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ARTICLE

Survival, Movement, and Distribution of Juvenile Burbot in a Tributary of the Kootenai River

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Abstract
Burbot *Lota lota* in the lower Kootenai River, Idaho, have been the focus of extensive conservation efforts, particularly the release of hatchery-reared juvenile Burbot into small tributaries. The Idaho Department of Fish and Game installed a fixed PIT antenna on Deep Creek, a tributary of the Kootenai River, to evaluate movement of juvenile Burbot to the Kootenai River. Since then, approximately 12,000 juvenile Burbot have been PIT-tagged and released into Deep Creek, but few Burbot have been detected at the antenna, thus raising questions about their fate in the creek. The objectives of this study were to evaluate survival, movement, and distribution of Burbot released into Deep Creek. During 2014, 3,000 age-0, 200 age-1, 16 age-2, and 16 age-4 Burbot were released at two different locations; during 2015, 3,000 age-0 Burbot were released at six different locations (i.e., 500 fish/site). Five additional stationary PIT tag antennas were installed on Deep Creek prior to stocking in 2014. Mobile PIT tag antennas were used to survey the creek in 2015 and 2016. A Barker model in Program MARK was used to estimate survival. Stationary and mobile PIT tag antennas relocated 3,372 (56%) of the Burbot released in Deep Creek during 2014 and 2015. Eighty-eight percent of PIT tags relocated during mobile surveys were relocated within 1 km of a release location. Mobile surveys of release locations in Deep Creek suggested poor dispersal from stocking locations. Survival did not vary across years or release groups. Initial 7-month survival in Deep Creek was 0.27, and survival improved to 0.63 after the first 7 months. Although survival did not differ between years or among release groups, managers may consider releasing Burbot at lower densities across multiple locations.

Burbot *Lota lota* is the only freshwater member of the family Gadidae and has a circumpolar distribution. In North America, Burbot are found throughout Canada, Alaska, and the northern tier of the continental United States. In portions of their distribution, some Burbot populations are imperiled or declining (Stapanian et al. 2010). For example, only 4 of 24 Eurasian countries reported "secure" Burbot populations in a review of worldwide Burbot population status (Stapanian et al. 2010). Thirteen countries reported Burbot populations that were imperiled, declining, or vulnerable to extirpation, and Burbot have been extirpated from Belgium, the UK, and parts of Germany (Stapanian et al. 2010; Worthington et al. 2010). In the United States, 8 of 25 states reported having "secure" Burbot populations, 11 states reported populations that were

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either imperiled or vulnerable to extinction, and Burbot have been extirpated from Kansas and Nebraska (Stapanian et al. 2010). Reasons for the decline include alterations to habitat, overexploitation, interactions with nonnative species, and barriers to movement (Paragamian 2000; Stapanian et al. 2008, 2010).

In Idaho, Burbot are native only to the Kootenai River and its tributaries (Simpson and Wallace 1982; Wallace and Zaroban 2013). Like most rivers in North America, the Kootenai River has been highly altered since European settlement. Anthropogenic alterations began with the construction of levees on the lower portion of the river in the late 19th century (Northcote 1973). By 1935, over 90% of Idaho's portion of the Kootenai River floodplain was organized into drainage districts (Partridge 1983; Richards 1997). However, construction of Libby Dam in 1972 near Libby, Montana, may have had the greatest influence on the Kootenai River. Libby Dam has altered the river's thermal, hydrologic, and nutrient regimes (Paragamian et al. 2000), and all of these changes have had deleterious effects on native riverine fishes (Paragamian et al. 2000, 2001; Paragamian 2002).

Traditionally, Burbot in the lower Kootenai River supported subsistence, recreational, and commercial fisheries (Paragamian and Hoyle 2003; Ireland and Perry 2008). However, since 1959, the lower Kootenai River Burbot population has been in decline (Partridge 1983), and the rate of decline has increased since the 1970s (Paragamian et al. 2000). By the 1990s, all recreational and commercial fisheries for Burbot were closed in Idaho and British Columbia (Paragamian et al. 2000). Despite closure of the fisheries, Burbot continued to decline, and it was thought that they could become extirpated from the lower Kootenai River system in less than a decade without intervention (Paragamian and Hansen 2009).

A multiagency coalition consisting of the Kootenai Tribe of Idaho (KTOI), Idaho Department of Fish and Game (IDFG), and British Columbia Ministry of Forests, Lands, and Natural Resource Operations (BC-FLNRO) has begun restoration efforts for Burbot in the lower Kootenai River system. Intensive and extensive conservation aquaculture techniques have been developed and are the current focus of restoration efforts (Jensen et al. 2008; Paragamian and Hansen 2009, 2011; Paragamian et al. 2011). Conservation aquaculture activities by the KTOI and University of Idaho have been practiced at a relatively small scale, with approximately 73,000 juvenile Burbot released since 2009 (University of Idaho, unpublished data). A hatchery operated by the KTOI was opened in October 2014 and has greatly increased the number of Burbot released into the system. In its first year of operation, about 253,000 juvenile Burbot were released into the Kootenai River system. Although a variety of stocking strategies (i.e., fish size, number of fish, timing, and location) have been and will be employed, one strategy of particular interest is the release of fish into small tributary streams. Data suggest that Burbot in the Kootenai River, Idaho, and Kootenay Lake, British Columbia, historically expressed a variant adfluvial life history, moving freely between Kootenay Lake and the Kootenai River to use small tributaries in the basin for spawning (Paragamian 1995). Additionally, previous work suggested that the standard operations of Libby Dam inhibit Burbot spawning migrations and make the mainstem Kootenai River less suitable for Burbot (Paragamian 2000; Paragamian et al. 2005; Paragamian and Wakkinen 2008). The goal of releases in small tributaries is to re-establish spawning runs in tributaries (Hardy and Paragamian 2013).

During 2012, the IDFG implemented a project on Deep Creek, Idaho, to evaluate movement of stocked Burbot into the Kootenai River. In October 2012, IDFG constructed a fixed PIT tag antenna array on Deep Creek near its confluence with the Kootenai River. Three-thousand age-0 Burbot in 2012 and 2,500 age-0 Burbot in 2013 were implanted with PIT tags and released at two locations upstream of the IDFG PIT tag antenna. From those releases, 59 Burbot were detected at the array in 2012, 77 were detected at the array in 2013, and 33 were detected in 2014 (IDFG, unpublished data). These data raise questions regarding the status of tagged Burbot that have not been detected. Key questions include whether the remaining fish are alive and the characteristics of fish that died (e.g., effect of stocking location). Other important questions focus on the spatial distribution and movement of survivors. An understanding of mortality rates, movement dynamics, and spatial distribution of Burbot released into tributaries is critical for ensuring that stocking practices are efficient and effective. Thus, our objectives were to estimate survival for Burbot stocked in Deep Creek and to describe their movement and spatial distribution in the system.

METHODS

Study area.—The Kootenai River has an international watershed of approximately 45,600 km^2, primarily located within the province of British Columbia, with smaller portions located in Montana and Idaho (Knudson 1994). The Kootenai River originates in Kootenay National Park, British Columbia, and initially flows south into Montana before turning west into Idaho. From Idaho, it flows northward back into Canada, where it enters the Columbia River. Many small tributaries contribute to the Kootenai River, including Deep Creek, a third-order stream that originates east of White Mountain, Idaho. The creek is impounded approximately 10 km from its headwaters to form McArthur Lake. From there, Deep Creek flows 33 km north to its confluence with the Kootenai River, approximately 5 km west of Bonners Ferry, Idaho (Figure 1). The study area included the portion of Deep Creek between the McArthur Lake Dam and the PIT tag antenna installed by IDFG (7 km from the Kootenai River confluence; R5 in Figure 1).

