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ARTICLE

Behavior and Survival of Stocked Trout in Southern Appalachian Mountain Streams

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Abstract

Stocking of trout to support recreational fisheries is a common practice among state and federal agencies to meet angling and harvest demands. Success of stocking efforts relies upon fish behavior and survival to maximize the availability of fish to anglers. We quantitatively described the movement behavior and survival of stocked Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, and Rainbow Trout *Oncorhynchus mykiss* in three southern Appalachian Mountain streams in western North Carolina, USA, that were managed under delayed harvest regulations. Hatchery trout were tagged with a combination of PIT tags and radio transmitters (radio tags); stocked into "Delayed Harvest Trout Waters" of the North Toe, East Prong Roaring, and Little rivers; and monitored during the catch-and-release season from October to June. Assessed according to river and species, 19–65% of trout emigrated from the delayed harvest study reaches, while 1–29% died within the reaches. The majority of radio-tagged fish (71%; 59–85% by river) remained within 2 km of the stocking location, whereas 6% migrated over 10 km from the stocking location. Few trout stocked during fall (October and November) were available to anglers the following June due to a combination of migration and mortality. Emigration from delayed harvest study reaches was associated with stocking and high-flow events. Multi-state modeling detailed these observations with weekly estimates of migration and survival rates. River-specific differences in emigration and mortality suggested that emigration was a greater source of trout loss than mortality in all rivers; no pattern related to river size was apparent in emigration, but mortality was greater in small streams. Brook Trout mortality rates were highest among the three species, and large fish of most species showed higher emigration and mortality than catchable-sized trout. Fisheries managers can apply our results to alter stocking regimes so as to enhance the efficiency of stocking and the acclimation of stocked trout to instream environments.

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Stocking of trout (Salmonidae) to support recreational fisheries is a common practice among state and federal agencies in the United States. Trout fishing is among the most popular freshwater fishing pursuits in the United States behind fishing for black bass *Micropterus* spp. and closely tied with fishing for sunfish *Lepomis* spp. and catfish (Ictaluridae; USFWS and USCB 2006). Mountain trout streams, such as those in the southern Appalachian Mountains of western North Carolina, are typically small water bodies with low productivity, and fisheries in these streams cannot support a high level of harvest or mortality (Whitworth and Strange 1983; Waters 1992; Wallace 2010). Additionally, Appalachian Mountain wild trout fisheries have been negatively impacted by habitat degradation, water quality issues, and climate change (Jones et al. 1999; Sutherland et al. 2002; Flebbe et al. 2006). Therefore, supplemental stocking is required to meet human demand for trout fishing and harvest.

Stocking of hatchery fish is routinely performed to supplement wild fish populations for restoration purposes or to provide recreational activities (Cowx 1994; Heidinger 1999). In 2004, U.S. federal hatcheries produced and stocked 9.4 million trout in 16 states (USFWS and USCB 2006). The North Carolina Wildlife Resources Commission (NCWRC) has an active program of stocking trout in many mountain streams in the western region of the state. The fisheries promoted by this stocking activity provide economic benefit, supporting nearly 3,600 jobs and providing US$383 million in economic effect in 2014 (Responsive Management 2015; Responsive Management and Southwick Associates 2015). However, a substantial funding investment by the agency is required to produce, maintain, and stock trout to maintain stream fisheries.

Success of stocking efforts relies upon the behavior and survival of fish to maximize the availability of fish to anglers. Stocking efficiency can be improved by manipulating stocking rate, timing, location, fish size, species composition, and hatchery rearing practices (Wiley et al. 1993; Cowx 1994; Jonssonn et al. 1999; Brown and Day 2002). Therefore, an understanding of how stocked trout behave and survive once in the wild is crucial to guide such stocking and rearing decisions. Behavior and survival of hatchery-reared fish, however, are variable among systems and are not well understood (Helfrich and Kendall 1982; Bettinger and Bettoli 2002; Aarestrup et al. 2005; Baird et al. 2006; High and Meyer 2009).

One goal of a fish stocking program is to maximize angler satisfaction while minimizing costs (i.e., maximizing efficiency). Typically, fish are stocked periodically to sustain angling and harvest (e.g., "Hatchery-Supported Trout Waters" in North Carolina). Another strategy applied in North Carolina is delayed harvest trout stocking and a regulation designed to improve the overall quality of the fishery by increasing catch rates and allowing harvest seasonally (Borawa et al. 1993). In North Carolina's "Delayed Harvest Trout Waters," trout are stocked in streams during fall and spring for catch-and-release fishing until early summer, when harvest is allowed. This approach seeks to maximize the efficiency of hatchery-reared fish by allowing individuals to be caught multiple times and then harvested once waters warm the following summer. However, the delayed harvest approach relies on stocked trout remaining in the area designated with the prescribed angling regulations.

We conducted research to quantitatively describe stocked trout behavior and estimate their persistence and survival in North Carolina Delayed Harvest Trout Waters, thereby allowing identification and mitigation of any obstacle to the agency goal of maximizing the efficiency of trout stocking in stream and river fisheries. The objectives of our research were to describe (1) stocked trout migration rates over time, (2) migration spatial patterns of stocked trout, and (3) stocked trout persistence among streams. We accomplished this by using two tagging approaches to track trout that were stocked into three different delayed harvest reaches over a 2-year period. By monitoring tagged fish, we determined whether stocked trout remained in these reaches, emigrated, or died, and we estimated the rates at which these events occurred. Three reaches in rivers of varying size were studied to evaluate trends associated with physical characteristics and stocking rates, species, and timing. We then developed a multi-state modeling approach to estimate movement rates and mortality and ultimately model the number of trout retained in each reach.

STUDY AREA

We studied stocked Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, and Rainbow Trout *Oncorhynchus mykiss* in three different southern Appalachian river systems from October 2012 through June 2014 (Table 1). From October 2012 to June 2013, research took place in the North Toe River (NTR) delayed harvest water. The NTR is a tributary of the Nolichucky River and ultimately the Tennessee River. The reach was 3.7 km long and located in Mitchell County, North Carolina, in the town of Spruce Pine. The study reach was located within a predominantly urban environment, with a mix of riparian development.

Research from October 2013 to June 2014 occurred on the delayed harvest waters of the East Prong Roaring River (EPR) and Little River (LTR). The EPR study reach spanned two delayed harvest reaches (Stone Mountain Creek; and EPR, upper), was 7.2 km long, and was located almost entirely within Stone Mountain State Park in Wilkes County. It is a tributary of the Roaring River in

TABLE 1. Physical characteristics of the three "Delayed Harvest Trout Waters" studied in North Carolina. The North Toe River was sampled in 2012–2013; the East Prong Roaring and Little rivers were sampled in 2013–2014. The North Carolina Department of Environment and Natural Resources (NCDENR) assessment column is the stream quality rating based on benthic invertebrate, fish, and habitat metrics used to measure the health of aquatic ecosystems.

Study system	Drainage area (km^2)	Mean width (m)	Reach length (km)	NCDENR assessment	Latitude	Longitude
North Toe River	474[a]	24.4	3.7	Good to fair[c]	35.9125	−82.0655
East Prong Roaring River	57[b]	8.4	7.2	Good to excellent[d]	36.3972	−81.0637
Little River	47	11.7	4.0	Good to excellent[e]	36.4680	−81.1346

[a]Weaver and Kwak 2013.
[b]Wallace 2010.
[c]NCDENR 2003.
[d]NCDENR 2002.
[e]NCDENR 2004.

the Yadkin River/Pee Dee River basin. The reach was primarily forested, with minimal development. The LTR reach was 4.0 km long and located in Alleghany County. The LTR is a tributary of the New River and flows through a mixed forested and pasture landscape. The three study rivers were chosen on the basis of size, with the NTR representing a large trout stream, the EPR representing a small stream, and the LTR representing an intermediate stream.

Because there were no U.S. Geological Survey (USGS) streamflow gauges on the three study rivers, we applied discharge data collected at two spatially proximate gauges during the study as correlates. These were located on the Yadkin River at Elkin, North Carolina (USGS 02112250; data applied to EPR and LTR), and on the South Toe River near Celo, North Carolina (USGS 03463300; data applied to the NTR).

