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SPECIAL SECTION: BURBOT

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Abstract

As part of recovery efforts for the Kootenay population of Burbot *Lota lota*, we monitored 109 sonic-tagged, hatchery-reared Burbot released at 1–3 years of age throughout Kootenay Lake and the Kootenay River over a 3-year period. Our objectives were to evaluate broodstock choice, assess differences in survival and dispersal by release site and age, and evaluate spawning movements. Overall, release survival was high (66%) and there was dispersal throughout the system (up to 235 km), involving both lacustrine and riverine habitat. Spawning movements were extensive (up to 59 km/d upstream) and suggest the use of known spawning locations. However, most age-1 releases had lower survival and remained in the release tributaries for 1 year postrelease, which was longer than expected and which warrants further investigation. Overall, this telemetry study provides a positive outlook on the current aquaculture rehabilitation efforts for Kootenay Burbot and provides direction for further work.

In British Columbia, Idaho, and Montana, the population of Burbot *Lota lota* in Kootenay Lake and the Kootenay River (spelled Kootenai in the United States) is at risk of demographic extinction. Prior to 1972 the harvest of fishermen (both sport and commercial) in the Kootenay River was estimated at tens of thousands of kilograms, and in Kootenay Lake anglers annually harvested over 20,000 Burbot in the late 1960s and early 1970s (Paragamian et al. 2000; Ahrens and Korman 2002). With the completion of Libby Dam and other habitat changes, these popular fisheries neared collapse by the late 1970s and have not recovered since (Paragamian et al. 2000; Neufeld 2005). Studies on both sides of the Canadian–U.S. border date back to 1979, when the Kootenai River Fisheries Investigation was initiated by the Idaho Department of Fish and Game (Partridge 1980). Additionally, in response to the decline in the Burbot population in the lower Kootenai River, the Kootenai Tribe of Idaho coordinated a collaborative process through the Kootenai Valley Resource Initiative's Burbot Subcommittee to develop a conservation strategy to guide Burbot restoration activities (KVRI 2005; Ireland and Perry 2008). Although our current knowledge of the specific causes of the decline in the system is incomplete, habitat loss and degradation are the most likely, as has been seen with other riverine populations at risk (KVRI 2005; Stapanian et al. 2010).

As a stopgap measure while habitat restoration projects are being completed, hatchery-reared Burbot are now annually released into the Kootenay River (Neufeld et al. 2011a). Broodstock for the hatchery program are procured from a wild stock at Moyie Lake within the Kootenay River basin. Under the Burbot Conservation Strategy and the first Kootenai River

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Burbot 5-Year Operational Research Plan (2006–2011; KVRI 2005; Neufeld et al. 2009), studies were initiated to evaluate the success of the hatchery efforts as well as the release survival, movements, and habitat use of hatchery-raised Burbot.

In addition to in-river recapture efforts, sonic-tagged subadult and adult hatchery releases can be used as a passive method of tracking movement, habitat use, and survival. One variable that is best evaluated with telemetry is the dispersal of the hatchery-reared Burbot from various release sites. Due to the spatial and temporal variability of the natural environment, dispersal to suitable habitat is an important factor influencing survival (Hofmann and Fischer 2002; Slavik et al. 2005) and consequently the success of a hatchery-supported population. In the Kootenay River and Kootenay Lake, Neufeld et al. (2011a) evaluated the first ever release and tracking of sonic-tagged age-2 and age-3 hatchery-reared Burbot in North America. The 5-month pilot study documented a high survival rate and rapid dispersal for these fish; progeny from lake-origin broodstock showed successful behavioral plasticity in a natural riverine habitat (Neufeld et al. 2011a). In that study, 28 out of 30 Burbot survived the initial transport and release and the mean distance of dispersal was 80 km (range = 9.8–137.5 km). Furthermore, the sonic-tagged hatchery fish were detected in known spawning locations during the winter spawning months, suggesting that some hatchery progeny have contributed to spawning in the wild during their first year at large (Neufeld et al. 2011a).

In the current study, we expand upon this previous work by evaluating two and half years of continuous telemetry data from 121 sonic-tagged Burbot released over 3 years. Specifically, our objectives were (1) to determine the differences in survival and dispersal by release location and age at release, (2) to evaluate the movements of potential spawners during the spawning season that would indicate spawning locations, and (3) to investigate the potential for imprinting from release locations for hatchery-reared Burbot from Moyie Lake broodstock.

