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Length at Age of Mottled Sculpin in a Regulated High-Elevation River

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ABSTRACT

We characterized length-at-age relationships of mottled sculpin (*Cottus bairdii*) in the Lower Blue River, a regulated high-elevation river in the southern Rocky Mountain region, CO, USA. Sculpin was collected in May, August and October in a dry year and a wet year, and sagittal otoliths were sectioned for age estimation. Age-1 fish grew rapidly followed by slowed annual growth and a relatively long life span, with the oldest individual inferred to be 9 years old at 119 mm in total length. These patterns might be due to the altered flow regime characterized by hypolimnetic dam water release, resulting in suboptimal summer water temperatures for growth, oligotrophic conditions and low abundance of prey resources. Our study reports length-at-age relationships of a small-bodied species in an anthropogenically altered river, and additional research is warranted to compare their life history characteristics over space and time.

1 | 1 Main text

Fish age and length information is routinely used to characterize life history patterns, quantify anthropogenic impacts on fish populations and evaluate the success of fishery management activities (Quist and Isermann 2017). Age is estimated lethally and non-lethally, and otoliths are the most common structural part used for lethal age inferences (Maceina et al. 2007). As an index of body growth rates, length-at-age data are available for many freshwater fish species, but data on small-bodied non-game species are underrepresented in the literature (Burbank, Drake, and Power 2021; Saddlier, Koehn, and Hammer 2013). Here, we report length-at-age information on mottled sculpin (*Cottus bairdii*) in a regulated high-elevation river characterized by oligotrophic conditions and suboptimal temperatures for growth. A recent molecular study showed a spatial structure in the mottled sculpin complex in the Western USA, and our sculpin may comprise Colorado sculpin (*Cottus punctulatus*) and/or Eagle River sculpin (*Cottus annae*) (Young et al. 2022). In this article, we refer to our fish as mottled sculpin, while acknowledging the taxonomic uncertainty.

Sculpins are widely distributed in clear, cold streams and rivers in the northern hemisphere. The maximum body size of lotic sculpins depends on environmental conditions, ranging from 79 to 140 mm (Grossman, McDaniel, and Ratajczak 2002; Selgeby 1988). Their age information is limited, but the maximum age reported ranges from 5 to 8 years old among locations (Bailey 1952; Grossman, McDaniel, and Ratajczak 2002; Meyer, Cassinelli, and Elle 2008). Much of the limited knowledge comes from sculpin populations in free-flowing rivers. In hydropeaking rivers, slimy sculpin (*Cottus cognatus*) grew faster than in free-flowing rivers

