Assessing the Relative Importance of Local and Regional Processes on the Survival of Snake River Spring/Summer Chinook Salmon

Jessica A. Miller[1], David Teel[2], William T. Peterson[3] and **A. Baptista[4]**

[1]*Oregon State University, Department of Fisheries & Wildlife, Coastal Oregon Marine Experiment Station, Newport, OR 97365, USA*
[2]*NOAA Fisheries, Northwest Fisheries Science Center, Manchester Research Laboratory, P.O. Box 130, Manchester, WA 98353, USA*
[3]*NOAA Fisheries, Northwest Fisheries Science Center, Newport Field Station, 2033 Marine Science Drive, Newport, OR 97365, USA*
[4]*NSF Science and Technology Center for Coastal Margin Observation and Prediction, Oregon Health and Science University, 20000 New Walker Road, Beaverton, OR 97006, USA*

Snake River spring/summer Chinook salmon was listed as "threatened" under the US Endangered Species Act in 1992. The current management unit, identified as an Evolutionarily Significant Unit, includes all naturally spawned spring/summer Chinook salmon in the mainstem Snake River and the Tucannon, Grande Ronde, Imnaha, and Snake River sub-basins as well as numerous artificial propagation units. An estimated population of >1,000,000 fish in the late 1800s declined to <5,000 in the 1990s, and the current recovery goal is for smolt-to-adult return rates (SARs) in the 2-6% range with an average of 4%. However, from 1998 to 2010, Snake River spring/summer Chinook salmon SARs were well below the targeted recovery goal (<0.5 to 3.2%).

The vast majority of juvenile spring/summer Snake River Chinook salmon migrate to the ocean in spring and early summer as yearlings. Prior research indicates that in-river juvenile survival is positively related to body size (Zabel and Achord 2004; Achord et al. 2011) and that earlier emigrants tend to survive at higher rates than later emigrants (Scheuerell et al. 2009). However, a lack of clarity on the relative importance of freshwater, estuarine, and marine factors in the survival of Snake River spring/summer Chinook salmon continues to impede recovery efforts. We combined eight years of ocean collections off of Washington and Oregon with genetic stock identification and otolith structural and chemical analyses to examine key biological attributes of Snake River spring/summer Chinook salmon, including juvenile size and timing of marine entry and early marine growth rate. First, we characterized individual and interannual variation in these biological attributes and compared them with estimates of SARs to evaluate the growth-mortality hypothesis, i.e., that survival is positively related to body size. Second, to identify likely mechanisms of mortality, we determined which local and regional indicators of river, estuary, and ocean conditions accounted for the most variation in the relevant juvenile attributes, i.e., those related to survival. Finally, we used multi-model inference to evaluate the relative importance of river, estuary, and ocean indices in relation to variation in SARs from 1999 to 2008.