METHODS

Study Area

The study area extended along the Kootenay River from river kilometer (RKM; measured from the outlet of Duncan Lake, which flows into the north end of Kootenay Lake) 259 in Idaho downstream into British Columbia (Figure 1). The portion in British Columbia includes both riverine habitat (RKM 121–165) and lacustrine habitat in Kootenay Lake (RKM 18–120). Kootenay Lake has a surface area of 390 km^2 and is a fjord-like lake, running north–south in the trench formed between the Selkirk and Purcell mountains. The Kootenay River is regulated by Libby Dam in Montana, which was completed in 1972 to provide flood control and power generation.

Burbot Culture

The Burbot reared in the hatchery program originated from a lacustrine population in Moyie Lake. Gametes were collected from spawning adults captured via ice fishing; eggs were fertilized on site, and the adult Burbot were tagged and released back into Moyie Lake (further described in Neufeld et al. 2011b). These gametes were then transported to the Aquaculture Research Institute (ARI) at the University of Idaho, Moscow. Rearing at the ARI occurred in a recirculating system where photoperiod and water temperature were generally maintained similar to the conditions in the Kootenay River. The Burbot used in this study were reared to 1–3 years of age prior to tagging and release. All fish were weighed and measured prior to tagging (Table 1), and the mean sizes of the three ages were significantly different (Figure 2).

TABLE 1. Size of hatchery-reared Burbot prior to sonic tagging, for all releases from 2009 to 2011 ($n = 121$).

	Weight (g)			TL (mm)		
Age at release	Min	Max	Mean	Min	Max	Mean
1	62	115	83	205	270	240
2	65	818	326	215	270	266
3	409	800	413	350	480	548

Study Period and Releases

This study was initiated with the first release of sonic-tagged Burbot into the Goat River, a Kootenay River tributary, on October 21, 2009. Four subsequent releases occurred in 2010 and 2011 (Table 2). We used six release locations stretching across the study area that included both tributary and main-stem Kootenay River releases (Figure 1). Sonic receivers tracked Burbot movement from these release groups until the end of our study period on March 31, 2012.

Tagging

A total of 121 hatchery-reared Burbot 1–3 years old were tagged with passive integrated transponder tags (Biomark, Inc., Boise, Idaho) and sonic V9-2 L tags (VEMCO Division, AMIRIX Systems, Inc., Halifax, Nova Scotia). All sonic transmitters were 9 × 29 mm in length and weighed 4.7 g in

TABLE 2. Release dates, locations, and numbers for all sonic-tagged, hatchery-reared Burbot released into the Kootenay River and its tributaries from 2009 to 2011, in chronological order.

Release date	Release location	Number released
Oct 21, 2009	Goat River	30
Aug 10, 2010	Boundary Creek	20
Aug 10, 2010	Moyie River	20
Nov 3, 2010	Goat River	15
Aug 2, 2011	RKM 259 (mainstem)	6 (+ 3 delay-start tags)
Aug 2, 2011	RKM 240 (mainstem)	7 (+ 3 delay-start tags)
Aug 2, 2011	RKM 170 (mainstem)	7 (+ 4 delay-start tags)
Oct, 2011	Goat River	4 (+ 2 delay-start tags)