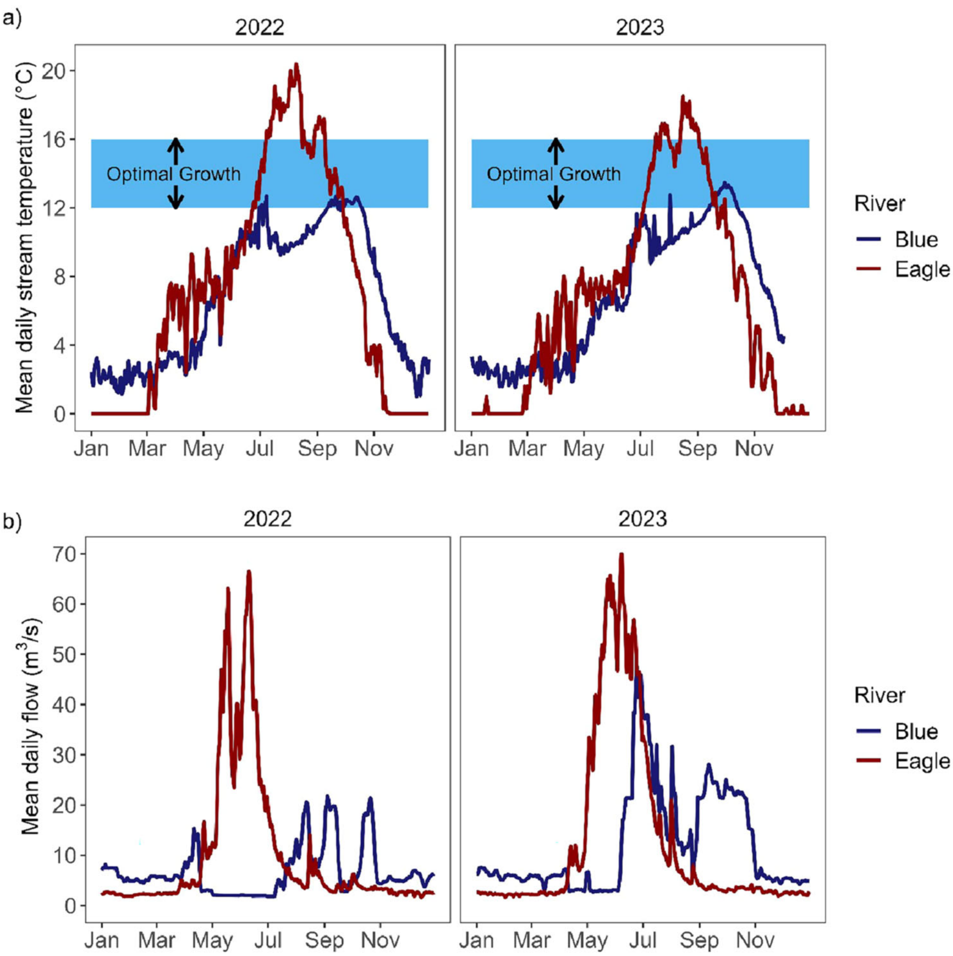

FIGURE 1 | Water temperature (a) and flow (b) patterns in the regulated Lower Blue River and an adjacent free-flowing Eagle River, CO, USA, in 2022 (dry year) and 2023 (wet year). For Lower Blue River, water temperature was measured hourly using a remote logger at the uppermost of the five study sites and flow data are based on the US Geological Survey gage below Green Mountain Reservoir (#09057500) located approximately 4.8 km upstream of the uppermost site. For Eagle River, temperature and flow data were based on the US Geological Survey gage #394220106431500. The optimal temperature range for growth (12°C–16°C) was based on a mark-recapture study of mottled sculpin in a small wadeable stream in South Carolina (Kanno, Kim, and Pregler 2023).

due presumably to more abundant food resources (Bond, Jones, and Haxton 2016; Kelly, Smokorowski, and Power 2016), a condition which does not apply to all regulated rivers (Poff and Hart 2002). Demographic and life history responses to altered flow regimes are poorly understood but are essential to a mechanistic understanding of fish–flow relationships (Freeman et al. 2022).

Our study was conducted in the Lower Blue River, a regulated river in the Southern Rocky Mountain region, CO, USA. The Lower Blue River is a tributary to the Colorado River; it is regulated by two major hypolimnetic-release dams: Dillon Reservoir upstream (surface area = 13.1 km^2 and volume = 0.32 km^3) and Green Mountain Reservoir downstream (surface area = 8.6 km^2 and volume = 0.19 km^3). They provide water for agricultural irrigation, urban and rural communities and hydroelectric power generation. The flow regime of the Lower Blue River is characterized by low-magnitude flows during snowmelt and peak flows in late summer through fall, accompanied by cold water temperatures in summer (Figure 1). The flow and thermal regimes of the Lower Blue River deviate greatly from those of a free-flowing reference river in the region, whose flow peaks during snowmelt (Figure 1). The dams have trapped nutrients, resulting in oligotrophic conditions downstream (Bauch, Miller, and Yacob 2014). Our five study sites (~100 m long each; mean wetted width = 35 m and range = 30–39 m) were located downstream of the Green Mountain Reservoir and ranged from 2280 to 2307 m in elevation. The uppermost site (39°54′50″ N 106°20′19″ W) was located approximately 4.8 km downstream of the Green Mountain Reservoir and was 3.2 km upstream of the lowermost site (39°56′36 ″ N 106°21′25″ W). Mottled sculpin and non-native brown trout (*Salmo trutta*) predominated fish assemblages at our study sites.