METHODS

Trout stocking and angling.— The southern Appalachian trout streams in our study were stocked and managed by the NCWRC under delayed harvest procedures and regulations. Delayed harvest management was established at different times among individual reaches, with the oldest (EPR delayed harvest waters) established in 1992. The NTR and LTR delayed harvest waters were established more recently (2008 and 2012, respectively). In each delayed harvest reach, trout stocking took place during fall (October and November) and spring (March, April, and May) of the following year. Stocking rate varied based on stream size (Table 2), but the species ratio was the same for all rivers: 40:40:20 (Brook Trout : Rainbow Trout : Brown Trout). Delayed harvest regulations allowed for catch-and-release, artificial-lure-only angling during October–May, after which harvest was permitted with a seven-fish daily creel limit and no size limit from the first Saturday in June to September. In hatchery-supported waters, where fish are available for harvest immediately after stocking, trout are typically harvested to near depletion after the season is open (Besler et al. 2005), which likely occurs in each reach after harvest is permitted.

Directly downstream of the EPR and LTR were reaches that the NCWRC managed as Hatchery-Supported Trout Waters. These reaches were stocked each month from March to August at the same species ratio but at lower densities than the Delayed Harvest Trout Waters. Angling regulations here stipulate a year-round seven-fish daily bag limit with no size limit, except during a closed period from March 1 to the first Saturday in April.

Fish tagging.— To elucidate the movement patterns and survival of stocked trout, subsamples of stocked trout received two different types of implanted tag: Advanced Telemetry Systems (ATS) radio transmitters (ATS, Inc., Isanti, Minnesota) and Biomark PIT tags (Biomark, Inc., Boise, Idaho). The radio transmitters were ATS Model F1580 units with an operating frequency of 48–50 MHz, a nominal weight of 3.6 g, expected battery life of 381 d, and a 20-cm external cable antenna. The PIT tags were 23-mm, half-duplex (HDX) tags. Tags were implanted into three trout species (Brook Trout, Brown Trout, and Rainbow Trout) obtained at NCWRC trout hatcheries (Armstrong State Fish Hatchery, Marion, North Carolina, in 2012–2013; Table Rock State Fish Hatchery, Morganton, North Carolina, in 2014). Radio transmitters were implanted into stocked trout in all three river systems, and fish that were stocked in the NTR and EPR were also PIT-tagged.

Passive integrated transponder tagging provided a large sample size with which to evaluate emigration from the reach and allowed fish movement to be monitored continuously. Because it was easier to manually detect radio transmitters than PIT tags, radiotelemetry provided more information on the fate of tagged trout and movement

TABLE 2. Number of trout that were stocked and tagged according to river and date. Total trout stocked includes tagged and untagged trout of all species (Brook Trout, Brown Trout, and Rainbow Trout). Trout that were radio-tagged in May 2014 were tagged with reused, recovered tags. The East Prong Roaring River study reach included two delayed harvest reaches (Stone Mountain Creek; and East Prong Roaring River, upper).

Stocking date	Total trout stocked	Radio-tagged trout	PIT-tagged trout
	North Toe River		
Oct 12, 2012	3,800	60	600
Nov 2, 2012	3,800		600
Mar 4, 2013	3,800	60	600
Apr 2, 2013	3,800		600
May 2, 2013	3,800		600
Total	19,000	120	3,000
	East Prong Roaring River		
Oct 14, 2013	2,460	30	600
Nov 1, 2013	2,460	30	600
Mar 3, 2014	2,460	30	600
Apr 1, 2014	2,460	30	600
May 1, 2014	2,460	14	600
Total	12,300	134	3,000
	Little River		
Oct 21, 2013	1,500	23	0
Nov 4, 2013	1,500	22	0
Mar 5, 2014	1,500	23	0
Apr 4, 2014	1,500	22	0
May 5, 2014	1,500	4	0
Total	7,500	94	0

outside of the study reaches. Complementary data from both methods informed the multi-state model; PIT tag data provided most of the emigration data, and radiotelemetry provided most of the mortality data. The multi-state model framework is dependent on data providing a known tag state with which to model accurate estimates.

Trout were PIT-tagged using procedures outlined by Bateman and Gresswell (2006), with the goal of maximizing retention and survival. Trout receiving a PIT tag were lightly anesthetized in aerated hatchery water containing tricaine methanesulfonate (MS-222) at a concentration of 60 mg/L for 2–3 min. After anesthetization, TL and weight were measured for each fish, and a PIT tag was implanted intra-abdominally by using an injection needle and syringe. Tagged trout were then placed in a holding tank for recovery. Each PIT tag implantation lasted approximately 30 s.

Fish that received a radio transmitter were anesthetized for 4 min in a 50-mg/L solution of MS-222. After anesthetization, TL and weight were measured, and each fish was moved to a surgery tank. Surgery occurred with the trout placed in a cradle, its head and gills submersed, with the dorsum extending above oxygenated water containing MS-222 at 30 mg/L. Radio transmitters required a 12-mm incision, and each surgery lasted approximately 8 min. Both a radio transmitter and a PIT tag were implanted intra-abdominally, with the trailing antenna exiting through the body wall. The main incisions were closed with two sterile sutures, while a third suture secured the antenna at the exit point. All instruments, PIT tags, and radio transmitters were disinfected in a solution of Benz-All surgical disinfectant and rinsed with distilled water before use.

A consistent number of 600 PIT tags was implanted in association with each monthly stocking during both years (Table 2). Tags were divided evenly among species, regardless of stocking rates, and were divided further between two fish size categories determined by the NCWRC: “catchable” (mean TL = 268 mm, SD = 29.2) and “large” (mean TL = 391 mm, SD = 44.2). The categories were not precisely based on size but were primarily based on differing hatchery protocols and stocking procedures. Between 10% and 20% of PIT tags, depending on the river, were implanted into the large size-group of each trout species. Radio transmitter numbers varied by river, with the NTR and EPR initially receiving 120 transmitters each and the LTR receiving 90. The species ratio of radio-tagged fish was 40:40:20 (Brook Trout : Rainbow Trout : Brown Trout) in the NTR and EPR and 39:39:22 in the LTR.

Trout were tagged several days before scheduled stockings and were held to monitor posttagging condition. Tagged trout were then stocked by NCWRC personnel at multiple locations within each study reach by use of standard procedures. In the NTR, radio-tagged fish were stocked on two occasions: October 2012 and March 2013. In the other two rivers, radio-tagged fish were stocked during all stocking events. Radio transmitters were implanted at a different species ratio because of a lower stocking rate for Brown Trout. After transmitters from fish mortality or angler capture were collected during the season, an additional 14 transmitters in the EPR (5 Brook Trout, 4 Brown Trout, and 5 Rainbow Trout) and 4 in the LTR (1 Brook Trout, 1 Brown Trout, and 2 Rainbow Trout) were reimplanted into new fish for the May stocking.

We monitored the PIT tags by using fixed antenna arrays placed at the upstream and downstream ends of each delayed harvest reach where PIT tags were deployed (i.e., NTR and EPR). Arrays were designed using approaches described by Zydlewski et al. (2006) and Smith and Kwak (2014). These arrays included reader components from Oregon RFID (HDX, long-range model), which were secured streamside in metal boxes. These arrays were designed to be in operation continually and were powered either by 12-V DC deep-cycle batteries or by direct connection to a 120-V AC power source where possible. Antennae were constructed from 14-gauge stranded wire and were deployed perpendicular to the river bank in an oblong loop along the river bottom. This horizontal pass-over design was used to protect the array from damage during flood events (Greenberg and Giller 2000). Antennae were secured to the river bottom by using natural substrate materials, sand bags, and rebar and then were tuned to maximize the detection range.

The PIT arrays were operational for most of each October–June study period, except during minimal occasional outages. Outages occurred in 13 of 242 d (5.3%) at the upper EPR array; 19 of 242 d (7.8%) at the lower EPR array; 28 of 246 d (11.4%) at the upper NTR array; and 13 of 246 d (5.3%) at the lower NTR array. Outages in the NTR were primarily related to high river flows, where the array either was damaged by flooding or was pre-emptively removed prior to anticipated rainfall events. In the EPR, outages were primarily a result of power supply issues resulting from maintaining charged batteries for the arrays. Despite regular battery changes, low winter temperatures resulted in additional frequent outages.