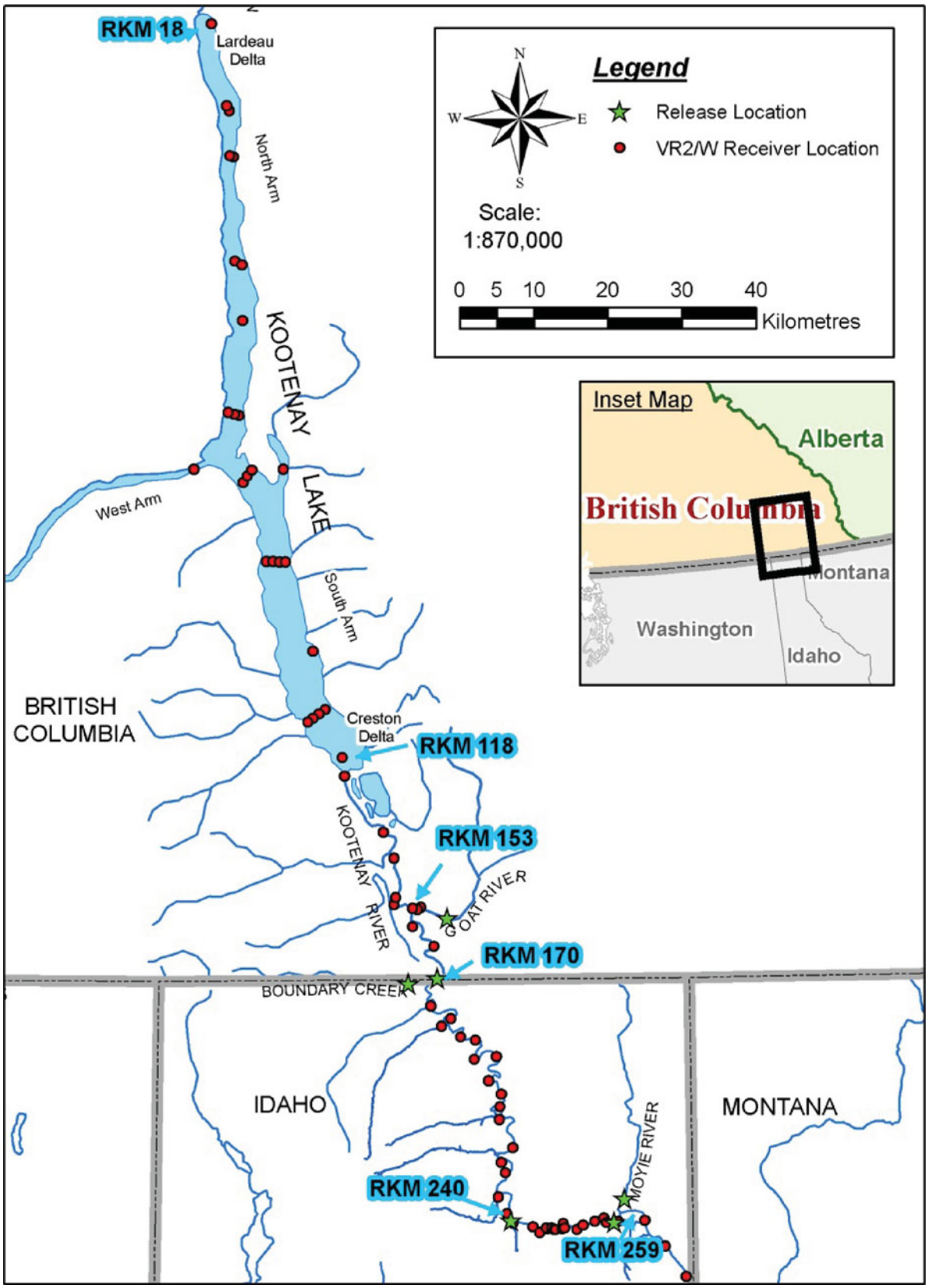

FIGURE 1. Map of study area, which extended from RKM 18 to RKM 259 in Kootenay Lake and the Kootenay River. The river flows from Montana through Idaho into British Columbia. The circles indicate the locations of the sonic receivers and the stars the release locations for the sonic-tagged hatchery Burbot. [Figure available in color online.]

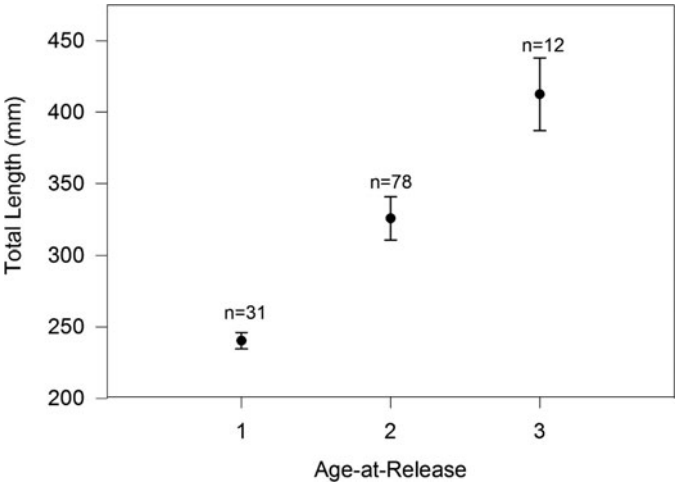

FIGURE 2. Mean TLs (whiskers = 95% CIs) of hatchery-reared Burbot, by age at release. The fish were measured prior to being tagged at the Aquaculture Research Institute at the University of Idaho from 2009 to 2011.

air and 2.9 g in water. In 2009, V9 tags with two different pulse rates were used to optimize the trade-off between battery life and pulse frequency. One-third of the tags ($n = 10$) were set with a delay time of 90–240 s between pulses (nominal delay = 165 s; battery life = 751 d), and the other two-thirds ($n = 20$) were set with a delay time of 60–180 s (nominal delay = 120 s; battery life = 573 d). All of the tags in 2010 ($n = 55$) and two-thirds of the tags in 2011 ($n = 24$) had a nominal delay of 165 s and a battery life of 751 d. The remaining tags in the 2011 releases ($n = 12$) were delay-start tags that also have a nominal delay of 165 s but that will not be active until 775 d posttagging. Therefore, these delay-start tags were not intended to be detected until summer 2013 and the data from them were not included in this movement analysis. In total, we analyzed 109 sonic-tagged Burbot for release survival, movements, and habitat use.