Deep Creek averages about 10 m in width and is dominated by cobble and gravel substrates downstream of McArthur Lake. However, directly downstream of McArthur Lake

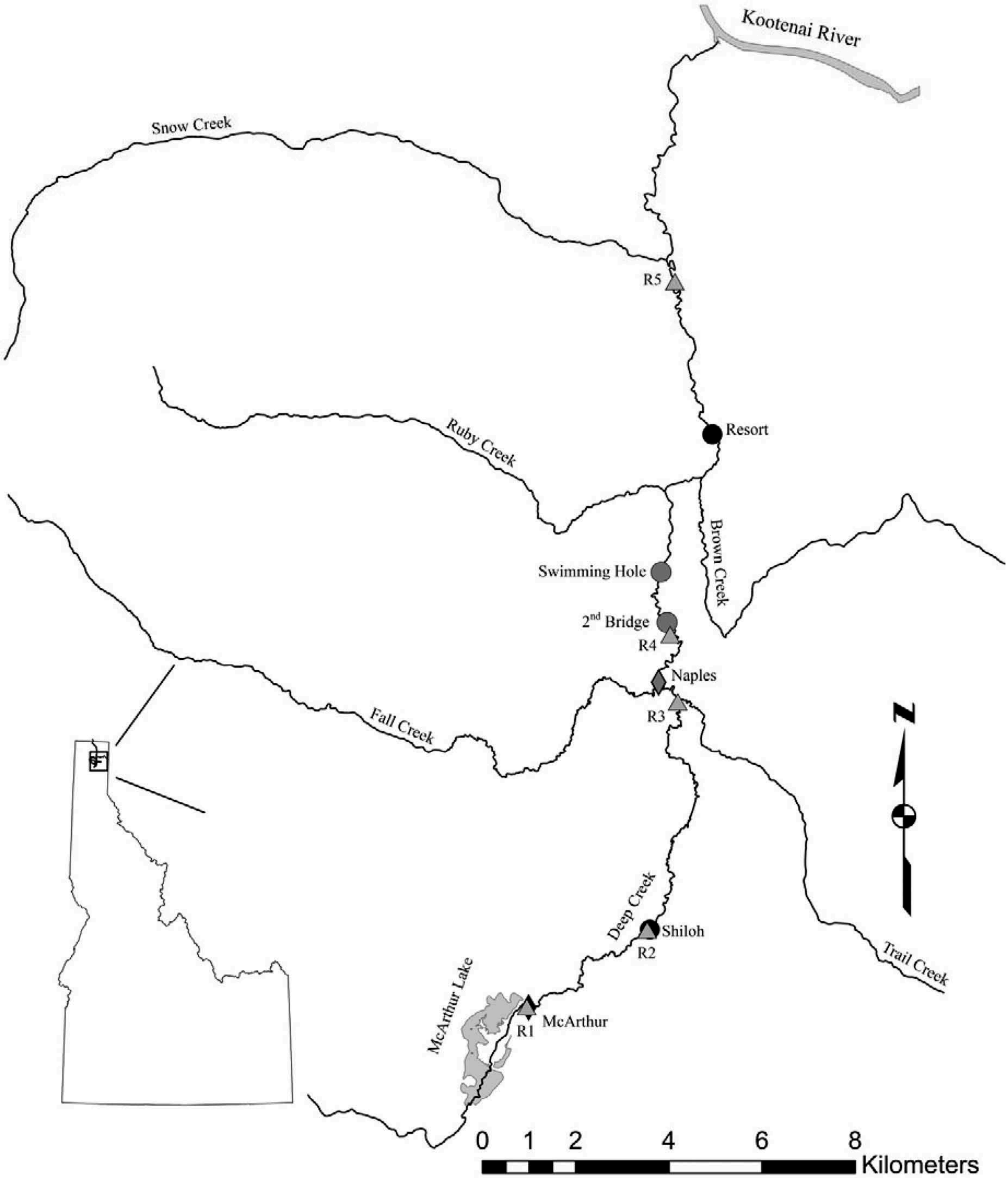

FIGURE 1. Map of the Deep Creek watershed, Idaho, showing the main channel of Deep Creek, the creek's five major tributaries (i.e., Trail, Fall, Ruby, Brown, and Snow creeks), and a portion of the Kootenai River. Light-gray triangles represent PIT tag antenna locations and are labeled R1 through R5 from upstream to downstream. Diamonds represent Burbot stocking locations that were the same in 2014 and 2015 (i.e., McArthur and Naples). Circles represent stocking locations that were new in 2015 (i.e., Shiloh, 2nd Bridge, Swimming Hole, and Resort). Dark-gray shading represents high-quality release locations; black shading represents moderate-quality release locations.

Dam, Deep Creek is dominated by deep pools and fine substrate. Water quality in Deep Creek is highly influenced by the impoundment and was listed on Idaho's Clean Water Act Section 303(d) list of impaired waters for excessive sediment and elevated temperatures (IDEQ 2006). Five major tributaries (Brown, Fall, Ruby, Snow, and Trail creeks) enter Deep Creek;

all except Snow Creek enter Deep Creek within the study area. Land ownership in the watershed is mixed, with the U.S. Forest Service, Idaho Department of Lands, Forest Capital, and Stimson Lumber Capital all managing forest lands, mostly in the upper portions of the watershed. Privately owned areas of wetland, agriculture, residential development, and forest occur in the lower portions of Deep Creek (IDEQ 2006).

Stocking.—In 2014, 12-mm half-duplex (HDX) PIT tags were implanted into 3,000 age-0, 200 age-1, 16 age-2, and 16 age-4 Burbot, and the tagged fish were released on October 30 at two different locations in Deep Creek (i.e., McArthur and Naples; Figure 1). Due to concerns regarding poor survival, the stocking strategy was altered in 2015. Three-thousand age-0 Burbot were measured for TL (mean ± SD = 100.5 ± 7.7 mm), implanted with HDX PIT tags, and released on October 30, 2015, at six different stocking locations (500 fish/site; McArthur, Shiloh, Naples, 2nd Bridge, Swimming Hole, and Resort; Figure 1). Stocking locations in 2015 were categorized as either high-quality habitat (i.e., Naples, 2nd Bridge, and Swimming Hole; Figure 1) or moderate-quality habitat (i.e., McArthur, Shiloh, and Resort; Figure 1). High-quality locations were those dominated by deep pools and large substrate (i.e., depth > 1.5 m; substrate > 64 mm) within 1 km of the release location. Deep habitats with large substrate are commonly reported as important habitat characteristics for Burbot (Dixon and Vokoun 2009; Eick 2013; Klein et al. 2015). Moderate-quality habitat locations lacked deep habitats with large substrate within 1 km of the release site.

Stationary antennas.—Prior to stocking in 2014, five stationary HDX antennas were installed on Deep Creek (Figure 1). Antenna locations were selected to separate Deep Creek into five equal segments and were also based on stream characteristics, accessibility, and landowner cooperation. Each HDX array consisted of a 141.9-L cooler, which contained four 12-V batteries (connected in parallel; 126 ampere-hours per battery; Interstate Batteries, Dallas, Texas) and the HDX PIT tag reader–data logger (Oregon RFID, Portland, Oregon). Each cooler was placed above the high-water mark at each site. Twinaxial cable connected the reader to an antenna-tuning box (Oregon RFID). On both sides of the stream, a 10.2-cm-diameter wooden post was partially buried; the tuning box was attached to the top of one of the posts. Antenna wire exited the tuning box, formed a loop around the stream, and returned to the tuning box (i.e., pass-through design). All antennas consisted of a single loop of 6-American wire gauge (AWG), class-K welding cable. Polypropylene rope was stretched between each wooden post to provide support for the top of each antenna loop. The antenna wire was run through 1.9-cm polyvinyl chloride (PVC) pipe to protect the bottom of the antenna loop. The PVC pipe was secured to the substrate by using a combination of rebar stakes and duckbill anchors.

