

TELEMETRY CASE REPORT

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A field evaluation of the growth and survival of age-0 *Oncorhynchus mykiss* tagged with 8-mm passive integrated transponder (PIT) tags

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Abstract

Background: In fish tagging studies, tag size limits the size of fish that can be tagged, the fraction of a population that can be represented, and ultimately inferences that can be made about the study population, particularly when juvenile fish are the subject of interest. Introduction of an 8-mm passive integrated transponder (PIT) reduced the minimum taggable size of fish, but it has not been evaluated in field trials. We evaluated the growth and survival of age-0 *Oncorhynchus mykiss* tagged with 8-mm PIT tags in four streams in southwest Washington, USA.

Results: A total of 351 PIT tagged fish and 340 control fish (marked with pelvic fin clips) were released, but recapture rates were low, particularly for control fish. Growth in length and mass did not differ between small (42–54 mm) and large (55–64 mm) PIT tagged fish. There was a slightly positive, but weak, relation between tag burden and growth in mass; however, there was considerable variability in this relation ($R^2 = 0.115$). Summer to autumn joint probability of fish surviving and remaining in the study area estimated with a Bayesian mark-recapture model ranged from 0.228 to 0.478 in study streams. We found no significant relation between tag burden and survival, suggesting neither tag burden nor fish size at tagging affected survival.

Conclusions: Although this study was limited in scope, it provided insight into how age-0 *O. mykiss* tagged with 8-mm PIT tags grew and survived under natural conditions. We showed that fish as small as 42 mm could be tagged without detrimental effects, which should allow researchers to represent a larger portion of study populations through PIT tagging.

Keywords: Passive integrated transponders, *Oncorhynchus mykiss*, Growth, Survival

Background

The introduction of passive integrated transponder (PIT) tags [1] for use in fishery studies created an array of opportunities for collecting information on individually marked fish often over their entire life. Because PIT tags allow identification of individual fish, recapture or subsequent remote detections of tagged fish can provide detailed information on population metrics such as growth, survival, and life history. Tag size, however, limits

the size of fish that can be tagged, the fraction of a population that can be represented, and ultimately inferences that can be made about the study population, particularly when juvenile fish are the subject of interest.

Recently, smaller PIT tags have become available enabling the tagging of smaller fish. The 12-mm PIT tag was the first tag to enjoy widespread use and allowed the tagging of salmonids as small as 56 mm [1], although a minimum size of ≥ 65 mm FL was adopted in places like the Columbia River basin [2]. The introduction of a 9-mm tag in 2006 further reduced the practical taggable size of fish to 50–55 mm [3, 4]. The introduction of an 8-mm tag in 2011 allowed even smaller fish to be tagged, and many

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laboratory studies were published soon thereafter on the effects of this tag on a variety of species (e.g., Oregon chub *Oregonichthys crameri* [5]; Chinook salmon *Oncorhynchus tshawytscha* [6]; humpback chub *Gila cypha* [7]; brook trout *Salvelinus fontinalis* [8]). These studies reported tagging fish as small as 35–40 mm, often with minimal effects on growth and survival. These laboratory studies, as well as others that used mesocosms [9] or field enclosures (e.g., [10, 11]), were conducted under controlled conditions. Thus, the lack of detrimental tag effects in these studies was not surprising. For 8-mm PIT tags to be truly useful in field studies, the performance of small, tagged fish needs to be evaluated in native habitat where they are subject to natural growth and mortality factors that are absent in the laboratory.

Field studies of small fish tagged with 8-mm PIT tags have likely not been conducted to date for at least two reasons. First, in open or large systems, it is difficult and uncertain whether sufficient numbers of tagged fish can be recaptured to reliably calculate performance metrics. Second, the selection of appropriate control fish for comparison is problematic because uniquely marking individuals is often not possible. We sought to overcome these limitations by tagging and releasing fish in streams with low summer discharge wherein recapture probability

would be sufficient to evaluate performance metrics, and emigration of tagged fish would be minimal. To compare the performance of tagged fish to untagged fish, fin-clipped fish were used as controls although they were not uniquely identifiable. Our objective was to evaluate the growth and survival of age-0 *O. mykiss* tagged with 8-mm PIT tags under field conditions.