The V9 tags were surgically implanted within the peritoneum by methods similar to those described by Neufeld and Rust (2009). Burbot were anesthetized with MS-222 (tricaine methanesulfonate), and a 12-mm incision was made on the lateral surface approximately two-thirds of the way from the ventral midline to the lateral line and midway between the pectoral girdle and the anal fin. Transmitters and PIT tags were cleaned with ethanol and rinsed with distilled water prior to being placed in the peritoneal cavity. The incision was then closed with two or three monofilament synthetic absorbable sutures (Ethicon 3/0 PDS II, SH-1 22 mm $\frac{1}{2}$ c taper needles). Burbot were monitored at the ARI for 30 d posttagging to ensure physical recovery prior to release.

Tracking

In the Kootenay River and Kootenay Lake there was an established array of 73 Vemco (VR2s and VR2Ws) 81-kHz receivers that extends from the border of Idaho with Montana, downstream throughout the Kootenay River, in the Goat River, and throughout Kootenay Lake (Figure 1). The receivers were set up as point stations on the river and as many as four receivers together serve as gate stations at specific transects on the lake. The mean distance between stations was 4.4 km (range, 13–100 m; further described in Neufeld and Rust 2009). All of the tracking locations of fish resulted from detections by this passive monitoring system.

Telemetry Data Analysis

Survival and data verification.—Detections were first evaluated to eliminate erroneous ones (methods are further described in Neufeld and Rust 2009). Release survival was defined as surviving a minimum of 1 month postrelease, as indicated by detections by receivers. Long-term survival was evaluated by identifying tags that were detected by sonic receivers a minimum of 1 year postrelease. To investigate the factors influencing survival, survival was compared across release locations and age at release.

Dispersal.—Dispersal from release sites was calculated as a linear distance using RKM locations for each fish, subtracting the most downstream detection location from the most upstream one. Dispersal period was defined as the first 6 months postrelease. Because tag codes were not recorded before the release of several fish, the specific release locations for several Burbot were assigned using the first detection location. Comparisons were made across years, release locations, and ages at release. A one-way analysis of variance (ANOVA) was performed (Sigma Plot version 12.3, SYSTAT software) to determine statistical significance.

Spawning movements.—We evaluated the movements of sonic-tagged Burbot that were age 3 or older during the spawning season. Without recapturing individuals we could not confirm their spawning condition, but sexual maturity often occurs at 3 years of age in other southern latitudinal populations in Canada (Arndt and Hutchinson 2000; Stapanian and Madenjian 2007). Additionally, data collected from hatchery progeny that were held and observed in captivity indicate that males and females can mature at sizes as small as 47 cm and 500 g (N. Jensen, ARI, unpublished data) and several of our sonic-tagged fish were this size at ages 2 and 3 at the time of tagging.

Peak spawning in the Kootenay River occurs in the first 2 weeks of February (Paragamian 2000; Paragamian and Wakkinen 2008). We analyzed the movements of all Burbot over 3 years old during a period from January 15 to February 28 in all 3 years (2010–2012) as representative of the spawning period. This study used passive telemetry, and we did not have daily detections of all fish during the spawning period. To fill this void, we manipulated our data set to simulate an active telemetry study in which we assigned a daily location for each fish. This daily location was the RKM of the last receiver where it was detected. These data were then used to calculate daily movements and areas of high use and to make comparisons across years in order to determine potential site fidelity and imprinting to release locations.

TABLE 3. Release survival (first month at large) for all releases of Burbot from 2009 to 2011, by release location and age at release.

Release location[a]	Release survival at age			
	Age 1	Age 2	Age 3	All
RKM 259		1/6 (17%)		1/6 (17%)
Moyie River	3/?[b]	4/?[b]	1/3 (33%)	8/20 (40%)
RKM 240		6/7 (86%)		6/7 (86%)
RKM 170		6/7 (86%)		6/7 (86%)
Boundary Creek	5/?[b]	5/?[b]	2/2 (100%)	12/20 (60%)
Goat River	11/15 (73%)	22/27 (81%)	6/7 (86%)	39/49 (80%)
All	19/31 (61%)	44/66 (67%)	9/12 (75%)	72/109 (66%)

[a]RKM values refer to the main-stem Kootenay River.

