–winter (mean range = 4,764 m) than in spring–summer (mean range = 1,752 m) (Hudson 1993). However, more frequent observations or nocturnal locations of Clinch River brown trout may have revealed greater movement (Clapp et al. 1990; Matthews et al. 1994; Young et al. 1997; Young 1999). The seasonal ranges of large brown trout in the Clinch River were larger than those reported for small brown trout in smaller systems. The average range of movement for small brown trout in the Chattooga River, Georgia, did not exceed 100 m during any season (Burrell et al. 2000). Similarly, small brown trout in the South Branch Au Sable River had a mean summer range of only 29 m (Regal 1992). Young (1994) found that large brown trout in Wyoming streams ranged farther than smaller brown trout. The increased range of movement for large fish may be attributed to differences in foraging strategies. Large brown trout may have larger ranges to support their need for more food and subsequently more living space (Shetter 1968). Jenkins (1969) and Bachman (1984) observed smaller fish to be stationary drift feeders; the sit-and-wait drift feeding strategy of smaller fish would likely lead to smaller seasonal ranges.

The increased fall activity by brown trout in the Clinch River was probably related to spawning. Solomon and Templeton (1976), Meyers et al. (1992), and Burrell et al. (2000) documented extensive movements (>2,000 m) of brown trout during the fall and associated those movements with spawning. In the Clinch River, each fish made extensive short-term movements, during which they were away from their home area for no more than 39 d. The three fish that moved upstream all moved to an area near the weir dam; fish attempting to spawn are often observed in this area. Previous electrofishing surveys also detected the movement of large (>375 mm TL) brown trout into the upper reaches of the tailwater during the fall (Bettoli and Bohm 1997). Movements from summer habitat to spawning areas in the Clinch River began in late September.

Clinch River brown trout did not use separate river reaches in different seasons. The lack of movement into other river reaches in different seasons may have been related to seasonal homogeneity of habitat throughout the tailwater. In other river systems with natural hydrographs, seasonal movements unrelated to spawning were common (Clapp et al. 1990; Meyers et al. 1992; Hudson 1993; Young 1994).

The expense of telemetry studies (both economic and logistic) limits the number of individuals that can be monitored. We assumed that the few brown trout we monitored adequately represented the behavior of large brown trout in the Clinch River. In general, the fish tracked in this study behaved similarly, exhibiting limited movement in the winter, spring, and summer, and extensive movements to spawning areas in the fall. The similar behavior of fish tracked in this study, and the agreement of our findings with other studies of large brown trout in smaller rivers, lend credibility to our assumption.

Management Implications

In 1993, a 6-km ''quality zone'' was created on the Clinch River. In this zone, bait was prohibited, and a size limit and reduced creel limit regulations were enacted. During most of the year, the brown trout that we tracked would have been easily encompassed within a 6-km quality zone, which would have afforded some protection from harvest. However, many fish would have been vulnerable to increased exploitation for a short period (<40 d) each fall when they made extensive movements. Although the quality zone and its restrictive regulations were subsequently abolished in 1995 due to protests by some anglers and landowners, the concept makes biological sense on the Clinch River if the objectives are to maintain healthy stocks of large fish and afford some protections to spawning fish. A precedent exists in Tennessee for protecting spawning trout in regulated rivers. In 1999, the Tennessee Wildlife Resources Commission created two seasonal no-fishing spawning refuges on an eastern Tennessee tailwater, the South Fork of the Holston River, after it was determined that spawning habitat was severely restricted and trout were vulnerable when they congregated in several short reaches with suitable spawning substrate each winter (Bettoli et al. 1999). If a quality zone or similar regulations are ever again proposed for protection of large trout in the Clinch River, complete protection will not be obtained without a closure or restrictions of harvest in the vicinity of the weir dam each fall.

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