Brook Trout predation on dispersing Cascades frogs shows invasive fish populations can impact amphibian recruitment from the broader landscape

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RESEARCH NOTE

Justin Garwood*, Grace Cunningham, Forest Peri, and Raziel Lederman-Beach

California Department of Fish and Wildlife, Northern Region, 5341 Ericson Way, Arcata, CA 95521, USA

https://orcid.org/0009- 0009-7402-3145 (JG)

**Corresponding Author: justin.garwood@wildlife.ca.gov*

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To expand recreational fisheries across the western United States, thousands of formerly fishless mountain lakes were stocked with nonnative salmonids by the 1960s, including over 2,000 mountain lakes in California (Bahls 1992; Pister 2001). Through predation and competition, nonnative salmonids have reshaped ecological communities in these lake ecosystems and are correlated with widespread declines in amphibian abundance and distribution (Bradford 1989; Knapp et al. 2001; Pilliod and Peterson 2001; Kats and Ferrer 2003; Welsh et al. 2006). Despite these apparent amphibian population declines,

documentation of direct amphibian predation by invasive salmonid predators in natural habitats is lacking for most species, including the Cascades frog (*Rana cascadae*).

Most direct salmonid predation records on frogs in the western U.S. come from Sierra Nevada yellow-legged frogs (*Rana sierrae*) (RASI) in the Sierra Nevada, California. Needham and Vestal (1938) describe a 249 mm long nonnative golden trout (*Oncorhynchus aguabonita*) from a mountain lake with an adult RASI in its stomach. Additionally, they described another adult golden trout swimming with an adult RASI oriented sideways in its mouth. Nonnative rainbow trout (*O. mykiss*) were also observed consuming adult and juvenile RASI in Sierra Nevada lakes, including one adult RASI dissected from the stomach of an adult rainbow trout (Roland Knapp, pers. comm). Vredenburg (2004) also documented rainbow trout consuming RASItadpoles inside constructed net field enclosures at three Sierra Nevada mountain lakes. Duff (1976) found multiple Anuran (ssp.) tadpoles in a stomach in a Trinity Alps mountain lake that had an abundance of tadpoles along the lake shore. Bradford (1989) described *Oncorhynchus* (spp.) and Brook Trout (*Salvelinus fontinalis*) also striking at RASI tadpoles after they were placed in a lake with these nonnative salmonids. Similarly, Grasso et al. (2010) found Brook Trout consumed over 80% of available Pacific chorus frog (*Pseudacris regilla*) tadpoles during controlled feeding trials. Pilliod (2001) found a nonnative cutthroat trout (*O. clarkii ssp.*) consumed a Columbia spotted frog (*Rana luteiventris*) metamorph in an Idaho mountain lake after inspecting the trout's stomach contents. Lastly, in 2022, we dissected a juvenile Cascades frog from the stomach of an adult Brook Trout that was captured in a monofilament gill net at a Trinity Alps mountain lake (**Fig. 1**).

Figure 1. Photo of a dissected adult Brook Trout measuring 305 mm with its stomach containing a partially digested Cascades frog on 27 July 2022 at Salmon Lake, Trinity Alps, Siskiyou County, CA, USA. Examples of the frog's femur, tibio-fibula, astragalus, and calcaneum bones are visible and resting on the knife blade (blade height 16 mm). Note frog eyes and upper jaw musculature facing camera. (Photographed by Forest Peri)

To reduce historical impacts of invasive salmonids on aquatic breeding amphibians in the Klamath Mountains (Welsh et al. 2006; Pope 2008), we initiated a restoration program in 2023 to remove Brook Trout from multiple mountain lakes and ponds. We chose restoration waters having high regional conservation value for native aquatic breeding amphibians, while also having marginal angler use. Restoration site 26187 (California Lakes Water ID) is a pond with a depth of 1.95 m and a surface area of 0.43 ha located at 2,158 m elevation in the northern Trinity Alps (41.2143°, –122.7923°), Siskiyou County, CA (**Fig. 2A**). Between 2023 and 2024, we used monofilament gill nets to remove 668 Brook Trout from site 26187, highlighting a high-density fish population relative to the small size of the pond. On 20 September 2024, we removed 119 Brook Trout from seven gill nets that we deployed the previous evening (example catch in **Fig. 2B**). While processing the fish, we opportunistically found two recently metamorphosed young-of-the-year Cascades frogs that were deceased in the stomach of an adult Brook Trout measuring 250 mm total length (**Fig. 2C**).

Figure 2. (A) Middle Boulder Lake Basin, Trinity Alps, Siskiyou County, CA. Site 26186 has remained fishless; site 26187 has hosted a self-sustaining Brook Trout population for at least the past 55 years. (B) Example Brook Trout catch using gill nets at site 26187 in 2024. A Brook Trout removal project to restore amphibian breeding habitats was initiated at site 26187 in 2023 and is ongoing.

(C) Two deceased recently metamorphosed Cascades frogs opportunistically dissected from the stomach of a single Brook Trout captured at site 26187 on 20 September 2024.

Based on four multi-day restoration trips, and three formal amphibian surveys across the summer of 2024, we did not detect any Cascades frog eggs or tadpoles at site 26187 (**Table 1**). The nearest fishless Cascades frog breeding pond (site 26186) is located 43 meters west of site 26187 (**Fig. 2A**, **Table 1**). The two ponds are at similar elevations in the same drainage but are not connected by streams. With multiple surveys dating back to 2001, pond 26186 has been a reliable breeding location for Cascades frogs while pond 26187 was only used for breeding in one out of the seven survey years (**Table 1**).

Table 1. Presence (Y) or absence (N) of Cascades frogs, Cascades frog breeding evidence, and Brook Trout during visual encounter surveys results at adjacent ponds in the northern Trinity Alps during seven survey years between 2001 and 2024.

Site	Year	Cascades Frog[a]	Cascades Frog Breeding[b]	Brook Trout
26186	2001	Y	Y	N
26186	2006	Y	Y	N
26186	2012	Y	Y	N
26186	2021	Y	Y	N
26186	2022	Y	Y	N
26186	2023	Y	Y	N
26186	2024	Y	Y	N
26187	2001	N	N	Y
26187	2006	Y	N	Y
26187	2012	Y	Y	Y
26187	2021	Y	N	Y
26187	2022	N	N	Y
26187	2023	Y	N	Y
26187	2024	Y	N	Y

[a]Juvenile (yearling or greater) or adult Cascades frogs detected at site
[b]Cascades frog eggs or tadpoles detected at site indicating reproduction

In systems invaded by salmonids, fishless sites are often smaller with less amphibian carrying capacity than larger lakes chosen for fish stocking (Denoël et al. 2016). Studies have also found that amphibian distributions and abundances are lower at fishless sites in invaded basins relative to fishless basins indicating amphibian population impacts caused by salmonid predators reach beyond the invaded waters

(Pilliod and Peterson 2001; Pilliod et al. 2010). Juvenile Cascades frogs are highly aquatic but have high rates of dispersal between separate lake, pond, and meadow habitats in mountain lake basins (Garwood 2009). Our isolated observation of Brook Trout predation on Cascades frogs that had recently emigrated from a separate breeding site shows that invasive salmonids likely influence broader Cascades frog population recruitment and related gene flow through habitat exclusion and additive mortality.

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