[b]There were 6 age-1 and 10 age-2 Burbot that were never detected and could not be properly assigned to a release location (which could be either the Moyie River or Boundary Creek). Including these fish, the release survival of age-1 Burbot was 31% and that of age-2 Burbot was 47%.

RESULTS

Detections and Survival

The survival of the tagged Burbot was very high; 121 Burbot survived the 30-d posttagging laboratory observation period and were successfully released at six different release sites on the Kootenay River. Only 1 Burbot did not survive the initial observation period and likely never recovered from anesthesia. Of the 121 Burbot released 109 were evaluated postrelease, as the remaining 12 were tagged with delay-start tags that were not active during our study period. Based on the pilot study analyzing the data from the first release in 2009 (Neufeld et al. 2011a), there were no differences in detectability between the two different pulse delay tags used in the first release (nominal delays of 120 and 180 s); as a result, only the longer pulse interval tags were used for tagged fish in 2010 and 2011 to ensure the longest battery life possible. Overall, the release survival of all Burbot was high; 72 of 109 (66%) were subsequently detected for a minimum of 1 month postrelease by the array of sonic receivers.

A more detailed analysis of survival rates during the first month postrelease suggests that release survival differs across release sites and ages at release. The releases at the two sites furthest upstream (the Moyie River and RKM 259 of the main-stem Kootenay River) had the lowest release survival; all other release locations had 60% survival or better (Table 3). All release data were pooled to investigate potential survival differences with age at release. This analysis showed that the age-1 release group had the lowest survival and that survival increased with age (Table 3). In addition to release survival, the length of this study permitted a look at annual survival rates for the first 2 release years, which included all release ages and the three tributary release locations. The first-year survival for both the 2009 and 2010 releases was estimated at 54% (46/85); excluding the mortalities that occurred soon after release, annual survival increases to 78% (46/59).

Dispersal

There was high overall dispersal, with a mean of 50.5 km (SE, 6.6) for all released Burbot; dispersal extended from the Moyie River in Idaho downstream to the Lardeau River Delta in the North Arm of Kootenay Lake, covering a total linear distance of 235 km. Dispersal differed across release locations and included both upstream and downstream movements within the 6-month dispersal period. Of all the Burbot included in the dispersal calculations, 29% (21/72) entered Kootenay Lake at some point, 9 of which made it all the way to the Lardeau Delta (over 100 km [north-to-south distance] across the lake. There were significant differences in the mean dispersal distances for the six release locations (ANOVA: $F_{4, 68} = 5.89$, $P < 0.001$; Figure 3). When

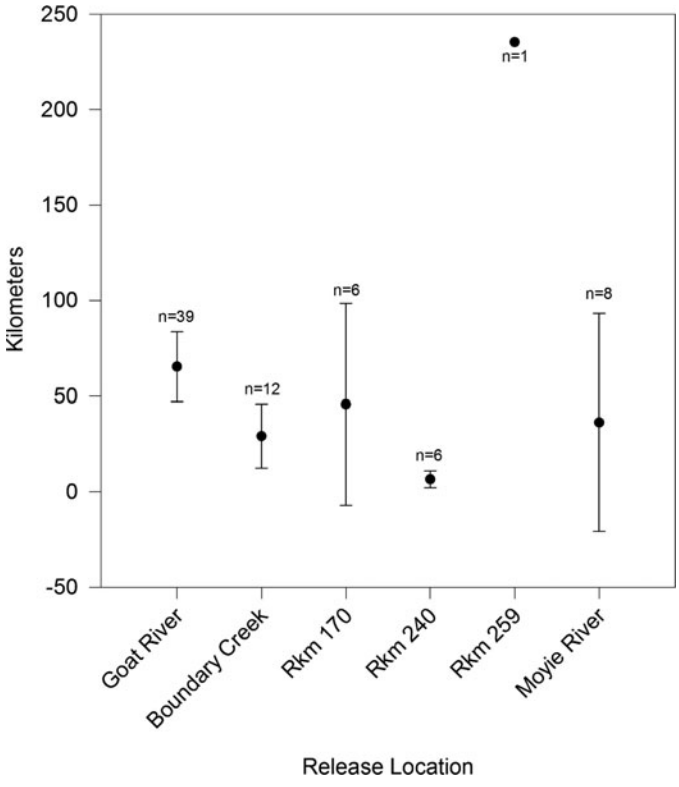

FIGURE 3. Mean dispersal distances (whiskers = 95% CIs) from release locations for sonic-tagged, hatchery-reared Burbot, by release location. The fish were released into the Kootenay River from 2009 to 2011.