In addition to the automated arrays, PIT tags were manually tracked during the study periods. During 2012–2013 in the NTR, tagged fish were tracked weekly by using a floating array. This consisted of a floating antenna attached to a 2.5-m, inflatable raft that was floated down the delayed harvest reach. Locations of detected PIT tags were recorded with a handheld GPS unit, and precise electronic time stamps from float tracks were used to attribute locations to PIT tag detections. Three passes were conducted through the reach to enhance detection. In the EPR during 2013–2014, manual tracking was performed monthly using a floating array that was waded by personnel through the reach.

Radio-tagged fish were tracked manually on a weekly basis in each river system. An ATS Model R2000 receiver was used with a hand-held loop antenna. Tracking was performed by floating in a raft or canoe, walking the riverbank, or wading in the river. Fish locations were determined by triangulation, with visual confirmation when possible. When a fish was located, its frequency, GPS location, date, and time were recorded.

Multi-state model.— A simple multi-state capture–recapture model (Lebreton et al. 2009) was developed to estimate movement and survival parameters over time in each study river. The model was generally based on that described by Kéry and Schaub (2012). The model allowed us to estimate weekly transition probabilities and apparent mortality in each delayed harvest reach. The capture–recapture model was based on a Cormack–Jolly–Seber model (Cormack 1964; Jolly 1965; Seber 1965), which relies on the repeated recapture of tags within a study area to estimate survival within the reach. Three states were designated in the model: (1) alive within the reach, (2) outside of the reach, and (3) dead within the reach (Table 3). A transition probability is the probability that an animal may move between given model states during a given time (Williams et al. 2002), and apparent mortality is the probability that an animal is not available to any state during the next time step (i.e., week). The model incorporated weekly binary capture history data for individuals based on detections of both radio transmitters and PIT tags. The model was executed using R and WinBUGS, a Bayesian Markov chain–Monte Carlo (MCMC) Gibbs sampler.

Three model parameters were estimated with a weekly time step: movement rate (psi [Ψ]), mortality (phi [Φ]), and detection probability (p). Model scenarios consisted of runs that projected combinations of constant and time-varying parameters (Table 4). Model runs were parameterized using uninformative priors (uniform distribution [0, 1] for Ψ, Φ, and p) based on PIT tag and radio tag data combined, except for the LTR, where trout were only radio-tagged. All models were run with 10,000 iterations and 5,000 iterations for burn-in (i.e., model initialization), and thinning was set at 2. Three chains were used for each MCMC run, and model chain convergence was monitored using the R statistic, where convergence is indicated by values approaching 1.0 (Brooks and Gelman 1998). The best, most plausible candidate model for each river was selected using deviance information criterion (DIC) values

TABLE 3. Structure of the multi-state model. The state transition matrix represents the transition probabilities between different model states. Apparent survival is represented by Φ, while Ψ represents the movement probability between states. The observation matrix simulates the detection probability at each state, represented by p.

True state	Observed state: In delayed harvest reach	Outside delayed harvest reach	Mortality (state transition matrix) or not detected (observation matrix)
State transition matrix			
In delayed harvest reach	$\Phi(1-\Psi_{AB})$	$\Phi\Psi_{AB}$	$1-\Phi$
Outside delayed harvest reach	$\Phi\Psi_{BA}$	$\Phi(1-\Psi_{BA})$	$1-\Phi$
Mortality	0	0	1
Observation matrix			
In delayed harvest reach	p_A	0	$1-p_A$
Outside delayed harvest reach	0	p_B	$1-p_B$
Mortality	0	0	1

generated by WinBUGS (Spiegelhalter et al. 2002; Kéry and Schaub 2012). Parameter estimates were then used to simulate the number of trout available in delayed harvest reaches throughout the study period. This was performed using a simple decay model that used weekly mortality and movement estimates to estimate the number of fish in each reach over time. Weekly estimates of movement and mortality were multiplied together to obtain monthly estimates.

Limitations of our data—most of which arose from uncertainty in the fate of tagged trout—could affect model results if bias occurred between fish with known and unknown fates. Data gaps occurred when live, PIT-tagged trout left the system undetected (e.g., fish migrating in groups; read range limitations), if there was an outage in an array (e.g., during flooding), or when tags from dead trout within the reach went undetected by manual tracking.

RESULTS

The approach to combine radiotelemetry and PIT-tagging methods to determine the behavior and survival of stocked trout proved effective. The PIT tag results indicated that trout emigrated from both rivers (EPR and NTR) after stocking, but the rate varied by river (Figure 1). Generally, emigration rates were highest immediately after stocking but declined over time. A von Bertalanffy curve was fitted to the emigration data, and the curves were significantly different ($P < 0.005$) for each river. Parameter values were asymptotic number of trout emigrated (N) = 327.07, emigration rate (K) = 0.01, and time at which emigrated number of trout was 0 (t_0) = −15.9 for NTR and N = 147.65, K = 0.03, and t_0 = −1.18 for EPR. The rate at which trout emigrated from delayed harvest reaches after stocking was relatively consistent among stocking cohorts, especially in the NTR. In the EPR, a steep rise in emigration several weeks after the October and November stockings was correlated with a large rainfall event after prolonged low streamflows during an "abnormally dry" low-flow period (Figure 2;

TABLE 4. Multi-state model descriptions and deviance information criterion (DIC) model selection values ([.] = constant parameter; [t] = time-varying parameter; [s] = site-varying parameter). A lower DIC score indicates a more strongly supported candidate model. Model parameters are weekly movement rate (Ψ), mortality (Φ), and detection probability (p).

Model	DIC
North Toe River	
Ψ(t), Φ(t), p(s)	4.85×10^{20}
Ψ(.), Φ(t), p(s)	5.04×10^{20}
Ψ(t), Φ(.), p(s)	5.06×10^{20}
Ψ(.), Φ(.), p(s)	5.27×10^{20}
East Prong Roaring River	
Ψ(t), Φ(t), p(s)	6.21×10^{19}
Ψ(.), Φ(t), p(s)	6.75×10^{19}
Ψ(t), Φ(.), p(s)	7.42×10^{19}
Ψ(.), Φ(.), p(s)	8.83×10^{19}
Little River	
Ψ(.), Φ(t), p(s)	3.08×10^{19}
Ψ(.), Φ(.), p(s)	3.20×10^{19}
Ψ(t), Φ(.), p(s)	3.26×10^{19}
Ψ(t), Φ(t), p(s)	3.28×10^{19}

National Drought Mitigation Center, University of Nebraska, Lincoln; http://www.droughtmonitor.unl.edu). Emigration patterns of PIT-tagged fish were supported by the movements of radio-tagged trout.

The number of daily detections recorded by the PIT arrays varied widely throughout the study period (Figure 2). Peaks in detections were associated with stocking dates and stream discharge. Daily activity range was similar between the two rivers, with 0–15 fish detections/d. Activity was fairly continuous throughout the season in the NTR, but periods without detections occurred, especially during winter, in the EPR. In both rivers, PIT arrays were installed at the upper and lower ends of the delayed harvest reaches, but trout in the EPR were unable to access areas upstream of the array due to a low waterfall that prevented upstream migration under typical flow conditions. Thus, we only observed downstream movement over arrays in the EPR, whereas we observed both upstream and downstream movement in the NTR. In the NTR, a slight majority of trout that left the reach (58%) did so by moving downstream. The PIT-tagged trout that remained within the reach exhibited the same predominantly downstream pattern.