Results

We collected more small fish for marking than large fish in our study streams (Table 1). Mean length of small fish ranged from 44 to 49 mm, and mean weight ranged from 0.9 to 1.3 g. Mean length of large fish ranged from 55 to 59 mm, and mean weight ranged from 1.5 to 2.3 g (Table 1). Mean tag burden ranged from 2.3 to 3.3% for small fish and from 1.3 to 2.0% for large fish. No fish died before release following tagging or fin clipping. We recaptured more tagged fish than control fish. Recapture rates for small, tagged fish ranged from 15 to 30% and from 0 to 10% for small, control fish, whereas recapture rates for large, tagged fish ranged from 14 to 32% and from 5 to 17% for large, control fish (Table 1).

We found no significant negative effects of the 8-mm PIT tag on growth. First, we found a slight but significant positive relationship between mass-standardized

Table 1 Mean \pm SD length and weight of age-0 *Oncorhynchus mykiss* used to evaluate 8-mm PIT tags in the Wind River, 2017

Site	Group	Size	Tagging			Recapture			Growth (mm/d)	Growth (g/g/d)
			N	FL (mm)	WT (g)	N	FL (mm)	WT (g)		
Layout	Tag	Small	53	44 \pm 2.2	0.9 \pm 0.2	11	54 \pm 4.9	1.8 \pm 0.5 ^a	0.16 \pm 0.012	0.012 \pm 0.006
	Control	Small	53	44 \pm 2.2	0.9 \pm 0.2	2	58 \pm 7.1	2.2 \pm 1.1	0.24 \pm 0.126	0.016 \pm 0.012
Trapper	Tag	Small	70	48 \pm 3.0	1.2 \pm 0.3	20	61 \pm 4.3	2.9 \pm 0.6	0.21 \pm 0.062	0.018 \pm 0.005
	Control	Small	69	47 \pm 3.5	1.2 \pm 0.3	2	60 \pm 1.4	2.7 \pm 0.2	0.22 \pm 0.025	0.017 \pm 0.002
	Tag	Large	32	59 \pm 2.7	2.3 \pm 0.4	5	71 \pm 3.8	3.8 \pm 0.8	0.19 \pm 0.082	0.010 \pm 0.007
	Control	Large	30	59 \pm 3.2	2.2 \pm 0.3	3	63 \pm 4.6	3.6 \pm 1.3	0.07 \pm 0.081	0.012 \pm 0.010
Wind	Tag	Small	74	48 \pm 3.0	1.1 \pm 0.2	11	59 \pm 5.1	2.6 \pm 0.6	0.22 \pm 0.059	0.020 \pm 0.008
	Control	Small	72	49 \pm 3.0	1.2 \pm 0.2	0	0	0		
	Tag	Large	7	56 \pm 1.4	1.6 \pm 0.2	1	66	3.2	0.20	0.019
	Control	Large	6	55 \pm 0.8	1.5 \pm 0.2	1	55	1.9	-0.006	0.006
Paradise	Tag	Small	74	49 \pm 3.8	1.2 \pm 0.4	22	61 \pm 5.3	2.9 \pm 0.6	0.20 \pm 0.085	0.017 \pm 0.006
	Control	Small	71	49 \pm 3.8	1.3 \pm 0.4	7	58 \pm 4.7	2.2 \pm 0.6	0.17 \pm 0.083	0.011 \pm 0.006
	Tag	Large	41	57 \pm 1.7	1.8 \pm 0.2	13	67 \pm 5.7	3.5 \pm 0.8	0.19 \pm 0.087	0.016 \pm 0.006
	Control	Large	39	57 \pm 1.5	1.9 \pm 0.3	2	66 \pm 1.4	3.3 \pm 0.1	0.16 \pm 0.025	0.013 \pm 0.006
All	Tag	Small	271	47 \pm 3.5	1.1 \pm 0.3	64 ^b	59 \pm 5.3	2.7 \pm 0.7	0.20 \pm 0.073 _x	0.017 \pm 0.006 _x
	Control	Small	265	47 \pm 3.6	1.2 \pm 0.3	11	58 \pm 4.3	2.3 \pm 0.6	0.19 \pm 0.083	0.013 \pm 0.007
	Tag	Large	80	58 \pm 2.5	1.9 \pm 0.4	19	68 \pm 5.2	3.5 \pm 0.8	0.19 \pm 0.081 _x	0.015 \pm 0.007 _x