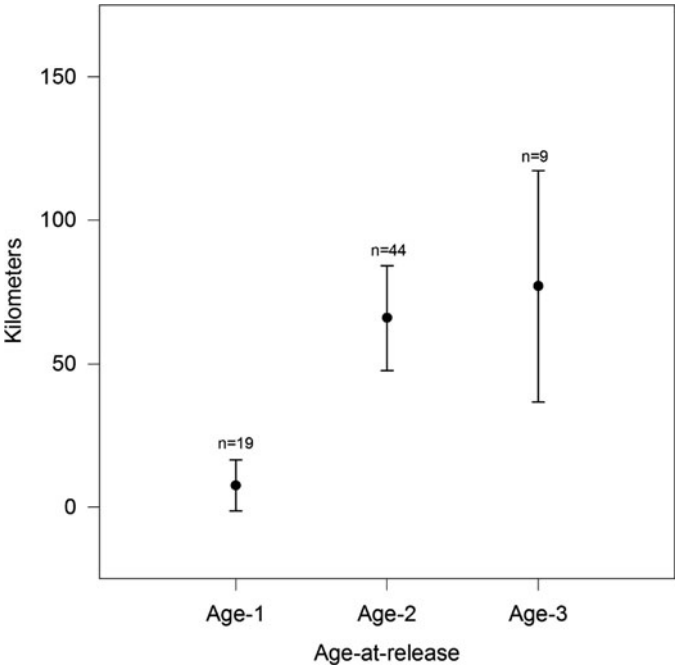

FIGURE 4. Mean dispersal distances (whiskers = 95% CIs) from release locations for sonic-tagged, hatchery-reared Burbot, by age at release.

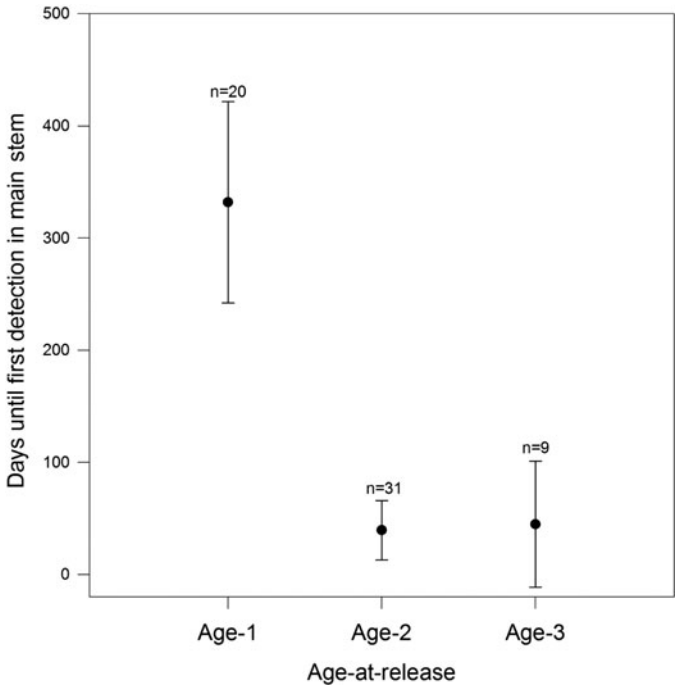

FIGURE 5. Mean times (whiskers = 95% CIs) taken to disperse from release tributaries to the main-stem Kootenay River by the sonic-tagged Burbot released in the Goat River, Boundary Creek, and the Moyie River from 2009 to 2011, by age at release.

we pooled the data from all release locations and stratified them based on age, they suggested that there are differences in dispersal distance based on age at release (ANOVA: $F_{2, 70} = 9.95$, $P < 0.001$; Figure 4). Given the magnitude of the difference for the Burbot released at 1 year old (mean, 7.2 km; SE, 4.0) and the older releases (age 2: mean, 65.9 km; SE, 8.9; and age 3: mean, 76.9 km; SE, 17.5), further investigations into the movements of the younger releases were initiated. Our analysis suggested that when released into tributaries, the youngest groups remained in the respective tributaries for on average 1 year postrelease, a significantly longer period than the older releases (ANOVA: $F_{2, 57} = 35.9$, $P < 0.001$; Figure 5).