Antennas operated continuously from October 30, 2014, to February 5, 2015. On February 5, a high-flow event damaged all five antennas, and they were inoperable until May 11, 2015, when they were reinstalled. After reinstallation, antennas operated continuously until the end of the study on July 3, 2016. Upon reinstallation, 140-W solar panels (Solartech Power, Inc., Ontario, California) were added, and the number of 12-V batteries was reduced from four to two (connected in parallel; 104 ampere-hours per battery; Sun Xtender, West Covina, California). Pass-over design antennas were installed during fall 2015 at each site to prevent damage during high-flow events. Pass-over antennas consisted of wire that exited the tuning box and formed a loop on the bottom of the stream before returning to the tuning box. Three pass-over antennas consisted of two loops of 12-AWG, 19-strand, thermoplastic, high-heat-resistant, nylon-coated (THHN) wire. The remaining two pass-over antennas consisted of a single loop of 10-AWG, solar photovoltaic wire. Antenna wire was run through 1.9-cm PVC pipe to protect the antenna, and the PVC pipe was secured to the stream bottom by using a combination of rebar and duckbill anchors. On December 15, 2015, antenna operation at all sites was changed from pass-through design antennas to the pass-over design exclusively.

The efficiency of each antenna was thoroughly examined by conducting detection tests every 3 months throughout the study under varying environmental conditions (e.g., discharge). For the pass-through antennas, a PIT tag was passed through each antenna at 50-cm intervals across Deep Creek on both a horizontal plane and a vertical plane (Compton et al. 2008). The tag was passed through three times at each location: on the first pass, the tag was positioned parallel to the antenna; on the second pass, it was positioned at 45° to the antenna; and on the third pass, it was oriented perpendicular to the antenna. For the pass-over antennas, a PIT tag was also passed over the antenna at different depths (i.e., bottom of the water column, midwater column, and at the surface). In addition, pass-through and pass-over antennas at each site were operated together for 2 weeks to provide another estimate of antenna efficiency. Antenna efficiency estimated from detection tests for individual pass-through design antennas in different environmental conditions varied from 74% to 100%. Efficiency estimates for individual pass-over design antennas in varying environmental conditions varied from 56% to 97%. During the 2 weeks in which pass-through and pass-over antennas were operating continuously, all pass-over antennas with the exception of R2 (see Figure 1 for reader locations and abbreviations) had efficiency equal to or greater than that of the pass-through antennas. Furthermore, another estimate of antenna efficiency was provided for all antennas except R1 by following the paths of individual Burbot that moved past multiple antennas. For example, if a Burbot was released upstream of R2 and was detected at R5, it had to move past R2, R3, and R4. Thus, we estimated efficiency by examining whether that individual Burbot was also detected at R2, R3, and R4. Efficiency estimates from this method varied from 43% to 79%.

A temperature logger (Onset Computer Corp., Cape Cod, Massachusetts) was installed at each stationary antenna on October 23, 2014, and recorded temperature every hour for the duration of the study. The temperature logger at R1 (see Figure 1) was lost and only recorded water temperature through September 13, 2015. In addition, the temperature logger at R2 had several periods during which it was out of the water; those data were removed from the analysis. Two water-level data loggers (Onset) were installed on April 23, 2015, at R3 and R5 and were used to record the water level every hour. Stream discharge was measured five times in 2015 and 2016 at each water-level logger location, and a regression between water level and stream discharge was used to estimate the stage–discharge relationships for both sites (Bower 2005).

Mobile surveys.—Mobile PIT tag antenna surveys were used to estimate the spatial distribution and movement of Burbot and to provide additional recapture information for estimating survival. Two mobile PIT tag surveys of Deep Creek were completed during 2015 and 2016. The first mobile survey was conducted from May 26 to June 23, 2015, and sampled Deep Creek from McArthur Lake Dam to the IDFG PIT tag antenna. The second mobile survey was conducted over the same area of Deep Creek from May 17 to May 31, 2016; this survey also included sampling of the four major tributaries (i.e., Trail, Fall, Ruby, and Brown creeks) up to the first major barrier to fish passage. Hereafter, both surveys are referred to as the longitudinal distribution surveys. The first mobile antenna was Oregon RFID's pole antenna for their backpack reader (Oregon RFID). The second mobile PIT tag antenna consisted of the antenna described by Fischer et al. (2012) mounted to an inflatable pontoon raft (The Creek Company, Steamboat Springs, Colorado). Both antennas were used to continuously scan the entire length of the study area in Deep Creek while operators waded in a downstream direction. When a tag was encountered, GPS coordinates were taken, and an attempt was made to disturb the fish by aggressively kicking at the substrate (i.e., large substrate was forcibly removed from the area) to determine the individual's status (i.e., dead or alive). A Burbot was considered alive (1) if it was disturbed and observed alive, (2) if it moved upstream from the last observation, or (3) when a tag was disturbed and moved over 1 m (Breen et al. 2009). If the tag was continually relocated but did not meet any of these criteria, it was assigned a "shed or dead" fate. Although tags were assigned a shed or dead fate in the field, Ashton et al. (2014) evaluated PIT tag retention in age-0 Burbot and found that retention rates were 99 ± 1%. Because the majority of (if not all) tags that were assigned this fate in our study were likely from dead Burbot, all tags assigned a shed or dead fate are hereafter referred to as "dead." If the tag could not be relocated after being disturbed, its fate was classified as unknown. We examined whether our protocol of disturbing the substrate would result in broken tags. Only 4% of the tested tags (n = 50) broke as a result of our protocol. Thus, tags with an unknown fate likely belonged to live Burbot that moved away after an attempt was made to disturb the area; hence, all tags that were assigned an unknown fate are hereafter referred to as "alive."

Data from the 2015 longitudinal distribution survey of Deep Creek suggested low survival and dispersal of Burbot from release locations. These findings led us to question how quickly the mortality of stocked Burbot occurred (i.e., immediately or slowly over time), how Burbot dispersed from the release locations over time, and how mortality and dispersal differed among stocking locations. Mobile PIT tag antenna surveys were conducted twice at each of the six 2015 release locations to monitor dispersal of Burbot after release. Mobile surveys at release locations were conducted on November 2–6, 2015, and on January 21–27, 2016. Hereafter, these surveys will be referred to as release location surveys. The release location surveys were 2 km in length centered on the stocking location. We chose 2-km reaches because data from the 2015 longitudinal distribution survey of Deep Creek indicated that most (88%) of the relocated tags were found within 1 km of the stocking site. Release location surveys were conducted in the same manner as the longitudinal distribution surveys of Deep Creek. Beginning at the upstream end of the reach, two mobile PIT tag antennas were used to scan the stream continuously: one antenna was the Oregon RFID antenna described previously, and the other was a 25.4-cm-diameter ring that used 18-AWG, THHN wire enclosed in PVC casing. When a tag was encountered, the protocol from the longitudinal distribution surveys was followed.

Efficiency for longitudinal distribution surveys and release location surveys was estimated by attaching PIT tags to rocks and conducting blind searches (Bubb et al. 2002). For each blind search, 30 PIT tags were placed beneath rocks in positions similar to where Burbot are normally found. Antenna operators, who had no prior knowledge of where tags were hidden, then scanned the reaches in which the tags were hidden using the methods described for the longitudinal distribution and release location surveys. Blind searches were conducted five times during the 2015 longitudinal distribution survey, three times during the 2016 longitudinal distribution survey, and two times during the November 2015 and January 2016 release location surveys. The mean (±SD) estimate of efficiency was 60.9 ± 13.5% for the 2015 longitudinal distribution survey; 51.7 ± 5.8% for the 2016 longitudinal distribution survey; 63.5 ± 6.4% for the November 2015 release location surveys; and 57.8 ± 5.5% for the January 2016 release location surveys. Maximum read range for all three mobile antennas was 0.38 m.

