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Temperature and depth profiles of Chinook salmon and the energetic costs of their long-distance homing migrations

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ABSTRACT

River warming poses an existential threat to many Pacific salmon (*Oncorhynchus* spp) populations. However, temperature-mediated risks to salmon are often complex and addressing them requires species- and population-specific data collected over large spatial and temporal scales. In this study, we combined radiotelemetry with archival depth and temperature sensors to collect continuous thermal exposure histories of 21 adult spring- and summer-run Chinook salmon (*O. tshawytscha*) as they migrated hundreds of kilometers upstream in the Columbia River basin. Salmon thermal histories in impounded reaches of the Columbia and Snake rivers were characterized by low daily temperature variation but frequent and extensive vertical movements. Dives were associated with slightly cooler salmon body temperatures (~ 0.01 to 0.02 °C/m), but there was no evidence for use of cool-water thermal refuges deep in reservoirs or at tributary confluences along the migration route. In tributaries, salmon were constrained to relatively shallow water, and they experienced ~ 2–5 °C diel temperature fluctuations. Differences in migration timing and among route-specific thermal regimes resulted in substantial among-individual variation in migration temperature exposure. Bioenergetics models using the collected thermal histories and swim speeds ranging from 1.0 to 1.5 body-lengths/s predicted median energetic costs of ~ 24–40% (spring-run) and ~ 37–60% (summer-run) of initial reserves. Median declines in total mass were ~ 16–24% for spring-run salmon and ~ 19–29% for summer-run salmon. A simulated + 2 °C increase in water temperatures resulted in 4.0% (spring-run) and 6.3% (summer-run) more energy used per fish, on average. The biotelemetry data provided remarkable spatial and temporal resolution on thermal exposure. Nonetheless, substantial information gaps remain for the development of robust bioenergetics and climate effects models for adult Chinook salmon.

1. Introduction

Most anadromous salmonids have both energetically-demanding adult migrations (Brett, 1995; Rand et al., 2006) and narrow thermal preferences (Pörtner and Farrell, 2008; Eliason et al., 2011). This life history combination makes many populations vulnerable to climate warming (Crozier et al., 2008; Jonsson and Jonsson, 2009; Mantua et al., 2010), especially those that currently encounter warm water in migration corridors (Keefer et al., 2008; Hinch et al., 2012; Strange, 2012) or on spawning grounds (Gilhousen, 1990; Bowerman et al., 2018). Evidence linking warm-water exposure to reduced adult survival and lower lifetime fitness has been rapidly accumulating (Pankhurst and King, 2010; Eliason et al., 2013; Jeffries et al., 2014). However, quantifying thermal experiences of individuals over long and complex migrations and then directly linking those experiences to survival and fitness outcomes remains technically challenging (Cooke et al., 2008; Keefer and Caudill, 2016).

Studies that pair telemetry with animal-borne bio-loggers have produced useful insights into the behavioral ecology of a broad suite of species in diverse natural habitats (Cooke et al., 2004; Hammerschlag et al., 2011; Wilmers et al., 2015). Anadromous salmonid applications have included studies of vertical movements and thermal habitat selection in oceans and estuaries (Walker et al., 2000; Hayes et al., 2011; Teo et al., 2013), behavioral thermoregulation in rivers and lakes (Donaldson et al., 2009; Keefer et al., 2009; Roscoe et al., 2010; Hasler et al., 2012), depth selection and burst swimming behaviors near dams (Johnson et al., 2010; Burnett et al., 2014), and acute and cumulative temperature exposure during freshwater homing migration (Strange, 2010; Caudill et al., 2013; Keefer et al., 2015). Biotelemetry studies often generate large, richly detailed datasets. However, the scientific

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