Spawning Movement

Of our sonic tagged Burbot, 51 individuals were of potential spawning age and were alive with active tags through a minimum of one spawning season; of these 51, 17 were active through two spawning seasons. There were extensive individual daily movements during the spawning season for many of the 51 Burbot, up to 59 km upstream and 33 km downstream. Furthermore, when we removed days of no movement and did not differentiate for directionality, the mean daily movement was 10.6 km/d (SE = 0.7).

There are three historically known wild Burbot spawning locations in the Kootenay River (Paragamian 2000), including Ambush Rock (RKM 244.7), the Goat River, and the Lardeau Delta on Kootenay Lake (RKM 18). These three locations had high use by sonic-tagged, spawning-age Burbot during the spawning season (Figure 6). However, there were no data to conclusively evaluate imprinting to release locations. Although a few Burbot released in the Goat River returned during the spawning period, even more Goat River releases were detected elsewhere during the spawning season. Dispersal and subsequent detections near multiple spawning locations, though not conclusive data for evaluating imprinting, suggest that

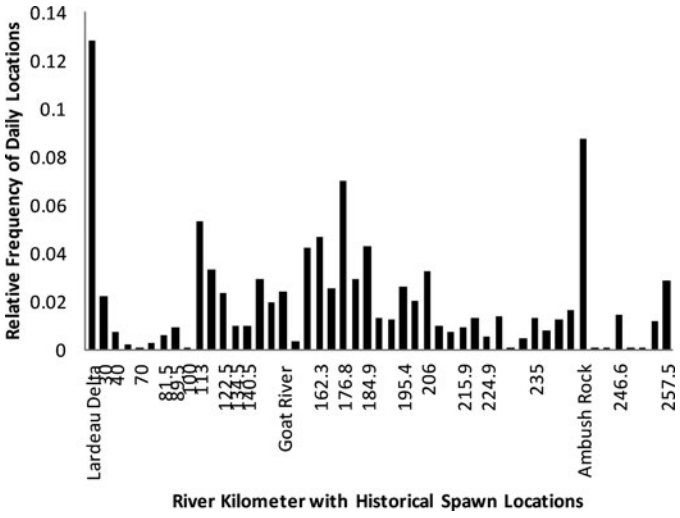

FIGURE 6. Relative frequency of the daily locations of adult Burbot (age 3+) in Kootenay Lake (RKM 18–121) and the Kootenay River (RKM 122–259) during all three spawning seasons (2010–2012). The three historical spawning locations—the Lardeau Delta, the Goat River, and Ambush Rock—are noted.

spawning site selection by hatchery fish is similar to that of wild individuals.

DISCUSSION

This telemetry study permitted the first evaluation of annual survival for subadult and adult hatchery-reared Burbot released into a historical range. The annual survival for the first year at large (54–78%) was comparable to the annual survival rate of wild adult Burbot from the broodstock source (Moyie Lake, which is within the Kootenay River drainage area) and has been estimated between 53% (Prince 2007) and 70–80% (Neufeld 2008). In another southern population, Schram (2000) estimated the total annual survival of adult Burbot in western Lake Superior at 57%. The comparably high annual survival suggests that this southern Kootenay system is suitable to support the long-term survival of adult and subadult Burbot.

The postrelease survival of all sonic-tagged, hatchery-reared Burbot from Moyie Lake broodstock was high. Additionally, the postrelease survival at the Moyie River and Boundary Creek may be underestimated because some released fish may have survived during the study period but remained undetected in these tributaries lacking receivers. Previous telemetry work in the Kootenay system focused on larger-scale movements, and as a result receivers were positioned to maximize coverage area (up to 7 km apart in the river and 13 km in the lake). The only tributary in this study area with sonic receivers was the Goat River, and these receivers were only deployed with the first release of sonic-tagged, hatchery-reared Burbot in 2009. The results from a pilot study with the first release of age-2 and -3 Burbot suggested that all Burbot moved out of tributaries quickly (Neufeld et al. 2011a). Therefore, due to sufficient coverage in the main stem and the assumed quick dispersal from release locations, receivers were not deployed in other release tributaries (Boundary Creek and the Moyie River). However, data from the 2010 and 2011 releases suggested that the majority of age-1 Burbot released into tributaries remained there for an extended length of time postrelease; this is evident from the Goat River receivers and the first detections of the other age-1 tributary releases in the main stem over 1 year postrelease. Perhaps this is related to an ontogenetic niche shift in food resource use; Amundsen (2003) found that Burbot are largely piscivorous but that Burbot smaller than 300 mm also had large amounts of zoobenthos in their diet. It is possible that tributaries provide a better food source for these smaller age-1 Burbot than for the large age-2+ Burbot.