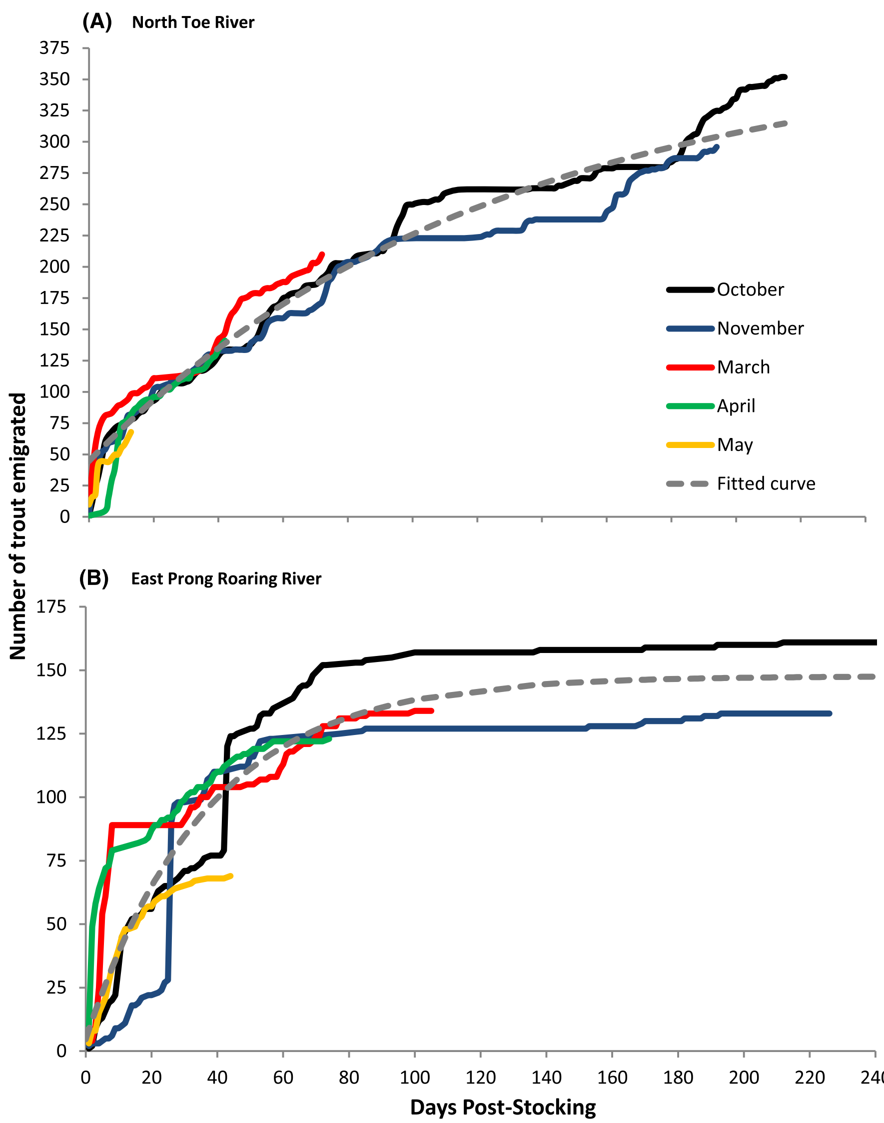

FIGURE 1. Observed cumulative number of PIT-tagged trout emigrating from reaches designated as “Delayed Harvest Trout Waters” over time after stocking, based on fixed PIT array detections in two North Carolina rivers. Each line represents a monthly trout stocking event. A von Bertalanffy curve was fitted to the data for each river, and parameter estimates were significantly different (P < 0.005) for each. Parameter values were asymptotic number of trout emigrated (N) = 327.07, emigration rate (K) = 0.01, and time at which emigrated number of trout was 0 (t_0) = −15.9 for the North Toe River (**A**); and N = 147.65, K = 0.03, and t_0 = −1.18 for the East Prong Roaring River (**B**).

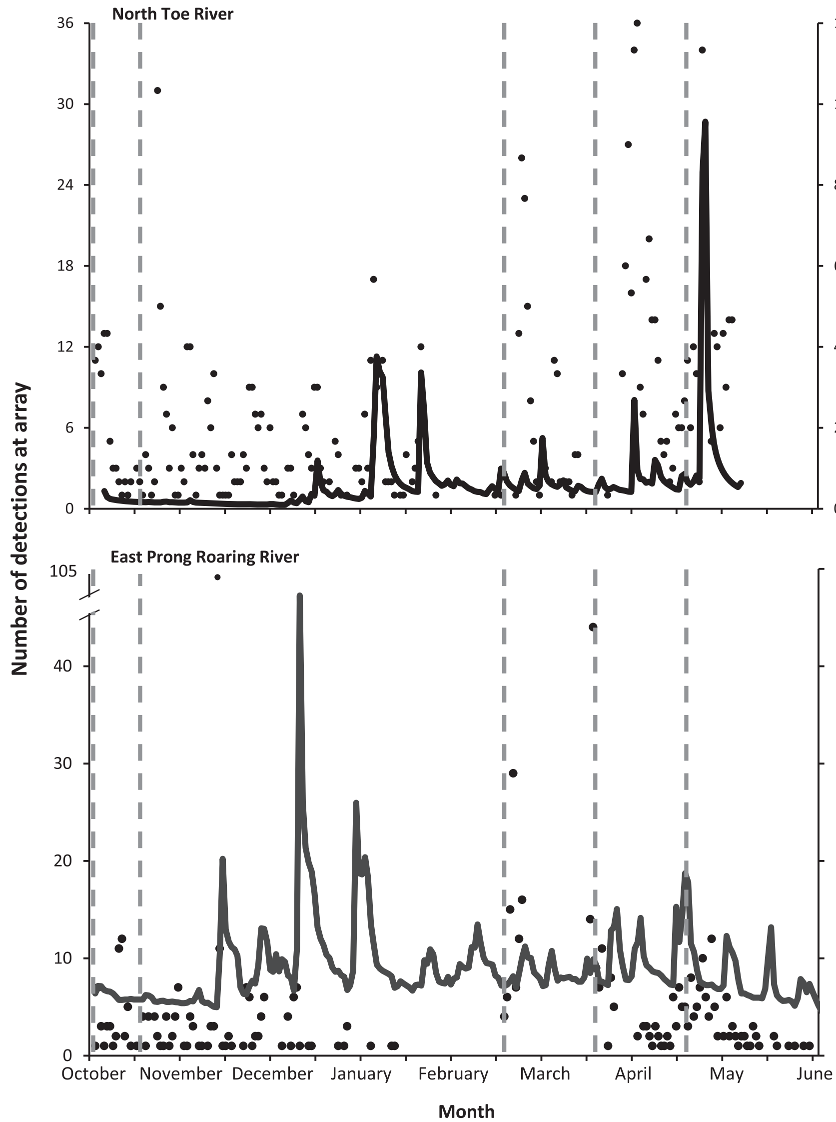

FIGURE 2. Number of daily PIT-tagged trout detections at receiver arrays (circles) and daily mean river discharge (solid line) during the 2013 (North Toe River) and 2014 (East Prong Roaring River) study periods. Dashed vertical lines represent stocking dates.

Overall, emigration was a greater source of trout loss from delayed harvest reaches than mortality (Figure 3), except in the cases of a few individual size-classes and species (Table 5). Mortality estimates were much lower in the NTR than in the other two rivers. There was not a consistent monthly pattern in mortality rates among rivers. The EPR was estimated to have high mortality rates during most of the spring months. Brook Trout mortality was highest among species. Large-sized trout showed higher mortality than that of catchable-sized trout for all species in all rivers.

Movement patterns varied by trout species, size, and river (Table 5). In the NTR, Brook Trout were more likely than the other two species to emigrate from the study reach, with nearly half leaving. In the EPR, Rainbow Trout were most likely to emigrate, with over two-thirds doing so. Species-specific emigration rates were more similar in the LTR relative to the other two rivers, but over half of all radio-tagged trout left the study reach. Large Brown Trout emigrated at a higher rate than catchable Brown Trout in all rivers, but large Brook Trout and Rainbow Trout emigrated more frequently than catchable trout in two of the three rivers, and large fish of all species emigrated at greater rates than catchable trout in the LTR.