Data analysis and summarization.—The distances moved upstream and downstream were calculated for each Burbot. Distance moved upstream was calculated as the furthest distance upstream from its release location that a Burbot was detected alive. Similarly, distance moved downstream was calculated as the furthest distance downstream from its release location that an individual was detected alive. In addition, the total number of detections and number of individual Burbot detected at each antenna were summarized by stocking location. Burbot detected at R5 were considered to have out-migrated from the study area. The percentages of detections that occurred during the day and at night were also calculated for each reader. Night was defined as 0.5 h after official sunset to 0.5 h before official sunrise. The number of detections and number of individual Burbot detected per month were plotted against mean daily temperature for each stationary antenna to examine patterns in movement associated with temperature. Discharge estimated from the water-level logger at R3 was plotted with the number of detections and individual Burbot by month for R1, R2, and R3. Discharge estimated from the water-level logger at R5 was plotted with the number of detections and individual Burbot by month for both R4 and R5. The number of tags relocated per 1-km segment during each longitudinal distribution survey was depicted using maps to visualize movement and distribution of Burbot in the system. For data collected from the release location surveys (surveys of 2-km reaches centered on release locations), a time series of maps depicting the number of tags relocated every 50 m for each stocking location reach was used to visualize how Burbot dispersed from release locations.

A Barker extension to the joint live–dead encounter model in Program MARK (Barker 1997, 1999; White and Burnham 1999; Al-Chokhachy and Budy 2008) was used to estimate survival (*S*) for Burbot released in Deep Creek during 2014 and 2015. The Barker model can incorporate capture–recapture data from individual sampling occasions as well as recapture data between sampling occasions, thereby improving the precision of estimated *S* over models that only incorporate recapture data from sampling occasions (Barker 1999). The Barker model can also provide estimates of (1) recapture probability (*p*), which is calculated based on the individual detection histories, making survival estimates more robust to low detection efficiencies; (2) the probability of resighting a dead animal (*r*); (3) the probability of recapturing an animal between sampling intervals (*R*); (4) the probability of recapturing an animal before the animal dies between sampling intervals (*R′*); (5) the probability that an animal at risk of capture in time *i* is at risk of capture at time *i* + 1 (*F*); and (6) the probability that an animal not at risk of capture at time *i* is at risk of capture at time *i* + 1 (*F′*; Barker 1999).

We used our stationary antenna data (pass-through and pass-over antenna recaptures) and the data from all mobile PIT tag antenna surveys (longitudinal distribution surveys and release location surveys) of Deep Creek for the Barker model analyses. We defined four detection events over the course of our study. The first detection event was the initial release in 2014 (October 30, 2014); the second event was the 2015 longitudinal distribution survey of Deep Creek (May 26–June 23, 2015); the third event was the 2015 stocking in combination with the November 2015 release location surveys (October 30–November 6, 2015); and the fourth event was the 2016 longitudinal distribution survey of Deep Creek (May 17–31, 2016). In addition, stationary antenna recaptures during the interval between detection events were incorporated as live resightings.

To evaluate *S* across stocking locations and release strategies, twelve candidate models were established. Candidate models were compared using Akaike's information criterion corrected for small sample size (AIC_c; Burnham and Anderson 2002). Top models were defined as those with AIC_c difference (ΔAIC_c) values less than 2 (i.e., AIC_c values that were within 2 units of the best-performing model) and were retained for interpretation. We considered candidate models that included group (release locations) and age effects (2014 and 2015 releases) for *S* and *p*; group and (or) age effects for *S* and a constant *p*; and age and release year effects on *S* and *p*. We also considered a model with all parameters estimated as time dependent and a null model (Lebreton et al. 1992). For models that included only age, release year, and (or) group effects on *S* and *p*, other variables that were less pertinent to our analysis (*F, F′, R*, and *R′*) were estimated as time dependent (Lebreton et al. 1992). Age effects resulted in estimates of *S* for the first 7 months after Burbot were released in Deep Creek. For Burbot released in 2014, an additional estimate of *S* was calculated for the time period after the initial 7 months in Deep Creek. We used the likelihood function in Program MARK to estimate the slope (β) for all parameters, and we employed a logit link function to transform β estimates into interpretable estimates of *S* (Al-Chokhachy and Budy 2008). In addition, the Markov chain–Monte Carlo parameter estimation procedure in Program MARK was used to improve the precision of *S*-estimates and provide 95% credible intervals (CRIs; White 2008).

The TL at release was not incorporated as a covariate in the Barker model because only Burbot released in 2015 had individual TLs measured prior to release. Therefore, the effect of TL at release on survival was evaluated by calculating the mean TL at release for Burbot that were released in 2015 and recaptured during the 2016 longitudinal distribution survey. Differences in mean TL for Burbot relocated with different fates were compared by using a *t*-test.

RESULTS

In total, 3,372 individual Burbot (1,741 from the 2014 release; 1,631 from the 2015 release) were relocated during the study via mobile antenna surveys (*n* = 1,006), stationary antennas (*n* = 1,693), or both methods (*n* = 673). Overall numbers of detections and individuals at antennas were low except at R1 and R2, which were close to Burbot release locations. In total, R1 had the most detections from the most individuals, followed by R2, R4, R3, and R5 (Table 1). Burbot released in 2014 were most commonly detected at antennas close to stocking locations. Burbot released at the McArthur release location in 2014 were detected primarily at R1 (50 m from the McArthur release location), with a few detections at the other antennas (Table 1). Burbot released at Naples in 2014 were most commonly detected at R4 (1,910 m downstream of Naples) followed by R3 (1,000 m upstream of Naples; Table 1). Similar patterns were observed with detections of Burbot released in 2015, for which the majority of detections occurred at antennas most proximate to release locations regardless of perceived habitat quality. For example, Burbot released at all three high-quality locations were detected most at R4 followed by R3, with few detections at other antennas. In addition, Burbot released at the Shiloh location were detected most frequently at R2 (70 m from Shiloh), whereas there were few detections at other antennas. Few Burbot were detected at R5 out-migrating from Deep Creek (Table 1). Age-2 and older Burbot released in 2014 are not included in Table 1; however, 81% were detected as out-migrating from Deep Creek during the first month postrelease. Age-1 Burbot released in 2014 (also not included in the Table 1) showed patterns similar to those of age-0 Burbot.

The mean (±SD) maximum distance traveled upstream for Burbot released in 2014 was 135 ± 435 m, and the maximum distance traveled downstream was 288 ± 1,533 m. For Burbot released at high-quality locations in 2015, the mean maximum distance traveled upstream was 781 ± 1,606 m, and the mean maximum distance traveled downstream was 171 ± 426 m. On average, Burbot released at moderate-quality locations moved 301 ± 1,046 m upstream and 106 ± 468 m downstream. Except for detections at R2, the majority of Burbot detections occurred at night. The percentage of detections that occurred at night was 52% at R1, 43% at R2, 86% at R3, 66% at R4, and 74% at R5. Plots of detections and individuals against temperature did not show consistent patterns.