Small (42–54 mm) and large (55–64 mm) control fish had their right or left pelvic fin clipped, respectively. Growth was calculated over 57 d. Growth in weight was mass standardized. Although not statistically analyzed, growth metrics of small and large control fish are shown for comparison. Means with the same letter are not significantly different

^a The sample size for calculating mean weight was 9

^b The sample size for calculating mean growth (g/g/d) was 62

growth rate and tag burden (slope=0.255, $P=0.002$); however, there was considerable scatter about this relation ($R^2=0.115$). Second, we found no significant difference ($t=-0.57$, $df=81$, $P=0.57$) in growth in FL between small and large fish tagged with 8-mm tags. Mean \pm SD growth of 8-mm tagged small fish was 0.20 ± 0.07 mm/d, and growth of 8-mm tagged large fish was 0.19 ± 0.08 mm/d (Table 1). Growth in mass also did not vary significantly by fish size ($t=-1.43$, $df=79$, $P=0.16$). Mean \pm SD growth in mass of 8-mm tagged small fish was 0.017 ± 0.006 g/g/d, whereas growth of 8-mm tagged large fish was 0.015 ± 0.007 g/g/d (Table 1).

We found that fish size had a strong effect on capture probability, but we found little effect of tag burden on survival. Capture probability varied among streams and increased sharply with fork length from 0.2–0.35 to 0.6–0.75 over the size range of fish captured (Table 2; Fig. 1). The slope for the effect of tag burden on survival was near zero and the 95% credible interval overlapped zero, suggesting no effect of tag burden on survival (Table 2). However, we found differences in mean survival among streams that ranged from 0.228 to 0.478 (Table 2).

Discussion

We demonstrated that age-0 *O. mykiss* as small as 42 mm could be tagged in the field with 8-mm PIT tags with minimal effects on growth and survival as compared to larger (55–64-mm) fish. Comparison of these metrics to those of control fish was difficult because few control fish were recaptured. The low recapture rate of control fish is puzzling because the fin clip was presumably less intrusive than PIT tagging, and we expected to recapture

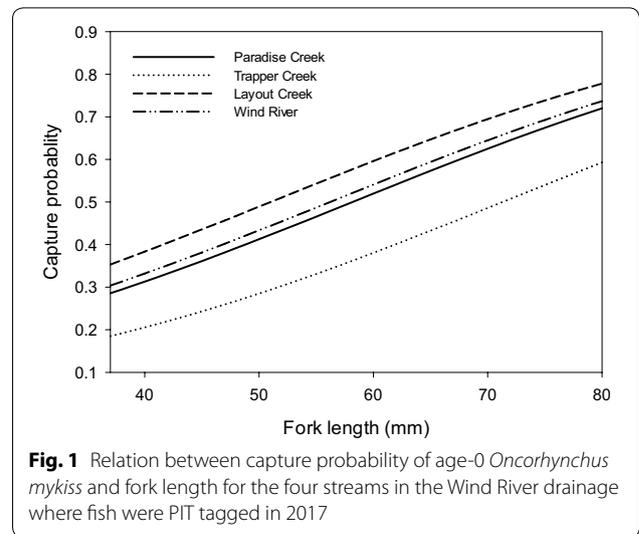


Fig. 1 Relation between capture probability of age-0 *Oncorhynchus mykiss* and fork length for the four streams in the Wind River drainage where fish were PIT tagged in 2017

more control fish than we did. There are a number of possible explanations for this. First, fin regrowth over the 57 days between marking and recapture could have contributed to misidentification of control fish. Second, control fish could have experienced higher mortality due to fin clipping. A number of studies have shown substantial long-term (e.g., overwinter) mortality of fin-clipped juvenile salmonids [12, 13], but others have not [14–16]. Control fish may have experienced higher mortality from predators such as brook trout, shorthead sculpin, and Pacific giant salamander *Dicamptodon* spp. if their swimming and escape ability was reduced by the missing fin. Third, control fish could have emigrated from

Table 2 Parameter estimates and credible intervals for the Bayesian mark-recapture model developed for PIT tagged age-0 *Oncorhynchus mykiss* in the Wind River drainage in 2017