Mottled sculpins were collected using backpack electrofishing units (Model LR-24, Smith-Root Inc., Vancouver, WA, USA) at the five study sites in May, August and October 2022–2023 as part of a larger study to characterize fish populations and river food webs (Platis et al. 2024). The size ranges for mottled sculpin were pre-defined in 10-mm increments and we attempted to collect individuals from all length increments evenly to represent the study population. We sacrificed 15 individuals ≥80 mm in total length (TL) per site and sampling occasion. In 2023, we collected additional samples of mottled sculpin <80 mm TL to characterize length frequency distributions more fully and increase the accuracy of our age estimation. A total of 450 individuals were collected in both study years. Our study took place in a dry year (2022) and wet year (2023) with markedly different hydrographs based on the US Geological Survey gage below Green Mountain Reservoir (#09057500) (Figure 1). Accordingly, we compared length-at-age from May through October between the 2 years to examine whether flows affected mottled sculpin growth.

In the laboratory, sagittal otoliths were removed for age determination. Each otolith was dried in resin for 72 h at 60°C and was sectioned using an isomet low-speed saw (Buehler, Lake Bluff, IL, USA). Otoliths were aged by two independent readers (ALB and TRH) who counted the number of annuli (i.e., pairs of opaque and translucence bands) under a microscope with 20–30× magnification. When the readers disagreed on estimated ages, they discussed the samples to reach a consensus. If no agreement was reached, the sample was removed from the data set, resulting in 379 individuals (84% agreement) for subsequent analysis (Supporting Information Appendix S1). Because age-1 individuals were distinguishable based on length–frequency histograms in 2023, we used them as a baseline to determine annuli patterns. We considered that fish became 1 year older on January 1.

We tested whether TL of mottled sculpin depended on age, month, year, site and an interaction between age and year, using a Type-III analysis of variance (ANOVA). The main effect of month and the interactive effect between age and year were of the greatest interest because the former quantified mottled sculpin growth from May through October and the latter evaluated whether length-at-age relationships differed between dry (2022) and wet (2023) years. The ANOVA was based on individuals aged 2–5 because these age classes were present in all months of both years. When significant effects were detected, we used a post hoc Tukey's Honestly Significant Difference (HSD) test to evaluate which pairwise comparisons were responsible for the significant effects. We characterized von Bertalanffy's growth functions using the FSA package (Ogle et al. 2023). The von Bertalanffy growth function was expressed as $E[L|t] = L_\infty\ (1 - e^{-K(t-t_0)})$, where $E[L|t]$ was the average TL (mm) at age t, L_∞ was the asymptotic average TL, K was the growth rate coefficient and t_0 was the hypothetical age when the average TL was zero. We pooled data across months, years and sites because data on age-1 individuals were available only in 2023 and age did not depend on site and month. We explored whether pooling across years influenced the estimates, and von Bertalanffy's growth functions were similar between 2023 alone and both years combined on the basis of overlaps of 95% confidence intervals in parameters (Supporting Information Appendix S2). Data management and analysis were implemented in R Program (R Core Team 2024), and statistical significance was evaluated at $\alpha = 0.05$.

We found that 94% of individuals ≥80 mm TL were estimated to be 2–5 years old in 2022 and 95% in 2023, but a single individual at 119 mm TL was estimated to be 9 years old in the Lower Blue River (Figure 2a). On the basis of a Type-III ANOVA test, TL of age 2–5 mottled sculpin differed significantly by age ($F = 152.1$; $p < 0.0001$) but not by month ($F = 2.0$; $p = 0.14$), year ($F = 0.4$; $p = 0.55$) or site ($F = 0.3$; $p = 0.89$) (Figure 2b). TL was significantly different among all pairwise comparisons of ages 2–5 (Tukey's HSD test). Age-at-length relationships were similar among months, indicating that growth of mottled sculpin was limited from May to October (Figure 2b). However, age-1 mottled sculpin grew during this period in 2023, showing more rapid growth rates initially followed by slower growth rates at older ages. The interactive effect between age and year significantly affected TL ($F = 4.2$; $p = 0.006$). However, Tukey's HSD test showed that this was due only to seemingly subtle biological differences in TL of age-3 fish (mean = 94 mm in 2022 and 100 mm in 2023), showing that contrasting flow conditions in the 2 study years had limited effects on body growth from May through October. A von Bertalanffy growth function based on 2022 and 2023 data combined was characterized as $E[L|t] = 115.44(1 - e^{-0.67(t+0.02)})$ (Figure 2b; Supporting Information Appendix S2).