Mobile Surveys

During the 2015 longitudinal distribution survey, relocated tags were only found in seven 1-km segments, and all were within 3 km of a release location (Figure 2). In addition, 88% of all relocated tags (n = 224) and 88% of relocated tags with an alive fate (n = 50) were relocated within 1 km of a release location. During the 2016 longitudinal distribution survey, tags (n = 534) were relocated throughout Deep Creek (Figure 2). Nevertheless, 88% of relocated tags and 91% of tags with an alive fate were relocated within 1 km of a release location. Additionally, three tags were relocated in tributaries of Deep Creek during the 2016 longitudinal distribution survey, all of which had a dead fate.

During the November 2015 release location surveys, 941 individual tags were relocated. The majority of tags with an alive fate (85–96% of tags) relocated at high-quality locations were within 200 m of the release location (Figure 3). Furthermore, during the January 2016 release location surveys (n = 411 relocated tags) and the 2016 longitudinal distribution survey at high-quality release locations, tags with an alive fate were evenly distributed throughout the 2-km reach. Patterns in distribution of relocated tags between high- and moderate-quality reaches from release location surveys and the 2016 longitudinal distribution survey were similar (Figure 4). For example, at moderate-quality release locations during the November 2015 release location surveys, the majority of tags with an alive fate (73–100% of tags) were relocated within 200 m of release locations. Additionally, during both the January 2016 release location surveys and the 2016 longitudinal distribution survey, the majority of relocated tags with an alive fate at two moderate-quality locations (i.e., Shiloh and Resort; Figure 4) were evenly distributed throughout the 2-km reach.

Survival

Mark–recapture analyses resulted in one model with a ΔAIC_c value less than 2 (Table 2). The top model included an age effect on S and a constant p, with the remaining parameters estimated as

TABLE 1. Number of detections at all five antennas (R1–R5; see Figure 1) for PIT-tagged age-0 Burbot released in 2014 and 2015 by release location. Numbers in parentheses represent the total number of individual Burbot. Data for 2015 are grouped according to high-quality and moderate-quality release locations.

Release location	R1	R2	R3	R4	R5
2014					
McArthur	262,061 (1,103)	9 (7)	5 (5)	5 (1)	8 (3)
Naples	0 (0)	14 (2)	497 (109)	727 (74)	34 (10)
2015 high-quality sites					
Naples	0 (0)	0 (0)	162 (34)	223 (9)	0 (0)
2nd Bridge	0 (0)	7 (2)	158 (55)	1,407 (102)	0 (0)
Swimming Hole	0 (0)	0 (0)	113 (35)	186 (50)	1 (1)
2015 moderate-quality sites					
McArthur	1,536,148 (436)	4 (2)	0 (0)	0 (0)	0 (0)
Shiloh	11,645 (26)	3,311 (282)	0 (0)	0 (0)	0 (0)
Resort	0 (0)	0 (0)	3 (2)	25 (9)	57 (7)

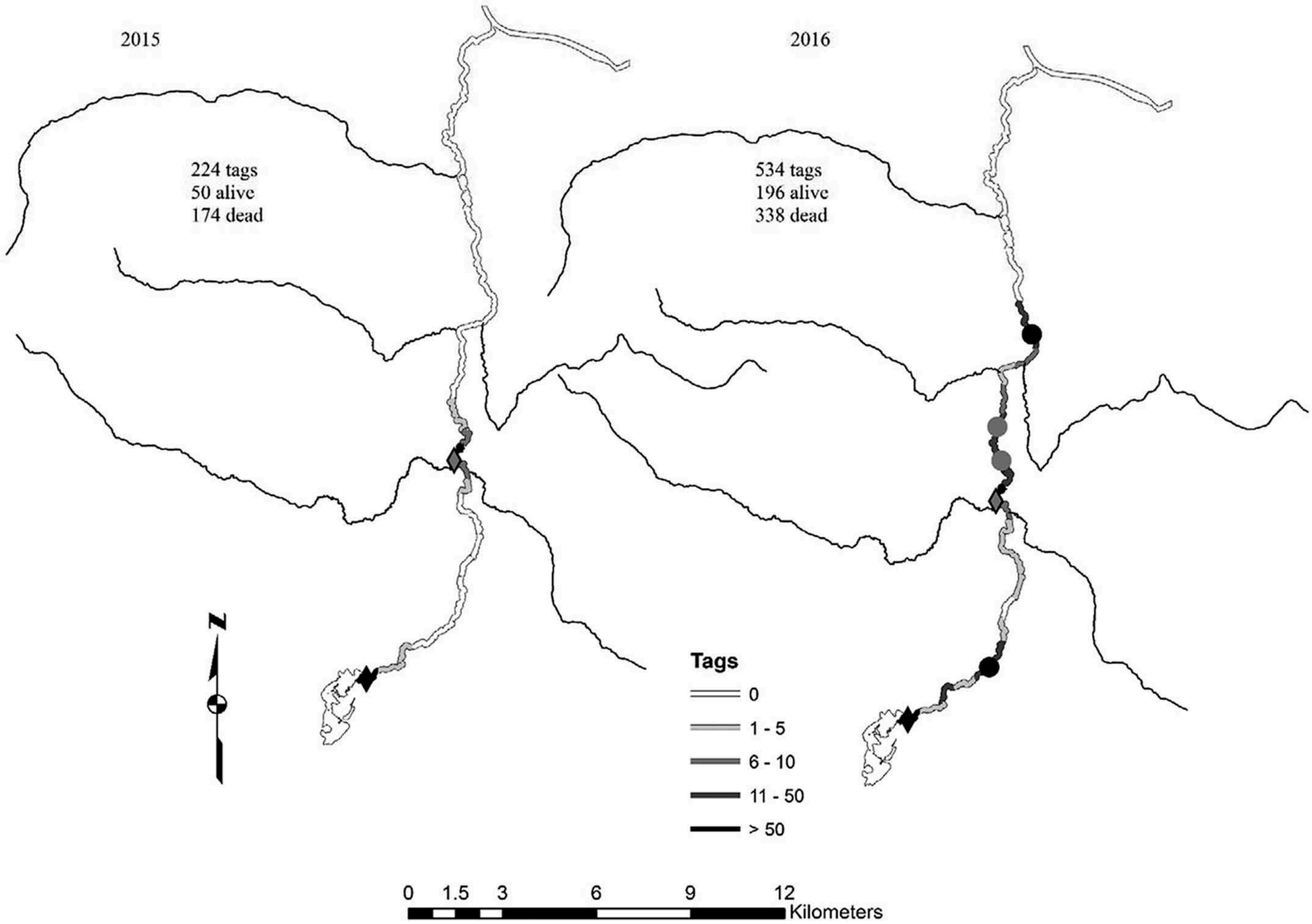

FIGURE 2. Maps of Deep Creek, showing the locations and the total number of tags and the number of tags by fate (alive or dead) relocated during the 2015 and 2016 mobile PIT tag surveys of Burbot in Deep Creek. Diamonds represent stocking locations that were the same in 2014 and 2015 (i.e., McArthur and Naples). Circles represent stocking locations that were new in 2015 (i.e., Shiloh, 2nd Bridge, Swimming Hole, and Resort). Dark-gray shading represents high-quality release locations; black shading represents moderate-quality release locations.

time dependent. Model selection results indicated that S did not differ across years or among release locations. Initial 7-month survival was 0.27 (95% CRI = 0.23–0.30; Figure 5). Recapture probability p was 0.26 (95% CRI = 0.20–0.33). After the first 7 months, S increased to 0.63 (95% CRI = 0.49–0.80). Mean TL at release for Burbot released in 2015 was similar between fates. Mean (±SD) TL at release was 100.8 ± 8.1 mm for Burbot relocated with an alive fate during the 2016 longitudinal distribution survey and was 100.3 ± 7.4 mm for Burbot with a dead fate. Differences in TL between live and dead Burbot were not significant ($t = 0.54$, df = 287, $P = 0.59$).