Patterns of radio-tagged trout agreed with those observed for the larger PIT-tagged population in the two rivers where both tagging approaches were applied. Radio-tagged trout persisted longer in the NTR—especially

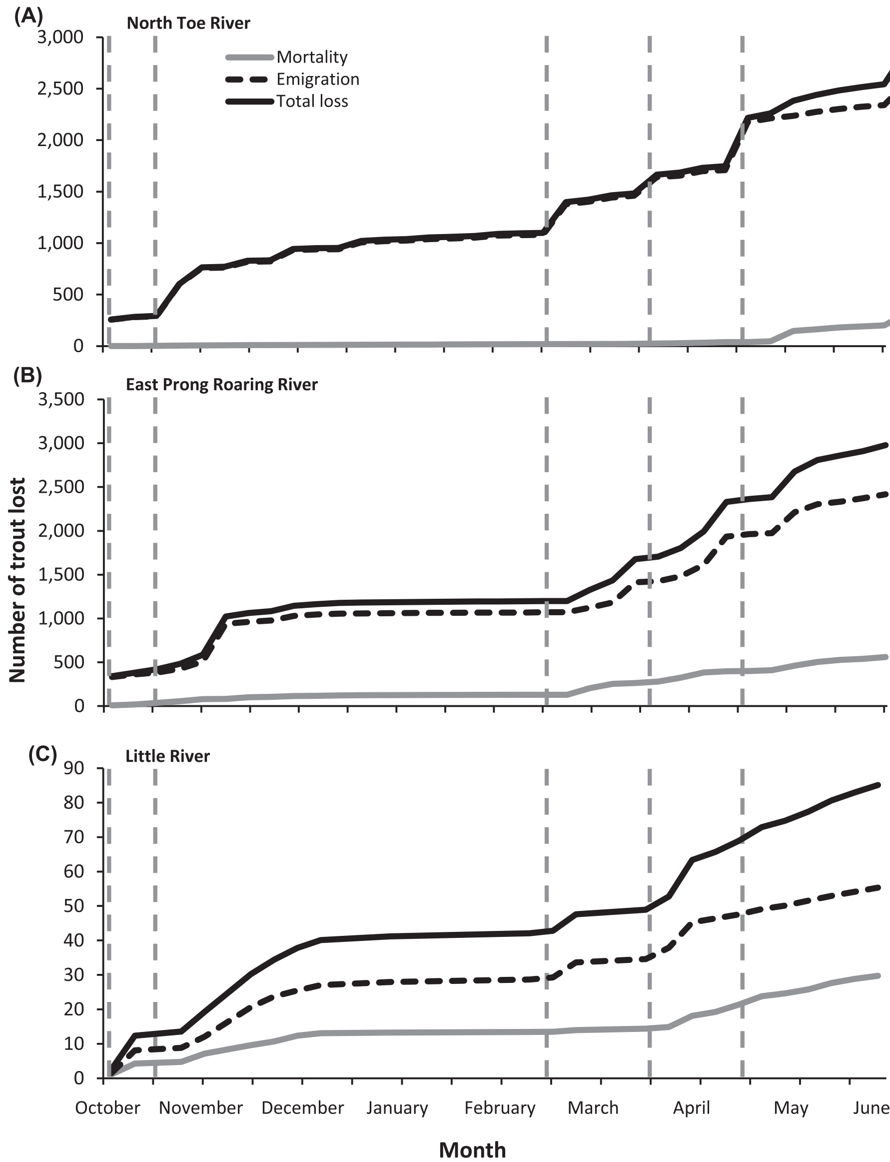

FIGURE 3. Modeled fates of tagged trout in each delayed harvest reach during the 2013 (North Toe River [**A**; PIT tags and radio tags]) and 2014 (East Prong Roaring River [**B**; PIT tags and radio tags] and Little River [**C**; radio tags]) study periods. Mean estimates of mortality and emigration parameters were used for projections.

during winter—than in the other two systems. The majority of individual radio-tagged trout moved little during the course of the study (Figure 4). Distance moved (km) and rate of movement (km/d) were calculated by measuring linear distance moved during a fish's time at large from stocking until death or the conclusion of the study (Table 6). Among radio-tagged fish, 71% (59–85% by river) remained within 2 km of the point where they were stocked. Generally, individual trout were observed to move for the first week or two after stocking and then remained within an area, displaying minimal movement. Trout in the NTR moved longer distances than those in the other rivers. At the end of the study, trout in the NTR were dispersed over 29.6 km of river (linear range) compared to 9.06 km for those in the EPR and 12.49 km for those in the LTR. Individual Brook Trout showed the longest movements in each river, with the longest overall range being 22.2 km downstream in the NTR.

Within-species comparisons revealed that trout in the NTR moved greater mean distances than those in the other two rivers (Table 6). Overall, Brown Trout were most sedentary relative to the other species. Brook Trout moved the most, followed by Rainbow Trout, except in the LTR, where Rainbow Trout were the most active species. Seasonally, results varied among rivers. In the NTR and LTR, Brook Trout moved the most during fall, and

TABLE 5. Observed proportions of radio-tagged and PIT-tagged trout of each species and size-class that were lost to emigration or mortality in delayed harvest waters within three western North Carolina mountain streams. Proportions were based on the observed fates of individual tags if available. Size-classes were determined by the North Carolina Wildlife Resources Commission (catchable-sized trout: mean TL = 268 mm, SD = 29.2; large trout: mean TL = 391 mm, SD = 44.2).

Species and size-class	*N*	Emigrated	Mortality
North Toe River			
All Brook Trout	1,000	0.47	0.01
Catchable	800	0.41	<0.01
Large	200	0.69	0.02
All Brown Trout	1,000	0.33	0.01
Catchable	800	0.33	0.01
Large	200	0.33	0.02
All Rainbow Trout	1,000	0.29	0.01
Catchable	800	0.25	0.01
Large	200	0.43	0.02
East Prong Roaring River			
All Brook Trout	1,030	0.19	0.19
Catchable	853	0.16	0.14
Large	177	0.39	0.65
All Brown Trout	954	0.38	0.12
Catchable	852	0.40	0.09
Large	102	0.28	0.24
All Rainbow Trout	1,030	0.65	0.11
Catchable	853	0.64	0.09
Large	177	0.70	0.22
Little River			
All Brook Trout	31	0.55	0.29
Catchable	22	0.59	0.23
Large	9	0.44	0.44
All Brown Trout	31	0.58	0.13
Catchable	22	0.55	0.05
Large	9	0.45	0.27
All Rainbow Trout	32	0.59	0.22
Catchable	23	0.70	0.13
Large	9	0.33	0.44

Rainbow Trout moved most in spring. Movement rates (km/d) ranged from 0.02 to 0.10 km/d and were correlated to distance moved. Rainbow Trout in the LTR had the highest rate of movement, while Brown Trout in the NTR had the lowest.

Although many tagged trout stayed within the delayed harvest study reaches, a number of radio-tagged trout (33 fish; 10.1% of all radio-tagged fish) moved greater than 5 km downstream in each system. Some of these movements were rapid, occurring a few days after stocking, but most took place over the course of several weeks. Among the slowest moving trout were 12 fish (0.004% of the total) that traveled the entire 7.2-km length of the EPR delayed harvest reach, taking approximately 4 weeks to do so (mean = 27.8 d).

The most plausible modeling scenarios (lowest DIC values) were the same for the NTR and EPR (Table 4). These scenarios included time-variable movement and mortality. The best-supported model for the LTR included time-variable movement but constant mortality. Detection probability varied across all states but was generally higher for live trout within the study reaches than for trout outside the reaches or dead trout. Using parameter estimates derived from the models, we simulated the number of tagged trout in each delayed harvest reach throughout the study season. A majority of stocked fish that were unavailable to anglers emigrated from the reach as opposed to dying, although the proportion that emigrated varied among rivers. In general, population numbers declined steeply immediately after stocking and then less so over time. In all reaches, trout numbers were lowest during the winter months (December–February), with the EPR approaching zero remaining tagged fish (Figure 5). The NTR was estimated to retain more tagged fish overall, especially during winter.

The models and associated parameter estimates provided insight into the causes of observed declines in tagged trout numbers over time in the delayed harvest reaches (Figure 3). In each system, emigration from the delayed harvest reaches was the greatest contributor to population decline. There were no clear patterns in movement and emigration rates over monthly time periods, but movement rates appeared slightly higher during stocking months in the NTR and EPR and over the last few months of each study year (Table 7).

DISCUSSION

Tagging showed that the number of stocked trout available to anglers varied over the course of the study but was lowest at the end of winter, just prior to the March stocking, for all rivers (Figure 5). Low winter availability and survival of stocked trout have been observed in other studies (Cresswell and Williams 1983; Bettinger and Bettoli 2002; Hartman et al. 2012). Fish availability to anglers was highest within the first few weeks poststocking in each river system, but only in the NTR was there an appreciable accumulation of trout numbers prior to the opening of fish harvest. Estimated mortality increased during the final month of the study period, coinciding with warming water temperatures and the opening of harvest (Table 7), and few trout remained in the system afterward (Besler et al. 2005; Weaver and Kwak 2013). In the EPR and Cane Creek (a tributary of the NTR), a tagging depletion study using stocked trout was performed during 2012–2013 and showed a similar decline in trout density after stocking events (J. Fischer and colleagues, North Carolina State University, unpublished data).