Our length-at-age data show that mottled sculpin in Blue River are characterized by rapid growth in age 1 followed by slow growth rates in ages 2–5, and then by negligible growth in older fish, a pattern reported similarly for mottled sculpin in the Southeastern USA (Grossman, McDaniel, and Ratajczak 2002). We inferred that our sculpin lived up to 9 years old, the oldest specimen known in riverine cottids in the literature to our knowledge (Bailey 1952; Grossman, McDaniel, and Ratajczak 2002; Meyer, Cassinelli, and Elle 2008). We think that the long life span of our sculpin might be due to flow regulation resulting in suboptimal water temperature and oligotrophic conditions. Specifically, water temperature for the most part remained colder than the optimal water temperature range for mottled sculpin's somatic growth (12°C–16°C: Kanno, Kim, and Pregler 2023; Figure 1) due to the altered flow regime including the release of hypolimnetic water from Green Mountain Reservoir located upstream of our study area. In addition, the reservoir has contributed to an oligotrophic condition downstream (Bauch, Miller, and Yacob 2014), which can affect the production of benthic macroinvertebrates, the primary food resource for sculpin in Blue River (Platis et al. 2024). Further research is warranted to evaluate whether the reservoir has affected the production of prey resources and consequently fish growth and age in Blue River. Intriguingly, faster growth rates of slimy sculpin were reported in hydropeaking rivers relative to their free-flowing reference rivers, where water temperatures were higher (13°C–27°C in summer) in both types of rivers than in our study (Bond, Jones, and Haxton 2016; Kelly, Smokorowski, and Power 2016). Our results along with these previous studies suggest that fish growth responses to flow regulation are not uniform and depend on physical and operational characteristics of dams.

Length-at-age relationships did not markedly differ between dry (2022) and wet (2023) years, and age-specific body size was similar from May through October in each year. Despite contrasting flow patterns, temperatures were similar between the two study years in terms of magnitude and seasonal variation, and mottled sculpin experienced suboptimal temperatures for growth in both years (Figure 1). This suggests that temperature may supersede influences of stream hydrography on growth. However, additional investigations are needed to test this hypothesis especially because our sample size was limited to 1 dry and 1 wet year. In general, length-at-age data are limited for small-bodied non-game species (Burbank, Drake, and Power