DISCUSSION

Results of the 2015 longitudinal distribution survey of Deep Creek suggested that there was little movement of Burbot away from release locations. Low numbers of detections at stationary antennas provided further evidence that Burbot moved little after release into Deep Creek. The 2015 longitudinal distribution survey of Deep Creek also suggested that survival was low. We hypothesized that the two release locations provided suitable habitat for juvenile Burbot, and fish were not motivated to move great distances. We also hypothesized that high densities of fish at a stocking location may have attracted predators and (or) decreased the per-capita resource availability. Therefore, some release locations with a lack of high-quality habitat were selected during 2015 in an attempt to prompt movement of Burbot. Additionally, Burbot were stocked in lower numbers across more release locations in 2015 to reduce the risk of predation and limit the possible effect of low prey availability. Despite changes in release strategies from 2014 to 2015, Burbot that were released in Deep Creek continued to move short distances from the release locations and experienced similar

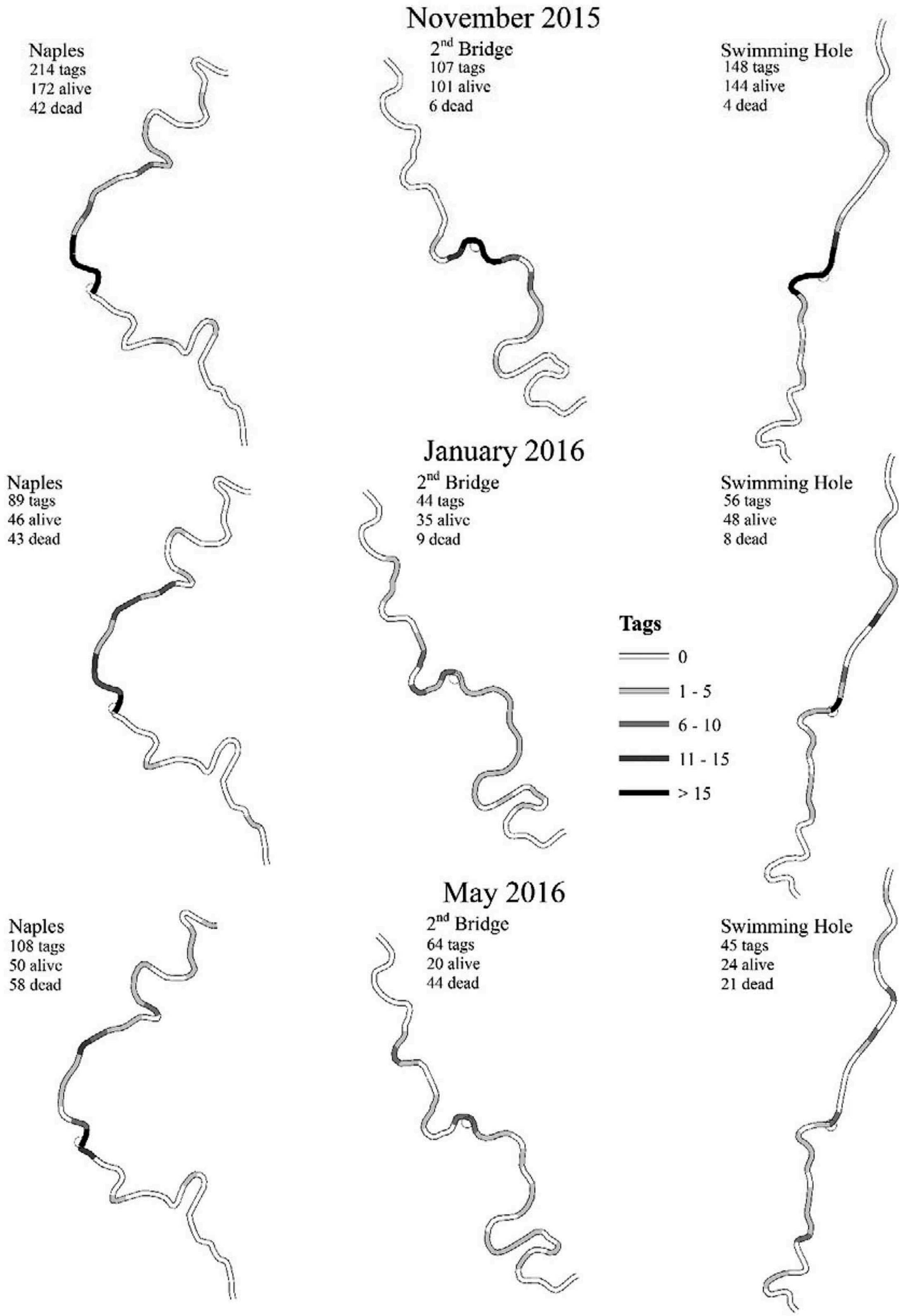

FIGURE 3. Maps of the 2-km segments centered on the three high-quality release locations in 2015, showing the locations and the total number of Burbot tags relocated for the mobile surveys conducted in November 2015 and January and May 2016. Total numbers of tags relocated with each fate (alive or dead) are also provided. Open circles represent the stocking locations. Five-hundred PIT-tagged Burbot were released at each site on October 30, 2015.