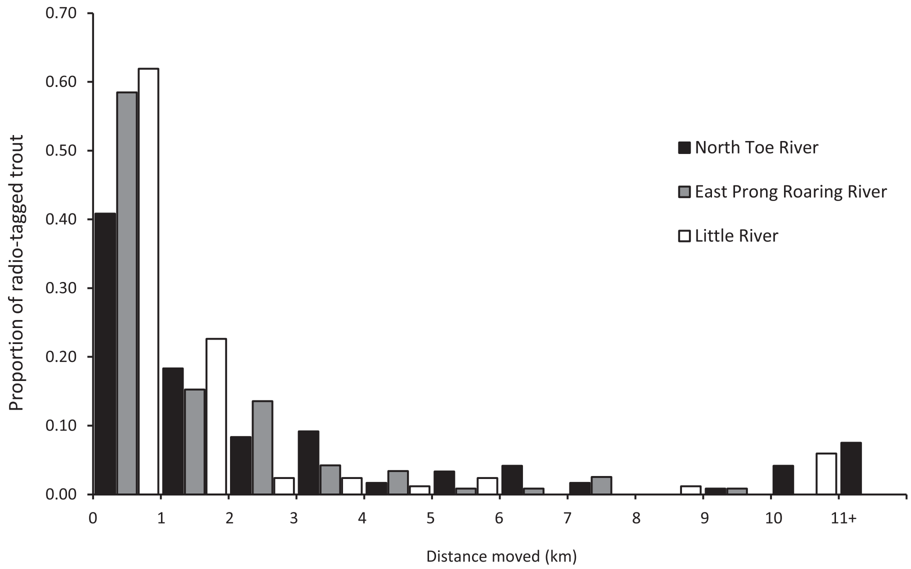

FIGURE 4. Distance moved by radio-tagged trout in each of the three study rivers in North Carolina. The maximum distance a trout was observed to move in the North Toe River was 22.2 km.

TABLE 6. Median (SE in parentheses) distance and daily rate of movement for radio-tagged stocked trout according to river, species, and season.

	Fall		Spring		Combined	
Species	Median distance (km)	Median rate (km/d)	Median distance (km)	Median rate (km/d)	Median distance (km)	Median rate (km/d)
			North Toe River			
Brook Trout	6.86 (0.62)	0.03 (0.01)	1.22 (0.39)	0.02 (0.01)	2.33 (0.95)	0.03 (<0.01)
Brown Trout	0.71 (0.31)	0.01 (<0.01)	0.48 (0.33)	0.01 (0.01)	0.65 (0.35)	0.01 (<0.01)
Rainbow Trout	2.28 (0.41)	0.13 (0.01)	1.25 (2.11)	0.14 (0.30)	1.58 (0.83)	0.01 (0.01)
			East Prong Roaring River			
Brook Trout	0.18 (0.54)	0.01 (0.02)	2.01 (0.57)	0.06 (0.02)	0.91 (0.30)	0.04 (0.01)
Brown Trout	0.62 (0.42)	0.01 (0.01)	0.56 (0.69)	0.02 (0.04)	0.57 (0.28)	0.02 (0.01)
Rainbow Trout	0.75 (0.52)	0.03 (0.02)	0.70 (0.55)	0.02 (0.01)	0.73 (0.27)	0.03 (0.01)
			Little River			
Brook Trout	1.25 (1.27)	0.04 (0.05)	0.33 (0.93)	0.01 (0.04)	0.87 (0.52)	0.03 (0.05)
Brown Trout	0.73 (0.85)	0.03 (0.02)	0.19 (0.14)	0.01 (<0.01)	0.29 (0.31)	0.01 (0.01)
Rainbow Trout	1.74 (0.63)	0.04 (0.07)	0.70 (1.54)	0.01 (0.10)	0.98 (0.60)	0.02 (0.05)

Our observations of stocked trout movements were similar to those by other investigators (Helfrich and Kendall 1982; Bettinger and Bettoli 2002; Baird et al. 2006; High and Meyer 2009; Hartman and Logan 2010; Quinn and Kwak 2011; Hartman et al. 2012) in that most stocked trout remained within a few kilometers of where they were

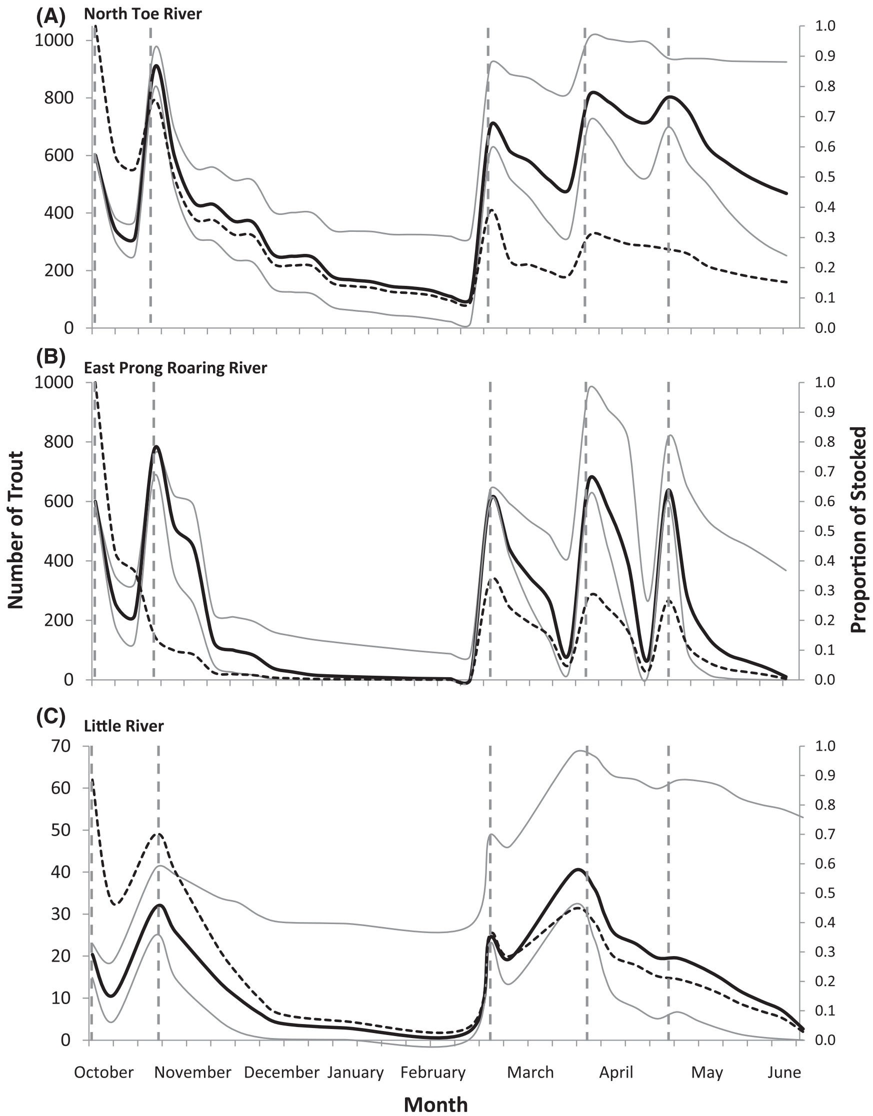

FIGURE 5. Modeled number of tagged trout (all species) in each delayed harvest reach during the 2013 (North Toe River [**A**]) and 2014 (East Prong Roaring River [**B**] and Little River [**C**]) study periods. The dark line represents the actual number of tagged trout; gray lines denote upper and lower 95% credible intervals; the dashed line is the proportion of tagged trout remaining; and the vertical dashed lines represent stocking dates.

stocked, but a small proportion moved several kilometers away (Figure 4). These movements support the "restrictive movement paradigm," which suggests that fish spend most of their time in short stream reaches (Gerking 1959; Rodríguez 2002). Stocked trout appear to move greater distances than wild trout (Jenkins 1971; Helfrich and Kendall 1982; Bachman 1984; Bettinger and Bettoli 2002; Weber and Fausch 2003).