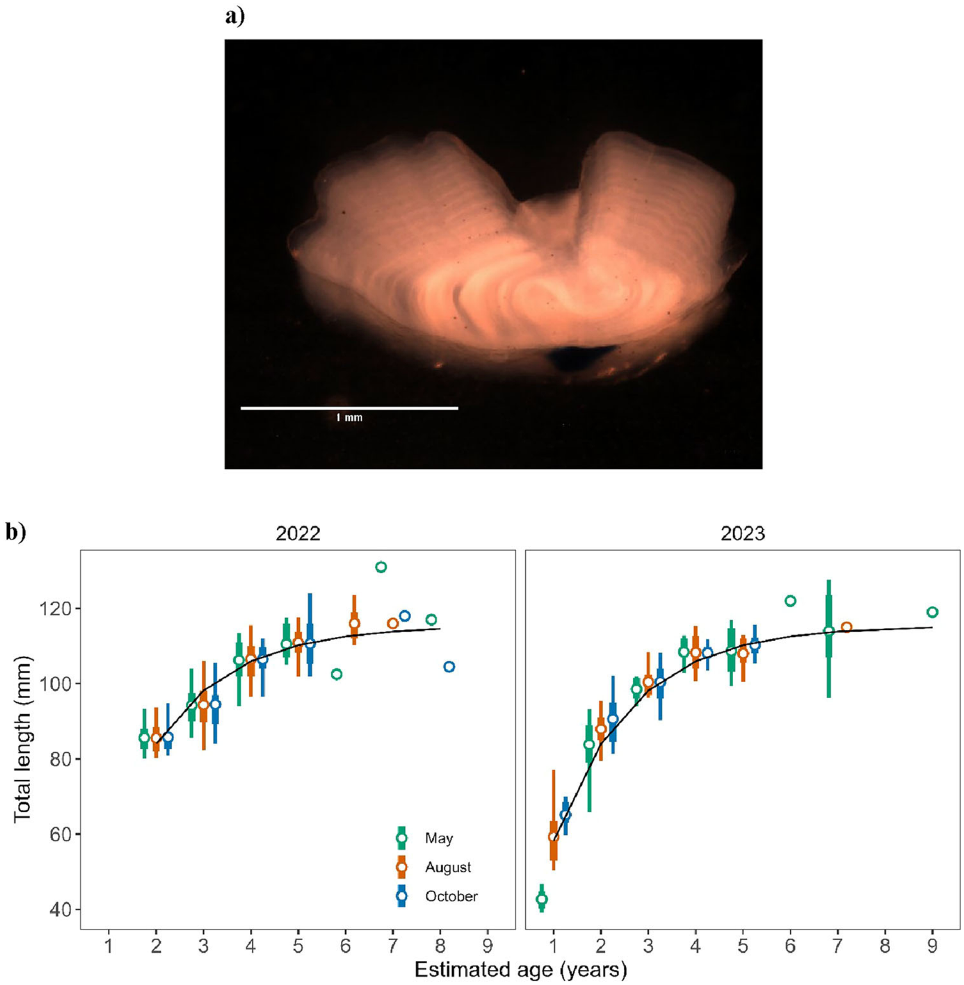

FIGURE 2 | An otolith of an individual estimated to be 9 years old (scale bar = 1 mm) (a), and length-at-age relationships of mottled sculpin in the Lower Blue River by sampling month and year with von Bertalanffy growth curves shown in black solid lines (b). In 2022 (a dry year), we collected mottled sculpin over 80 mm in total length. In 2023 (a wet year), we collected mottled sculpin of all sizes encountered. Mean age-specific total length values are shown by dots with 25th–75th percentiles (thick lines) and 2.5th–97.5th percentiles (thin lines).

2021; Saddlier, Koehn, and Hammer 2013), and our study shows that they provide information on their natural life history and anthropogenic impacts on lotic organisms. In our case, further research should incorporate spatially and temporally replicated samples to evaluate whether the long life span of mottled sculpin is attributable to flow regulation or reflects natural life history patterns common to high-elevation streams.

Author Contributions

Alexandra L. Brown: data curation, investigation, methodology, visualization, writing–original draft. **Travis R. Hackett**: data curation, formal analysis, investigation, methodology, validation, visualization, writing–review and editing. **Baylor K. Lynch**: data curation, formal analysis, investigation, methodology, validation, visualization, writing–review and editing. **Brien P. Rose**: funding acquisition, investigation, resources, writing–review and editing. **Brett M. Johnson**: conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, writing–review and editing. **Yoichiro Kanno**: conceptualization, formal analysis, funding acquisition, investigation, project administration, supervision, writing–original draft.

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Conflicts of Interest

BPR's employer provided funding for this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Peer Review

The peer review history for this article is available at https://publons.com/publon/10.1002/aff2.70030

Ethics Statement

This research was conducted under the Colorado State University IACUC Animal Use Protocol #1677, and the Colorado Parks and Wildlife Scientific Collector Permit #22AQ4740 and #23AQ4740.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.