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Estimating thermal exposure of adult summer steelhead and fall Chinook salmon migrating in a warm impounded river

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Abstract – Rising river temperatures in western North America have increased the vulnerability of many Pacific salmon (*Oncorhynchus* spp.) populations to lethal and sublethal risks. There is a growing need to predict and manage such risks, especially for populations whose life history or geography increases the likelihood of warm-water exposure. We estimated thermal exposure of adult summer steelhead (*O. mykiss*) and fall-run Chinook salmon (*O. tshawytscha*) as they migrated through a warm (often > 20 °C), 157-km reach of the impounded Snake River, Washington. Archival temperature loggers and radiotelemetry were used to reconstruct thermal histories for 50 steelhead and 21 salmon. Encountered temperature maxima were mostly inside dam fishways and ranged from 15.8 to 24.0 °C (mean = 19.6 °C) for steelhead and from 18.0 to 21.6 °C (19.9 °C) for salmon. Behavioural thermoregulation was evident for ~50% of steelhead and ~30% of salmon in one of three reservoirs. Degree days (DDs) calculated from archival tags ranged from 74 to 973 DDs (median = 130) for steelhead and from 56 to 220 DDs (133) for salmon. Models using river temperature data and fish migration times accurately estimated total DDs for both species except some steelhead with extended thermoregulation. In a predictive application, we estimated exposure for 10,104 steelhead and 9071 Chinook salmon with passive integrated transponder-tag detections at dams and found considerable DD variability across individuals, species and years. This estimation method, combined with baseline thermal surveys and existing monitoring infrastructure, can help to address long-standing questions about how warm-water exposure affects Snake River salmon and steelhead phenology, bioenergetics, physiology, survival and reproductive success.

Key words: behavioural thermoregulation; biologger; degree day; fishway; reservoir

Introduction

The Snake River in eastern Washington is used annually by more than a hundred thousand anadromous Pacific salmonids (*Oncorhynchus* spp.) as they migrate to spawning habitat in Washington, Oregon and Idaho. The lower ~250 km of the river, from near its confluence with the Columbia River to Idaho's Clearwater River, flows through the arid steppes and grasslands of the Columbia Plateau. The reach was historically warmer than the adjacent Columbia River and the thermal regime of both the Columbia and Snake rivers helped to shape the adult migration phenology of Chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead (*O. mykiss*) (Brannon et al. 2004; Crozier et al. 2008). In summer and early fall, lower Snake River water temperatures routinely exceed 21–23 °C, a range associated with migration cessation (McCullough et al. 2001; Richter & Kolmes 2005) and behavioural thermoregulation (Keefer et al. 2009; Strange 2012) in regional *Oncorhynchus* populations. Selective pressure to avoid exposure to these potentially stressful temperatures likely explains why most Snake River adult salmon and steelhead migrate through the lower river either before or after annual peak temperatures.

Four large hydroelectric dams currently impound the lower Snake River. These dams – plus additional

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