Previous research suggests that trout tend to move downstream more in smaller streams relative to movement in larger rivers (Cresswell 1981). Trout could not move upstream in the EPR due to a natural impediment. In the NTR, 65% of stocked Brook Trout and Rainbow Trout moved downstream, whereas 58% of Brown Trout moved upstream. The tendency of Brown Trout to move upstream (Brynildson 1967; Helfrich and Kendall 1982) and the tendency of Rainbow Trout and Brook Trout to move downstream (Moring and Buchanon 1978; Helfrich and Kendall 1982) have been observed in other studies. Daily activity at PIT arrays was more consistent in the NTR (Figure 2), likely attributable to the river's larger size relative to the other reaches.

Genetics, habitat suitability and availability, food resources, and fish density constitute likely influences on emigration variability among species and among rivers (Lewis 1969; Cresswell 1981; Wilzbach 1985). Observed

TABLE 7. Monthly estimates of emigration and mortality rates (proportions) by river for all trout species combined (NTR = North Toe River; EPR = East Prong Roaring River; LTR = Little River). Values were derived from weekly model estimates. Values in parentheses are 95% credible intervals.

	Emigration			Mortality		
Month	NTR	EPR	LTR	NTR	EPR	LTR
Oct	0.47 (0.37–0.56)	0.61 (0.45–0.73)	0.37 (0.13–0.59)	<0.01 (<0.01–0.02)	0.08 (0.02–0.22)	0.27 (0.06–0.53)
Nov	0.53 (0.43–0.65)	0.82 (0.69–0.90)	0.46 (0.14–0.70)	0.02 (0.01–0.04)	0.26 (0.12–0.45)	0.26 (0.03–0.55)
Dec	0.42 (0.28–0.59)	0.77 (0.37–0.96)	0.39 (0.20–0.72)	0.01 (<0.01–0.05)	0.44 (0.05–0.93)	0.40 (0.13–0.70)
Jan	0.40 (0.19–0.61)	0.42 (0.19–0.79	0.34 (0.07–0.96)	0.02 (0.01–0.03)	0.25 (0.04–0.70)	0.19 (0.01–0.54)
Feb	0.26 (0.02–0.55)	0.48 (0.19–0.82)	0.49 (0.06–0.74)	0.02 (<0.01–0.04)	0.26 (0.04–0.70)	0.14 (0.02–0.38)
Mar	0.33 (0.11–0.54)	0.93 (0.67–0.98)	0.36 (0.07–0.69)	0.01 (<0.01–0.05)	0.51 (0.12–0.77)	0.13 (0.03–0.32)
Apr	0.61 (0.51–0.72)	0.87 (0.71–0.95)	0.27 (0.03–0.64)	0.03 (0.01–0.04)	0.43 (0.14–0.76)	0.29 (0.08–0.52)
May	0.75 (0.66–0.88)	0.82 (0.44–0.97)	0.33 (0.01–0.73)	0.04 (0.01–0.18)	0.59 (0.15–0.91)	0.33 (0.09–0.64)
Jun	0.12 (<0.01–0.37)	0.66 (0.15–0.98)	0.35 (0.02–0.70)	0.29 (<0.01–0.51)	0.60 (0.06–0.97)	0.56 (0.04–0.98)

species-specific differences in emigration are likely due to variable habitat affinities among species. Brook Trout are adapted to small streams with abundant cover and stable flows (Lewis 1969; Fausch and White 1981; Cunjak and Green 1983) and, therefore, tended to emigrate from the larger NTR at a greater rate than emigration observed from the smaller EPR. Petty et al. (2012) reported that Brook Trout in larger main-stem streams moved more than those in smaller tributary streams.

A primary assumption of the multi-state model we developed was that the future state of a trout is dependent on its current state (Lebreton et al. 2009; Jackson 2011). In general, this assumption was satisfied, as trout were available in delayed harvest study reaches to be detected as moving out. Detection was generally higher for radio tags than for PIT tags; PIT arrays detected 50% of the passing radio tags in the NTR and 67% in the EPR (i.e., in situ detection efficiency; Zydlewski et al. 2006). In situ detection efficiency estimates for PIT arrays are rare in the literature because double tagging, multiple arrays, or other redundant detection techniques are required for estimation. Adams et al. (2006) estimated that in situ detection efficiency of a PIT array for Common Snook *Centropomus undecimalis* in tidal creeks was 67%. Bliss et al. (2015) estimated in situ detection efficiency at 62–83% (mean = 72.0%) for arrays for warmwater and coolwater stream fishes. Finally, Raabe (2012) found that in situ detection efficiency varied widely among seasons, fish species, and arrays (mean = 67.2%; range = 0–100%) in coastal streams. Similarly, there were issues in determining the exact timing of radio-tagged fish mortality when tags were stationary for an extended period.

Mortality has been identified as a major factor in the loss of tagged trout from streams (Bettinger and Bettoli 2002; High and Meyer 2009; Quinn and Kwak 2011). Angling mortality was likely higher in the EPR because the entire delayed harvest reach was within Stone Mountain State Park and adjacent to a major park road that provided easy angler access. Borawa et al. (2002) observed that the EPR had the highest angler effort of any delayed harvest reach in their study. Anecdotally, we observed fewer anglers in the NTR and LTR, and those sites were less accessible to anglers because they were bordered by more private land or spanned deeper habitats that were difficult to wade.

We anecdotally observed sources of mortality both inside and outside of study reaches that included illegal harvest, predation by natural predators (birds, snakes, and mammals), and catch-and-release hooking mortality. Several radio tags were found on the ground adjacent to streams, away from angler areas, suggesting predation. It was impractical to detect PIT tags in these same areas, but this suggests that a number of tags could have left the reach undetected through this process. Passive integrated transponder tags were especially difficult to locate manually given their limited detection range. Less effort was expended searching for dead fish or dropped tags in the NTR than in the EPR and LTR, and the larger river size and deeper water of the NTR also rendered it more difficult to search for fish mortalities and tags.

We observed high (>99%) short-term PIT tag retention between tagging and stocking. Although we had little information about long-term retention, other investigators estimated retention rates greater than 95% for smaller and non-spawning trout (Bateman and Gresswell 2006; Meyer et al. 2011). Significant radio tag expulsion (23–59% of radio tags) has been observed in previous studies (Chisholm and Hubert 1985; Burrell et al. 2000; Bettinger and Bettoli 2002), which would increase estimates of mortality. Although this may have been a factor in our study, recapture data at the end of the closed season and observations of fish decline in the reaches suggest that tag expulsion was not a significant factor. We observed only one incidence of radio transmitter expulsion: a trout that was tagged with both a PIT tag and a radio transmitter was subsequently harvested by an angler, but it retained only the PIT tag at harvest.

Another factor that may have reduced mortality in the NTR is water clarity. The NTR reach is located in an urbanized area, and mining activities are common in the watershed just downstream of the delayed harvest study reach; it was one of only two sites in the basin where turbidity levels exceeded the water quality standard for trout waters over 10% of the time (NCDENR 2003). Excessive turbidity can affect trout in conflicting ways; it can cause physiological stress and impact growth rates, but it can also reduce predation on trout and decrease fish vulnerability to angling (Abrahams and Kattenfeld 1997; Gregory and Levings 1998; Sweka and Hartman 2001).

Among the study species, the mortality rate was typically highest for Brook Trout, consistent with the general belief that Brook Trout are adapted to stable flows and vulnerable to angling (Helfrich and Kendall 1982; Baird et al. 2006). Greater mortality in large trout may be a result of angling effects (Fisher 1997; Hutt and Bettoli 2007), but fish stocked at a larger size are more adapted to hatchery surroundings and feeding regimes and hence may be more vulnerable to all mortality sources in the stream environment (Cresswell and Williams 1983; Bachman 1984; Young 1994).

The observed differences in trout behavior among rivers may be related to river size (Table 1). The NTR is a much larger river than either the LTR or the EPR; for example, the NTR is over three times as wide as the EPR and two times as wide as the LTR (Table 1). Large rivers are known to contain more diverse and abundant instream habitat than small streams (Pringle et al. 1988; Lamouroux et al. 1999) and thus have greater resources available for fish, including stocked trout. Smaller streams can be flashier and contain fewer refuges from high flows that hamper the ability of stocked trout to hold their position (Cresswell 1981). Food limitation may be an important issue for the survival of stocked trout, as the availability of prey is related to fish density and physical habitat and cover (Wilzbach 1985; Josephson et al. 2012). A larger, more habitat-diverse and productive stream, such as the NTR, would provide more resources than smaller mountain streams. Similarly, density dependence effects observed in stocked trout are a result of competition over limited food and spatial resources, which are closely tied to habitat limitations (Fausch 1984; Grant and Imre 2005; Olsson et al. 2006; Huntsman and Petty 2014).

