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MANAGEMENT BRIEF

Condition-Dependent En Route Migration Mortality of Adult Chinook Salmon in the Willamette River Main Stem

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Abstract
Episodically high adult mortality during migration and near spawning sites has hindered the recovery of threatened spring-run Chinook Salmon *Oncorhynchus tshawytscha* in Oregon's Willamette River basin. In 2011–2014, we assessed migration mortality for 762 radio-tagged adults along a ~260-km reach of the main stem of the Willamette River. Annual survival of salmon to spawning tributaries ranged from 0.791 (95% CI = 0.741–0.833) to 0.896 (0.856–0.926), confirming concerns about mortality in the migration corridor. In a series of general linear models, descaling, marine mammal injuries, and head injuries to adult Chinook Salmon were linked to reduced survival during migration to tributaries. Many injuries were minor (i.e., epidermal abrasions), which we hypothesize were unlikely to have caused direct mortality but may have increased salmon vulnerability to pathogens or other disease processes. Mortality in the main stem was not significantly associated with salmon body size, energetic status, sex, origin (hatchery, wild), river discharge, or water temperature metrics. The ~10–21% estimates of en route mortality in this study provide an important benchmark for the main stem of the Willamette River. The estimates complement ongoing efforts to quantify mortality of adult Chinook Salmon in Willamette River tributaries and after collection and transport to spawning sites above high-head hydroelectric dams.

Adult mortality prior to reproduction by semelparous salmonids (*Oncorhynchus* and *Salmo* spp.) can constrain population growth and size, and in some cases threatens population viability (McClure et al. 2003; Spromberg and Scholz 2011). Accurately estimating mortality rates of adult salmon and understanding causal mechanisms and effects on populations have therefore been the focus of salmon research, management, and conservation programs range-wide (e.g., Kareiva et al. 2000; Cooke et al. 2008; Lundqvist et al. 2008). In-river fisheries typically account for the largest proportion of adult salmon mortality in freshwater, but a variety of other sources can be important. Episodic or chronic adult mortality has been associated with physical and environmental migration barriers (e.g., Caudill et al. 2007; Hinch et al. 2012; Sigourney et al. 2015), physiological limitations (e.g., Cooke et al. 2012; Eliason and Farrell 2016), predation (Quinn et al. 2003; Keefer et al. 2012), and a variety of pathogens and parasites (e.g., Bakke and Harris 1998; Wagner et al. 2005; Benda et al. 2015).

Adult salmon mortality in freshwater is often partitioned into two components: en route mortality along migration corridors (Cooke et al. 2004; Keefer et al. 2008) and prespawn mortality on or near spawning grounds (Scholz et al. 2011; Bowerman et al. 2016). Both mortality types have been the focus of research and management actions for spring-run Chinook Salmon *O. tshawytscha* in the Willamette River, Oregon, a threatened population listed under the U.S. Endangered Species Act (NMFS 1999). Steep declines in Chinook Salmon abundance followed the construction of high-head dams that blocked access to a large proportion of Willamette River spawning tributaries, extensive urbanization and agricultural development in the watershed, and concomitant degradation of the migration corridor (NMFS 2008). En route and prespawn mortality of Willamette River Chinook Salmon have been associated with warm river temperatures (Schreck et al. 1994; Keefer et al. 2010; Roumasset 2012), a variety of pathogens (e.g., *Renibacterium salmoninarum* and *Aeromonas salmonicida*: Kent et al. 2013; Benda et al. 2015), predation by an expanding aggregation of California sea lions *Zalophus californianus*, Steller sea lions *Eumetopias jubatus*,

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