Parameter	Study stream	Posterior median	95% credible interval
α_0 (intercept)	Paradise	0.014	-0.494, 0.483
	Trapper	-0.553	-1.106, -0.092
	Layout	0.325	-0.121, 0.695
	Wind	0.100	-0.350, 0.521
α_1 (slope for fork length)	All	0.359	0.078, 0.650
β_0 (intercept)	Paradise	-0.068	-0.836, 0.621
	Trapper	-0.173	-1.005, 0.769
	Layout	-0.834	-1.729, 0.252
	Wind	-1.221	-1.972, -0.452
β_0 (slope for tag burden)	All	0.027	-0.445, 0.476
Mean survival probability (φ)	Paradise	0.478	0.302, 0.651
	Trapper	0.457	0.268, 0.683
	Layout	0.303	0.131, 0.530
	Wind	0.228	0.119, 0.382

α = parameters of the capture probability model, β = parameters of the survival model

our study sections. There was a large rain event a week before our recapture sampling that could have caused control fish to emigrate from the study sections, but we would have expected the same response from tagged fish. We did detect some PIT tagged fish emigrating from our study sections and passing downstream PIT tag detection antennas, but the incidence of this was low (12 fish). Although antenna detection probability was unknown, it was likely high given low stream discharge, good antenna coverage (e.g., shallow water depths flowing over antennas), and likelihood of age-0 *O. mykiss* generally remaining close to the substrate, and thus antennas, which is consistent with their behavior at this age. Also, most of these tagged fish emigrated before the rain event.

We recognize that tagged and control fish were somewhat confounded by mark type. We believed that fin clipping was the least intrusive batch mark available for our study, and it is a common marking technique in fishery studies. Because control fish were not uniquely marked, there was no way to compare survival of tagged and control fish in a mark-recapture framework, and they did not influence those results.

Small fish tagged with 8-mm tags grew equally as well as large, tagged fish suggesting that the presence of the tag had little effect on growth over the summer interval we evaluated regardless of fish size. In fact, the positive slope between growth and tag burden suggested that smaller fish with a larger tag burden grew slightly better (in mass) than larger fish with a lower tag burden—a counter-intuitive result. This was likely an artifact of the large amount of variability in this relation, and it would have been more concerning had the relation had a negative slope. Although few control fish were recaptured, which precluded unbiased statistical comparisons, they do provide a qualitative comparison to growth of tagged fish. Growth in both length and mass of control fish was generally equal to or slightly lower than that of similar-sized tagged fish. However, the growth of control fish could be biased toward slower growing fish if fast-growing fish regenerated their fins. Nonetheless, our results suggest that growth of age-0 *O. mykiss* as small as 42 mm would not be compromised by tagging fish with 8-mm tags.

Fish size strongly affected capture probability for several likely reasons. First, electrofishing is more effective on larger than smaller fish [17] resulting in a higher capture rate on larger fish. Second, large fish may be easier to see by technicians during sampling and thereby be sampled disproportionately [18]. Third, small fish may more easily evade capture by hiding or being uncapturable in coarse substrate (e.g., [19]). This may explain why capture probabilities were lowest in Trapper Creek because it generally contained the most complex habitat primarily

in the form of large substrates. Because fish size and tag burden are strongly correlated, we can infer from the negligible slope for tag burden that neither appreciably affected survival, even though fish size and tag burden varied at time of tagging.

The survival of tagged fish varied widely between study streams and was twice as high in Paradise Creek (0.478) than in the Wind River (0.228) despite those study sections being in closest proximity and sharing similar habitat and hydrologic conditions. It is difficult to determine causal mechanisms that would explain this differential survival. Greater emigration from the Wind River would have resulted in lower apparent survival, but we believe emigration was low for reasons discussed above. It is possible that predation differed between the streams although predator abundance was not known. Layout Creek was the only stream that contained brook trout—a known predator—and it had the third lowest survival (0.303). Field estimates of age-0 salmonid survival, however, are typically variable and density dependent. For Atlantic salmon *Salmo salar* fry, summer to autumn survival of 52.8% has been reported for 28–48-mm fish [20], whereas another study found that survival of 24–32-mm fish ranged from 2 to 35% depending on year [21]. Similarly, summer to autumn survival of 1-g steelhead *O. mykiss* fry ranged from 30 to 68% [22]. Although we did not calculate fish density in our study sections, our survival estimates are within the ranges reported by others while recognizing that these studies did not estimate survival with mark-recapture techniques.