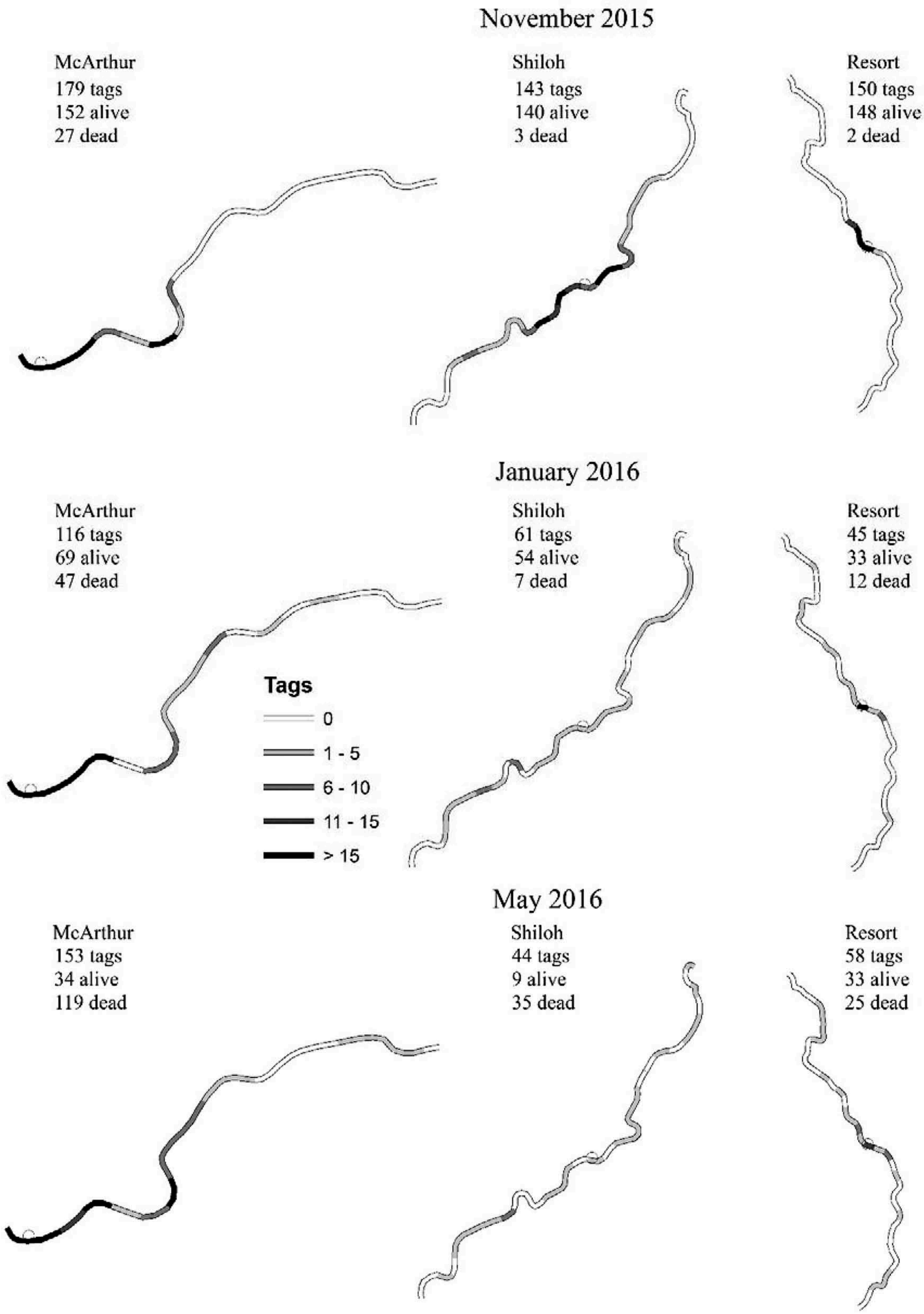

FIGURE 4. Maps of the 2-km segments centered on the three moderate-quality release locations in 2015, showing the locations and the total number of Burbot tags relocated for the mobile surveys conducted in November 2015 and January and May 2016. Total numbers of tags relocated with each fate (alive or dead) are also provided. Open circles represent the stocking locations. Five-hundred PIT-tagged Burbot were released at each site on October 30, 2015.

TABLE 2. Summary of model selection among Barker mark–recapture models used to estimate survival (S) for Burbot released into Deep Creek in 2014 and 2015 (p = recapture probability based on individual detection histories; r = probability of resighting a dead animal; R = probability of recapturing an animal between sampling intervals; R' = probability of recapturing an animal before the animal dies between sampling intervals; F = probability that an animal at risk of capture in time i is at risk of capture at time i + 1; F' = probability that an animal not at risk of capture at time i is at risk of capture at time i + 1; a = age; g = release group; y = release year; t = time; + = additive parameter; period symbol = no difference across time or release group). Akaike's information criterion adjusted for small sample size (AIC_c) was used to rank the candidate models. The AIC_c difference (ΔAIC_c), model weight (w_i), number of parameters, and model likelihood are included for each model.

Model	AIC_c	ΔAIC_c	w_i	Parameters	Model likelihood
$S_{(a)}p(.)r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,562.92	0.00	1.00	53	1.00
$S_{(a+g)}p_{(t)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,579.65	16.73	0.00	63	1.00
$S_{(a+g)}p_{(a+g)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,579.65	16.73	0.00	63	0.00
$S_{(g)}p_{(t)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,580.36	17.44	0.00	63	0.00
$S_{(t)}p_{(t)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,583.36	20.44	0.00	62	0.00
$S_{(a)}p_{(a)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,613.91	50.99	0.00	54	0.00
$S_{(a)}p_{(t)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,615.69	52.78	0.00	55	0.00
$S_{(a+y)}p_{(a+y)}r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,624.89	61.97	0.00	48	0.00
$S_{(a+g)}p(.)r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,636.98	74.06	0.00	58	0.00
$S_{(a+y)}p(.)r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,648.96	213.94	0.00	50	0.00
$S_{(g)}p(.)r_{(t)}R_{(t)}R'_{(t)}F_{(t)}F'_{(t)}$	14,835.06	2,638.78	0.00	62	0.00
$S(.)p(.)r(.)R(.)R'(.)F(.)F'(.)$	17,692.93	3,130.01	0.00	6	0.00

S (0.27). Thus, our hypotheses regarding the initial release strategy were incorrect.

During the 2015 longitudinal distribution survey, all tags were relocated within 3 km of a release location, and 88% of all tags were relocated within 1 km of a release location. Results from the 2016 longitudinal distribution survey were nearly identical: 91% of tags with an alive fate and 88% of all tags were relocated within 1 km of a release location. Additionally, the proportion of tags with an alive fate that were relocated within 1 km of a release location was similar to the proportion of tags relocated within 1 km of a release location, suggesting similar distribution patterns for live and dead Burbot.

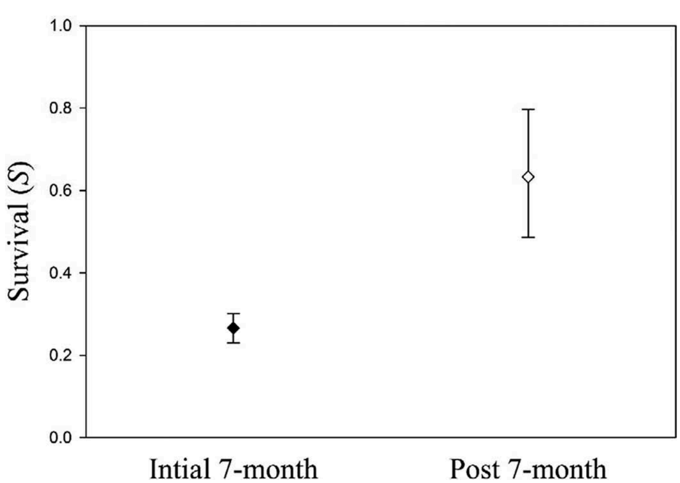

FIGURE 5. Estimates of survival (±95% credible interval) calculated from mark–recapture analyses of Burbot stocked into Deep Creek, Idaho, during 2014 and 2015. Black diamonds represent initial 7-month survival rates. Open diamonds represent survival rates after the first 7 months.

Reasons for the lack of observed movement by Burbot after release into Deep Creek remain unclear. One reason may be that habitat at all sites was suitable for juvenile Burbot and the fish did not need to move far to locate suitable habitat. However, this explanation seems unlikely given the observation that patterns in movement of Burbot stocked into locations with varying habitat quality were similar. Another potential reason Burbot did not move after being released into Deep Creek is that their life history is such that they simply do not move great distances during their first year. Two previous studies have attempted to evaluate dispersal of Burbot from small tributary releases in the Kootenai River system (Neufeld et al. 2011; Stephenson et al. 2013). Neufeld et al. (2011) found that all age-2 and age-3 Burbot stocked in the Goat River, British Columbia, out-migrated within 9 d. In contrast, Stephenson et al. (2013) reported that age-1 and younger Burbot remained in the Goat River, Boundary Creek (Idaho), and the Moyie River (Idaho) for an average of 1 year after stocking. Stephenson et al. (2013) also found that age-1 and younger Burbot had significantly shorter dispersal distances and longer dispersal times than age-2 and older Burbot. Results from Stephenson et al. (2013) are similar to those of our study in that age-0 Burbot in Deep Creek moved little and did not immediately out-migrate. It may be that age-1 and younger Burbot simply remain near their release location and rear for a period of time before out-migrating. Whether this behavior is unique to hatchery-reared fish is unknown because similar studies with naturally produced Burbot have not been conducted.