Tagging results and modeling projections were supported empirically by findings during angler recapture events at the opening of the angling harvest season within delayed harvest reaches (Table 8). In both the NTR and EPR, the most abundant trout stockings (by month) represented in early June harvest were the two most recent stocking events (April and May). In the NTR, fish from the most recent two stockings accounted for over half of the harvest; in the EPR, they accounted for over three-quarters of the creeled fish. In the EPR, fall-stocked fish appeared unavailable for harvest; there were no fish creeled from the October stocking and only one from the November stocking. These observations are similar to those of Borawa et al. (2002), who saw only a 4% return of fall-stocked fish in creel surveys, and Wallace (2010), who marked (adipose fin-clipped) 2,175 trout stocked in the EPR during October 2008 and only recaptured a single marked trout in April 2009 by electrofishing. Rainbow Trout made up over 40% of the total catch in the NTR, supporting the observation that these fish remained in the study reach at a higher rate and were available to anglers. In the

TABLE 8. Numbers of PIT-tagged trout creeled by anglers on the opening day of angling harvest (first Saturday of June) in 2013 and 2014, presented for each stocking month and species.

	Stocking month						
Species	Oct	Nov	Mar	Apr	May	Total	Proportion
North Toe River, 2013							
Brook Trout	2	2	5	15	7	31	0.28
Brown Trout	5	2	2	13	11	33	0.29
Rainbow Trout	8	9	9	9	13	48	0.43
Total	15	13	16	37	31	112	1.00
Proportion	0.13	0.12	0.14	0.33	0.28	1.00	
East Prong Roaring River, 2014							
Brook Trout	0	1	3	7	12	23	0.40
Brown Trout	0	0	4	2	4	10	0.17
Rainbow Trout	0	0	2	7	16	25	0.43
Total	0	1	9	16	32	58	1.00
Proportion	0.00	0.02	0.16	0.28	0.55	1.00	

EPR, the species composition of the harvest was similar to that of stocked fish (40% Brook Trout, 40% Rainbow Trout, 20% Brown Trout), which is likely due to the finding that most of the creeled trout originated from recent stocking events.

Management Implications

Our findings have several management implications that state and federal fisheries agencies can incorporate into planning strategies to adjust and optimize trout stocking programs in lotic environments. Managers of stream trout fisheries have five primary variables to control in designing a stocking program: fish numbers, species, size, timing, and spatial distribution (Wiley et al. 1993; Cowx 1994; Brown and Day 2002). Our findings provide quantitative empirical and modeling information to assist managers in developing and refining trout stocking programs. The differences in poststocking behavior and survival over time among fish species, fish sizes, rivers, and stocking dates can form the scientific basis for enhancing the efficiency of trout stocking. Our findings do not support or identify any single optimal stocking regime in terms of fish, timing, and spatial distribution because the objectives for trout stocking may vary among programs and management strategies. However, a common goal among stocking programs is to make fish available to anglers, and our findings can facilitate maximizing that interaction.

A key finding is that in all rivers, few trout remained in any of the delayed harvest reaches over the winter period. Thus, although fall stockings are required to support fall and winter fishing, they contribute little to the creel once harvest is allowed during June. Other studies have also observed higher return rates of trout from spring stocking events as opposed to fall stocking (Cresswell and Williams 1983; Wiley et al. 1993; Cowx 1994). In both the NTR and EPR, the most recent two spring stockings (April and May) contributed over half of the harvested trout on opening day. The primary benefit of October and November stockings is to maintain fishing opportunities during fall and winter. It may be cost effective to stock a minimum number of trout in fall that will maintain a fishery and to place more emphasis on spring stocking events. Given the lack of trout persistence in delayed harvest reaches and the high rate at which they are lost from those reaches, especially in small streams, another approach may be to engage in more frequent stocking with fewer trout per stocking event to maintain more constant fish densities within reaches over longer periods of time.

We found higher rates of emigration and mortality for large stocked trout relative to catchable-sized trout in most situations, and trout stocked at smaller sizes may persist longer in streams than those stocked at catchable sizes (Bettoli and Bohm 1997; Aarestrup et al. 2005). Given the objectives of delayed harvest management, it is not feasible to stock fingerling-sized trout, and although catchable trout may generally persist longer in delayed harvest reaches, large stocked trout provide a fishery component that is important to anglers, especially to those interested in catch-and-release fishing (Fisher 1997; Hutt and Bettoli 2007). Furthermore, economic costs and required facilities for rearing hatchery trout to large sizes may dictate the numbers of large fish that are available to fisheries agencies.

We quantified mortality and movement of trout stocked in delayed harvest reaches, and steps to reduce these losses will enhance retention of stocked trout in delayed harvest areas. Hatchery and stocking practices can be manipulated to enhance trout retention, and this is an ongoing topic of fisheries research. In natural streams, fish experience low densities in a structurally complex physical environment, contrary to the conditions experienced in a hatchery raceway (Brown and Laland 2001; Brockmark et al. 2007). Hatchery fish must learn wild-type behaviors (Brown and Laland 2001) to survive after stocking, and strategies such as rearing fish at lower densities in hatcheries (Kavanagh and Olson 2014), adding instream structure to raceways (Brockmark et al. 2007), and rearing in natural ponds (Zydlewski et al. 2003) have been shown to improve stocked fish growth, survival, and physical condition. Acclimating trout to stream environments has been shown to improve survival and reduce dispersion of stocked trout, thereby enhancing the fish's ability to maintain position without fatigue, especially during high-flow periods (Cresswell and Williams 1983; Wiley et al. 1993; Young and Cech 1993). Acclimation to the instream environment can be accomplished by methods such as physical conditioning (Young and Cech 1993), poststocking acclimation (Cresswell and Williams 1983; Jonssonn et al. 1999), and acclimation through matching water conditions (Wiley et al. 1993). Stocking of trout during periods other than high-flow periods will improve the retention of poorer-swimming individuals in target reaches (Wiley et al. 1993; Jonssonn et al. 1999), and trout stocked into pools may move less than those stocked into riffles (Helfrich and Kendall 1982). This line of research suggests potential considerations for enhancing the survival and behavior of hatchery-reared fish after stocking, but any such experimentation in hatchery practices will likely compromise fish production rates.

We studied trout behavior and survival in 3.7–7.2-km-long reaches that were managed under delayed harvest stocking and regulations, and reach length is an important consideration in planning. A vast majority of radio-tagged stocked trout in our study resided within a linear stream range of 8 km (Figure 4); thus, reaches of this length and longer should retain sufficient numbers of stocked trout. Expanding the length of delayed harvest reaches may enhance the retention of stocked trout. Stockings can be weighted to points in the middle of the target reach, which may reduce emigration of trout toward the ends of the reach; if upstream barriers exist in receiving streams, then stocking may be weighted to a point in upstream portions of reaches. Stocking more Rainbow Trout and Brook Trout upstream and more Brown Trout downstream within the delayed harvest reaches may compensate for the species-specific movement tendencies we revealed.

We quantified species-specific behavior and survival, and this information may guide stocking rates for individual trout species to suit individual rivers. This may include stocking more Rainbow Trout and fewer Brook Trout in larger streams and the reverse in smaller streams. In the streams we studied, trout that emigrate from delayed harvest reaches immigrate into adjacent hatchery-supported reaches that are also stocked by the NCWRC. Hatchery-supported management allows angling harvest 11 months of the year, so many fish that are stocked in delayed harvest reaches are vulnerable to harvest in the adjacent hatchery-supported reaches. Besler et al. (2005) estimated that in hatchery-supported stream reaches, most stocked trout were harvested within 2 weeks of stocking. In this case, agencies may adjust relative stocking rates in delayed harvest and hatchery-supplemented reaches to account for migrating trout based on our findings.

Studies such as ours form the scientific basis for managing stream trout fisheries more cost effectively to meet management objectives. Key to such efficiency is the knowledge of a fish's fate after stocking. Knowledge of stocked fish behavior and survival will improve the efficiency of stocking programs and the quality of such fisheries. Our study provides insight for stream trout stocking, and future research will further enhance understanding of stocking in other systems and with other species.

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