Conclusions

Although this study was conducted with only one year of data and our sample sizes were low, we were able to gain insight into how age-0 *O. mykiss* tagged with 8-mm PIT tags grew and survived under natural conditions. Overall, growth in both length and mass were similar between both sizes of tagged fish. Summer to autumn survival ranged from 0.228 to 0.478 and was in the range of that reported by other studies. We found no significant relation between tag burden and survival, suggesting neither tag burden nor fish size at tagging affected survival. Experienced tagging personnel were critical to the success of this study and should be a requirement for future studies using 8-mm PIT tags in small fish. Extra care must be taken when tagging fish smaller than 50 mm to avoid squeezing them too hard when they are being held and to insert the tagging needle just enough to make a small hole in the body cavity wall to receive the tag. We showed that fish as small as 42 mm could be tagged without detrimental effects, which should allow researchers to represent a larger portion of study populations through PIT tagging. Additional field studies using 8-mm PIT tags in

small fish will add to our understanding of PIT tagging effects and to the findings of this study.

Methods

Study area

Our study was conducted in the Wind River watershed, a fifth-order tributary of the Columbia River in southwest Washington's Columbia River Gorge (Fig. 2). The Wind River drainage extends north from the Columbia

River nearly 50 km into the Cascade Mountains where elevations range from 29 m at the river mouth to 1190 m on ridge tops in the northern portion of the watershed. The climate is temperate and most of the 280-cm average annual precipitation occurs between November and April. The Wind River supports a run of wild Lower Columbia River steelhead *O. mykiss*.

We conducted our study in four tributaries from late July to late September 2017 when discharge was low