If, in fact, there were lower survival rates for the Burbot released at the Moyie River and Boundary Creek release sites, our data suggest that this was due to season of release. Burbot are a stenothermal species that inhabit large cool rivers of north temperate regions, preferring temperatures below 14°C (Edsall et al. 1993; Pääkkönen and Marjomäki 2000; Hofmann and Fischer 2002). In summer, Burbot are less active than in the fall and winter months and can be found primarily in the profundal zone of lakes and cooler deep holes in rivers (Pääkkönen et al. 2000; Amundsen et al. 2003). Releases of Burbot in the Goat River were completed in the fall, while releases in Boundary Creek and the Moyie River were completed during the summer months when temperatures were higher (the summer release temperature ranged from 16°C to 18°C, the fall release temperature from 5°C to 8°C). It is possible that the lower survival at the Moyie River and Boundary Creek resulted from differences in season of release, as the highest mortality often occurs in the first few days to weeks postrelease (Brown and Day 2002). During this period, while Burbot are adjusting to feeding and predation avoidance in the wild, other stressors such as warmer water temperature may contribute to higher mortality rates; however, we were not able to suitably evaluate this possibility with our study design. Future experimental releases should target comparisons across all release sites by season.

Similar to the findings of Neufeld et al. (2011a) and other Burbot telemetry studies (Breeser et al. 1988), dispersal from release sites was extensive for age-2 and age-3 Burbot. In fact, the maximum daily movements that we recorded were greater than those in any other study (e.g., Breeser et al. 1988; Paragamian et al. 2005); fish traveled up to 59 km/d, which may indicate that Burbot are stronger swimmers than often thought. With dispersal throughout the river and downstream to the Lardeau Delta (RKM 18), these data suggest that a minimal number of release locations may be adequate to allow released Burbot access to all available habitats. However, our analysis suggested that age-1 Burbot do not disperse as far or as quickly as the older Burbot. For example, the majority of age-1 Burbot released into the Goat River in 2010 never left the Goat River, whereas the age-2 and age-3 Burbot released into the Goat River in 2009 all left the river within 1–9 d (Neufeld et al. 2011a).

The lower dispersal rates associated with younger hatchery-reared Burbot could have large implications for release strategies. Based on our data for age-2+ Burbot we expect that their movement and dispersal will increase as they get older, but there is a possibility that these Burbot will not disperse at all. Slavik et al. (2005) investigated the home ranges of riverine Burbot and found that they can be quite small (mean, ~7 km), with larger migrations during the spawning season. If younger releases tend to remain close to their release sites, more release locations would be needed to have Burbot throughout the Kootenay Burbot's historical range. Furthermore, if Burbot do disperse farther as they get older, there could be implications for spawning site selection, with potential imprinting from lengthy residence near their release location.

The movements of age-3+ Burbot during the spawning period were extensive, and telemetry detections (as indicators of habitat use) suggest that there was use of three known spawning locations (Ambush Rock, the Goat River, and the Lardeau Delta). Our data suggest that hatchery-reared Burbot have contributed to wild spawning, but our evaluation of imprinting from release locations was inconclusive. Imprinting has been observed for Burbot in other systems, in which

tagged wild Burbot demonstrated fidelity to specific rivers and estuaries (Hedin 1983; Hudd and Lehtonen 1987). Although our evaluation of imprinting for age-2 and -3 releases was inconclusive, imprinting may be more likely to occur for Burbot released at age 1 or younger, as these fish do not disperse as quickly. This is a subject that warrants further evaluation.

Overall, this evaluation of telemetry data for hatchery-reared Burbot supports a positive outlook on the current aquaculture-related rehabilitation efforts for the Kootenay Burbot population. As found in the first analysis of the telemetry data from hatchery-reared Burbot released into the Kootenay River (Neufeld et al. 2011a), the progeny of lake-origin broodstock had high survival and dispersed throughout the system, utilizing the entire range of available habitat (both riverine and lacustrine). This finding of behavioral plasticity in Burbot is supported by the current study, where the use of the Moyie Lake Burbot population as a brood source has proven to be successful for Kootenay River reintroduction efforts. Utilizing telemetry to the track dispersal and survival of hatchery-reared Burbot has also proven to be successful. Supporting mark–recapture efforts, this project provides a passive, data-rich method of evaluating Burbot release strategies. With the current low recapture results for hatchery Burbot in the Kootenay system, continued telemetry studies are crucial to evaluating the methodology and success of releasing hatchery-reared Burbot into the Kootenay River.

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