Hatchery-reared fishes often fail to move long distances after release into lotic waters (Cresswell 1981; Helfrich and Kendall 1982; High and Meyer 2009). For example, Cresswell (1981) reviewed studies that evaluated poststocking movements of Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, and Rainbow Trout *Oncorhynchus mykiss* and reported that most fish were recaptured within 4.5 km of the stocking location. High and Meyer (2009) reported that Rainbow Trout released in the Middle Fork Boise River, Idaho, were almost always found within 3 km of the release site, and over half were observed within 1 km of the release site. In Big Stony Creek, Virginia, 75% of Rainbow Trout, Brook Trout, and Brown Trout were recovered within 1 km of their release location (Helfrich and Kendall 1982). Although a lack of movement is commonly observed with hatchery-reared fish, reasons for the behavior are unclear. For Burbot released in Deep Creek, one reason may be that the fish are the progeny of lake-origin broodstock (i.e., Moyie Lake, British Columbia; Powell et al. 2008; Hardy and Paragamian 2013). However, other data suggest that Burbot progeny from lake-origin broodstock are acclimating to the Kootenai River system (e.g., exhibiting good dispersal; Hardy et al. 2015).

Burbot generally remained near (within 1 km of) the release locations, but some patterns related to movement direction and timing were observed in Deep Creek. For example, Burbot released in 2015 moved a greater distance upstream than downstream. However, this pattern differed for Burbot released in 2014. Changes in release strategy may explain this inconsistency, as one of the two release locations in 2014 did not allow for upstream movement. In addition to patterns in directional movement, it is worth noting that the majority of detections at all but one of the stationary antennas occurred at night. Burbot are more active at night, when they have been observed actively foraging (Lawler 1963; Boag 1989). Increased detections at night suggest that Burbot in Deep Creek display similar behavior.

Initial 7-month survival was 0.27 and did not differ across years or release locations. Recent estimates of survival over a similar time frame for 6-month-old juvenile Burbot released in the main stem of the Kootenai River varied from 0.02 to 0.20 (IDFG, unpublished data) and were lower than estimates of S for Burbot released in Deep Creek. Survival estimates over a similar time frame for other fish species reared in a hatchery and released at similar sizes are lower than our estimates. For example, Margenau (1992) estimated that overwinter survival of fall fingerling Muskellunge *Esox masquinongy* in four northern Wisconsin lakes averaged 0.19. Survival rates for Walleye *Sander vitreus* fingerlings released in three Iowa rivers varied from less than 0.01 to 0.16 (Paragamian and Kingery 1992).

Several factors may limit the survival of Burbot released into Deep Creek. One potential factor is the size at the time of release; however, this seems unlikely given that Burbot relocated during the 2016 longitudinal distribution survey with alive and dead fates had similar mean TLs at release. Another factor limiting Burbot survival may be predation. During summer 2015, a colony of North American river otters *Lontra canadensis* (hereafter, river otters) established a den 90 m downstream of the McArthur release location. River otter predation was investigated by scanning several river otter trails within 100 m of the release location by using the Oregon RFID mobile PIT tag antenna; during these scanning efforts, 16 individual tags were relocated in areas above the high-water mark, suggesting that at least some predation by river otters occurred. Moreover, Largemouth Bass *Micropterus salmoides* are also present in Deep Creek and are known to be highly piscivorous (Becker 1983). In addition to Largemouth Bass, cannibalism is common in Burbot populations (Gallagher and Dick 2015). Furthermore, several piscivorous bird species (e.g., great blue heron *Ardea herodias* and belted kingfisher *Megaceryle alcyon*) are common in the system and may prey on Burbot.

Prey resources are commonly cited as a factor limiting survival in many populations, particularly for juvenile fishes (Cushing 1969, 1990; Schlosser 1991; Hoxmeier et al. 2006). Previous studies have found that juvenile Burbot (41.0–152.6 mm) primarily feed on macroinvertebrates, such as Amphipoda, Ephemeroptera, Odonata, and Plecoptera (Beeton 1956; Ryder and Pesendorfer 1992; Fisher 2000; Klein et al. 2016). Low densities of macroinvertebrates in Deep Creek may have contributed to the survival rates observed for the initial 7 months after release. Unfortunately, data on macroinvertebrate assemblage structure and density are unavailable. Once Burbot survived the first 7 months in Deep Creek, S improved to approximately 63%. Additionally, estimated S for Burbot that survived the first 7 months were similar to previous estimates for age-1 to age-3 Burbot released into the Kootenai River system (0.54–0.78; Paragamian et al. 2008; Stephenson et al. 2013) and estimates for wild adult Burbot in Lake Superior (0.57; Schram 2000) and Moyie Lake (0.53–0.80; Prince 2007; Neufeld 2008). An increase in Burbot survival may reflect the attainment of larger sizes and the capacity to exploit a diversity of prey resources. Most fishes consume progressively larger and more diverse prey items as their gape size increases (O'Brien 1979, 1987; Schael et al. 1991). Although Burbot may exploit a diversity of prey resources as they grow, additional research is needed to identify the available prey resources in Deep Creek.

An important consideration of this study is that reduced detection efficiency may have limited our ability to monitor the movement and dispersal of Burbot released in Deep Creek. One concern is that only 56% of the Burbot released into the creek were relocated; several potential factors could explain why the remaining 44% of Burbot were never relocated. One possibility is that these Burbot simply out-migrated to the Kootenai River during high flows, when antenna efficiency was reduced, and thus were never detected. However, we think that this explanation is unlikely for several reasons. First, this would require a major difference in behavior between the Burbot that were relocated and those that were never relocated. Second, for Burbot to out-migrate to the Kootenai River, they had to move past a minimum of two antennas. Finally, only 0.19% of Burbot released in Deep Creek have been caught in hoop nets within the main-stem Kootenai River (IDFG, unpublished data). This is lower than the percentages observed for Burbot released at other stocking sites in the Kootenai River basin, which vary from 0.50% to 4.00%. We would expect the proportion of Burbot caught in hoop nets by IDFG to be higher than or similar to proportions from other release sites if 44% were out-migrating to the Kootenai River. Another possible explanation is the overestimation of mobile antenna efficiency. We strived to simulate live Burbot when conducting our mobile survey efficiency estimates, but rocks do not swim to avoid being detected, and our efficiency estimates were likely inflated. Therefore, our mobile surveys may not have been as efficient as our estimates suggested. Even with reduced efficiency of mobile PIT tag antennas, Burbot that were never detected would have to display distinctly different behavior than detected individuals to alter our conclusions. Removal of tags from Deep Creek by predators may also provide an explanation. If a Burbot was consumed by a predator such as a great blue heron or a river otter, the predator may not have defecated in Deep Creek, and thus the tag would no longer have been available for detection. Our estimate of S (0.27) indicated that 73% of Burbot released in Deep Creek died within the first 7 months after stocking. If a significant proportion of this mortality was from terrestrial predators, it may partially explain why so many tags were never relocated. Finally, high sediment loads during spring runoff may have buried tags from dead fish. Deep Creek is listed on Idaho's Clean Water Act Section 303(d) list of impaired waters for excessive sediment loads (IDEQ 2006) and routinely deposits large sediment loads during spring runoff. If tags were buried deeper than 0.38 m, our mobile antennas would not be able to relocate the tags.

Our research provides evidence that age-0 Burbot move little after being released and are slow to disperse from release locations regardless of perceived habitat quality. This research also yields some of the first estimates of survival for hatchery-reared age-0 Burbot released in lotic environments. Survival estimates were similar across years and release locations, and survival improved for Burbot that survived the first 7 months in Deep Creek. Although the use of multiple release locations and releasing Burbot at a lower density did not increase survival, this strategy may still be beneficial to managers. Release of Burbot at low densities across multiple locations reduces competition for resources and provides a buffer against localized events that may increase mortality. When developing release strategies, managers may consider that juvenile Burbot do not move great distances after release (i.e., they move < 1 km). Further research is needed to determine whether similar patterns in movement and dispersal occur at other release sites in the Kootenai River or whether this pattern is unique to Deep Creek. Additionally, future research determining the amount and importance of predation on Burbot and quantifying the diversity and abundance of prey resources within the system would provide additional insight to aid in developing release strategies for Burbot throughout the Kootenai River system.

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