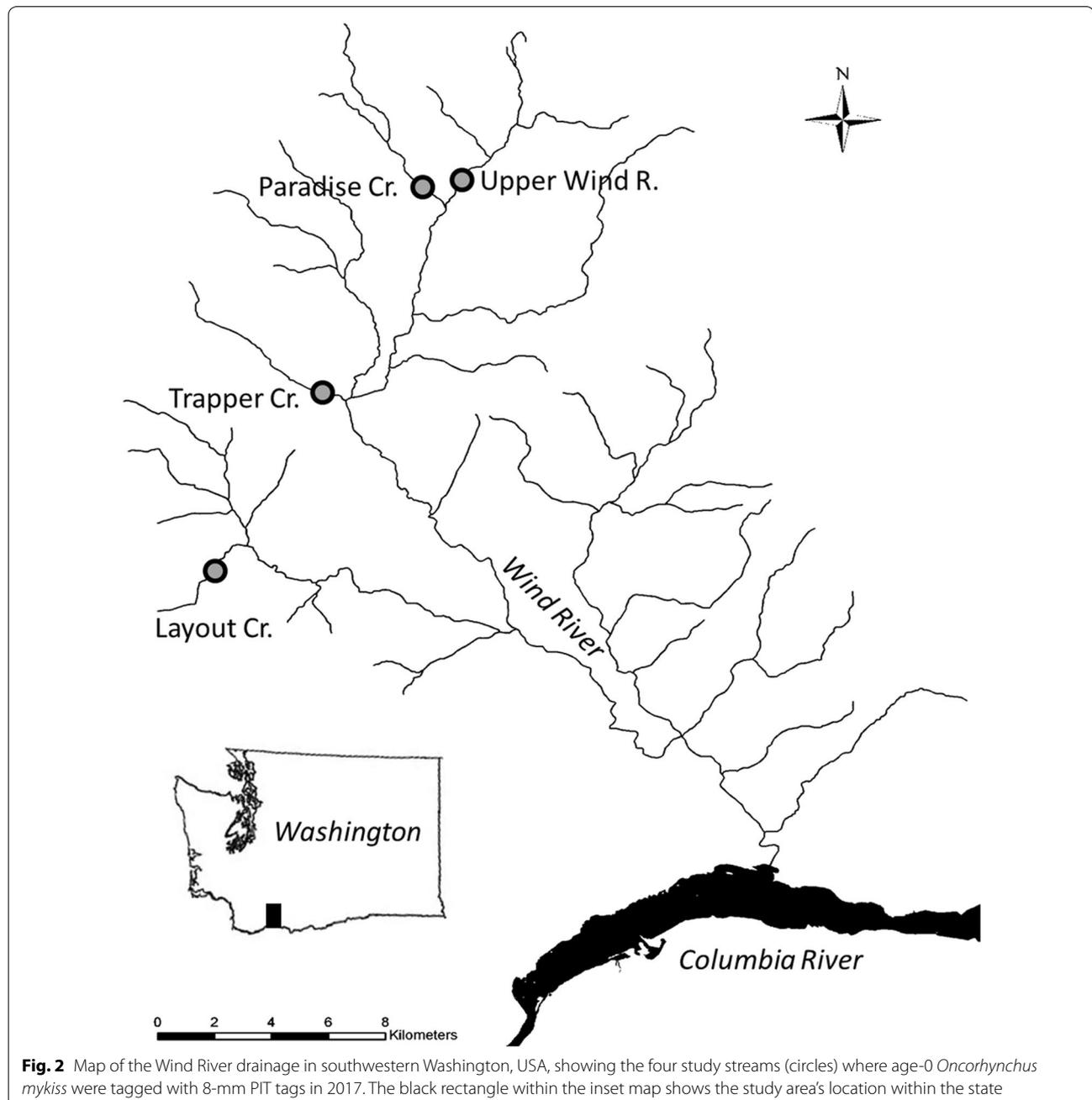


Fig. 2 Map of the Wind River drainage in southwestern Washington, USA, showing the four study streams (circles) where age-0 *Oncorhynchus mykiss* were tagged with 8-mm PIT tags in 2017. The black rectangle within the inset map shows the study area's location within the state

and fish emigration was likely to be minimal. Tributaries included Layout Creek, Trapper Creek, Paradise Creek, and a headwater section of the Wind River (Fig. 2). Study sections within each creek were 550–700 m. Previous sampling at these locations suggested that sufficient numbers of age-0 *O. mykiss* could be sampled to meet study objectives. Study sections had mean wetted widths ranging from 4.3 to 9.9 m; were generally not more than 0.5 m deep; had gravel, cobble, and boulder substrate; and had moderate gradients (2.4–3.4%). Temperatures declined seasonally from highs of 14.1–16.0 °C in early August to lows of 9.0–10.0 °C in late September following the first autumn rains. Mean daily temperatures over the study were warmest in Trapper Creek (13.8 °C) and coolest in Layout and Paradise creeks (12.5 °C). Discharges declined seasonally from 0.06 to 0.02 m³/s in Layout Creek, from 0.27 to 0.13 m³/s in Trapper Creek, from 0.10 to 0.04 m³/s in Paradise Creek, and from 0.27 to 0.13 m³/s in the Wind River. Discharge measurements were taken at the beginning and end of the study. Wild *O. mykiss* were present in each study section, brook trout were present only in Layout Creek, and shorthead sculpin *C. confusus* were present in the other three sections.

Fish collection and marking

We collected and PIT tagged *O. mykiss* during the first week of August 2017. Fish were collected with a backpack electrofisher with an output of 60 Hz DC, 6 ms pulse width, and 300–400 V. Fish were initially captured during one upstream pass through the study section. Captured fish were held in buckets or coolers with ambient stream water (14.1–16.0 °C) and bubblers and then anesthetised with a 5-ml dose of 100 g/L mixture of tricaine methane sulfonate per 19 L of water before handling. All fish were measured (1.0 mm FL) and weighed (0.1 g, wet).

In each study stream, we PIT tagged two size groups of *O. mykiss*: 42–54 mm (hereafter, small) and 55–64 mm (hereafter, large) with 8-mm 134.2 kHz tags (model MiniHPT8, Biomark, Boise, Idaho) that weighed 30 mg in air. Tags were inserted into the body cavity slightly to the side of the ventral midline and just posterior to the pectoral fin with a 14-gauge syringe following the methods of a recent laboratory study [6] and procedures outlined by Columbia Basin Fish and Wildlife Authority [23]. For comparison, we formed two control groups by completely clipping either the right (small size group) or left (large size group) pelvic fins of untagged fish. During marking, we alternated (every other fish) between PIT tagging or fin clipping. After marking, fish were held in fresh, ambient-temperature stream water, allowed to recover and regain equilibrium, and released at or near their point of capture.

We recaptured fish in each study section 57 days after the corresponding tagging event. The entirety of each section was resampled by electrofishing to recapture PIT tagged and control fish. To estimate the joint probability of survival and site fidelity of PIT tagged fish, we determined capture probabilities using removal methods [24, 25]. We conducted a three-pass removal in a representative subsection (80–100 m) of each site, which allowed us to apply estimated capture probabilities to the entire site [26, 27]. Removal subsections were block netted at the upstream and downstream ends to prevent immigration or emigration during sampling [28]. After each pass, fish were processed and held in a cooler with ambient stream water until all passes were complete. After recapture, all fish were scanned for PIT tags and checked for fin clips, measured and weighed, and released at or near the point of capture.

Data analysis

We calculated growth in length (mm/d) as the difference between tagging and recapture FL divided by elapsed days. To calculate growth in mass, we estimated the mass-standardized growth rate [29]:

$$\Omega = \frac{W_t^b - W_0^b}{bt}$$

where Ω is the mass-standardized growth rate (g/g/d), W_0 is the initial mass, W_t is the mass after t days of growth, and b is the allometric mass exponent that we set to 0.338 [30]. We then fit a linear model that expressed mass-standardized growth as a function of tag burden (tag mass/initial fish mass).

We compared growth in length and mass of small and large fish tagged with 8-mm tags. Our original intent was to compare growth of tagged and control fish but few control fish were recaptured, and there was potential bias associated with fin regrowth on control fish. Fish were pooled across study streams by tag group to obtain sufficient sample sizes. After testing the assumption of normality and equality of variances, two-sample t tests were used to compare growth metrics. Significance was assumed at P -values less than 0.05.

To evaluate potential tag effects on the joint probability of fish surviving and remaining in the study area (referred to as “survival” throughout), we developed a Bayesian mark-recapture model that estimated the effect of tag burden (tag mass/initial fish mass) on survival. For survival, the mark-recapture model assumed that binary recapture data (1 = recaptured, 0 = not recaptured) were Bernoulli distributed with probability $\phi \cdot P$ where ϕ is the joint probability of surviving and remaining at the study site, and P is capture probability conditional on surviving to the time of sampling. Capture probability was

estimated from the three-pass removal sample using a multinomial distribution with cell probabilities equal to the probability of being first captured on pass 1, 2, or 3. Jointly modeling the removal sample data with the single-pass recapture data allowed us to separately estimate ϕ and P .

To account for potential confounding effects of size-dependent capture probability on survival, we modeled capture probability as a function of fork length:

$$\text{logit}(P_{ij}) = \alpha_{0,k} + \alpha_1 L_i$$

where $\text{logit}()$ is the logit link function, P_{ij} is the probability of capturing individual i during removal pass j , $\alpha_{0,k}$ is the intercept for the k th study stream ($k = 1, \dots, 4$), and α_1 is the slope for the effect of fork length on capture probability. Similarly, survival was expressed as a function of tag burden with a separate intercept for each study stream:

$$\text{logit}(\phi_i) = \theta_{0,k} + \theta_1 B_i$$

where $\theta_{0,k}$ is the intercept for the k th study stream, θ_1 is the slope for the effect of tag burden on survival, and B_i is the tag burden for individual i . Both fork length (mean = 58.5, SD = 8.3) and tag burden (mean = 0.027, SD = 0.010) were standardized to zero mean and unit standard deviation prior to analysis.

Abbreviations

PIT: passive integrated transponder; FL: fork length.

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Authors' contributions

KFT, IGJ, and RWP conceived of the study. IGJ led the field work and collected the data. KFT and RWP performed data analyses. KFT wrote the paper with input from both coauthors. All authors read and approved the final manuscript.

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Availability of data and materials

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

All animal procedures adhered to those established by the PIT Tag Steering Committee of the Columbia Basin Fish and Wildlife Authority and U.S. Endangered Species Act section 10 permit 1135-10M.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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