We examined data from surveys that occurred during late May and late June from 1999 to 2008 (Fig. 1). A Nordic 264 rope trawl was towed in surface waters (Daly et al. 2009), and trawl catches were standardized to density (fish km^{-1}) based on trawl width and distance towed. On board, fish were identified, measured (fork length (FL), mm), and frozen. In the laboratory, fish were re-measured and weighed (±0.1 g). We combined genetic stock identification with otolith structure and chemistry to reconstruct juvenile size at and timing of marine entry and marine growth rates (% d^{-1}, mm) for the spring/summer Snake River stock group. Juvenile Chinook salmon were genotyped at 13 microsatellite DNA loci (Teel et al. 2009) and assigned to stock group using a standardized genetic database (Seeb et al. 2007; Barnett-Johnson et al. 2010). Stock assignments were made with the program ONCOR (Kalinowski et al. 2007) and the likelihood model of Rannala and Mountain (1997). We then determined size at and timing of marine entry based on variation in otolith Sr:Ca. Sagittal otoliths were polished using wet-or-dry paper (240-2500 grit) and lapping film (1- 30 µm) to expose the dorsal-ventral growth axis using standard procedures for elemental analysis (Miller 2009). Otolith Sr and Ca were measured along the dorsal-ventral growth axis using laser ablation-inductively coupled plasma mass spectrometry. Image analysis was combined with Sr:Ca data to determine otolith width at freshwater emigration and to estimate the date of freshwater emigration. For each individual, the otolith width at the time of freshwater emigration was determined by the initial and abrupt increase in otolith Sr:Ca, which indicates exit from freshwaters, prior to stabilizing at marine values (Miller et al. 2010, 2011).
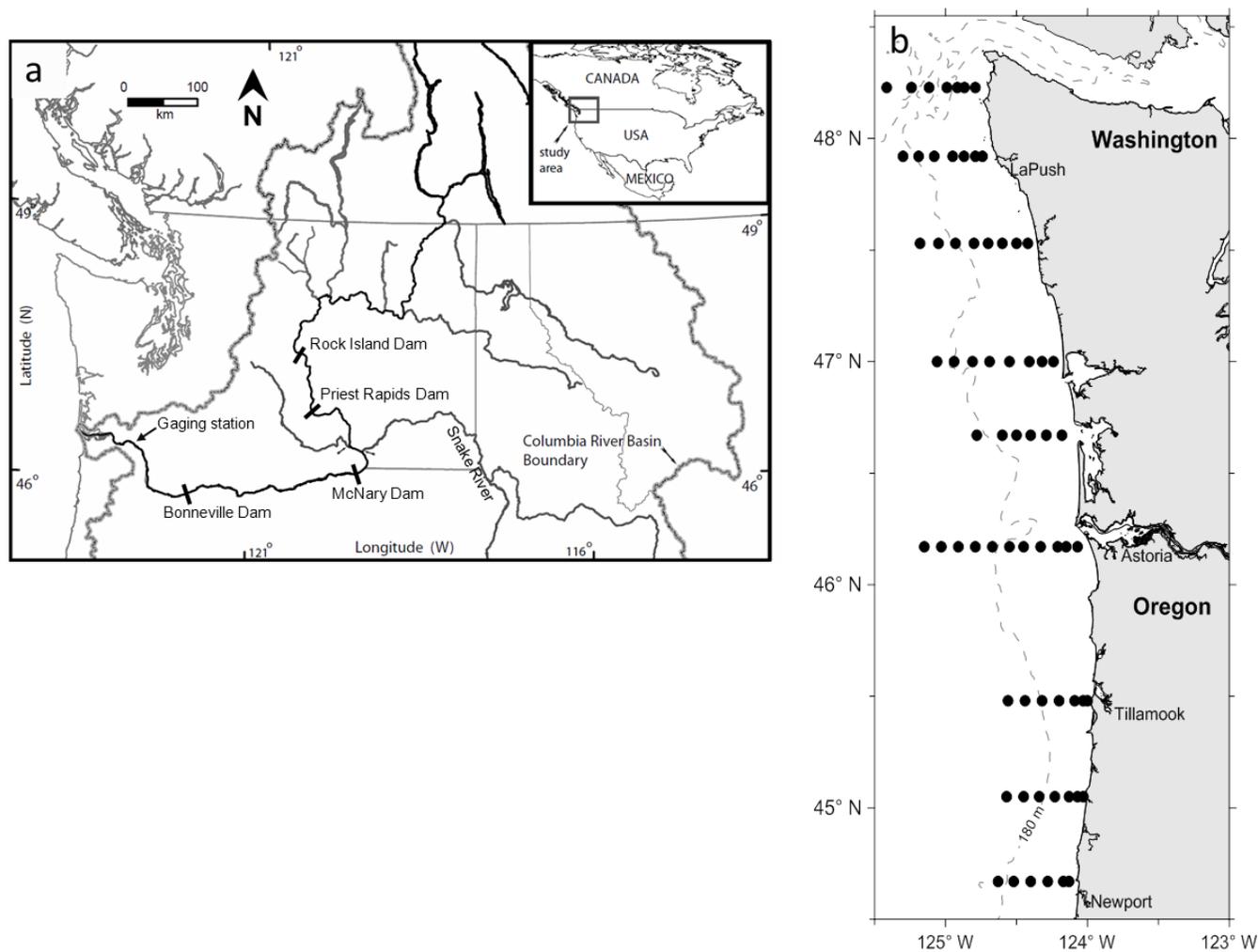
Fig. 1. (a) Columbia River watershed with locations of the mainstem dams and gaging station referred to in text. (b) Transect and station locations for ocean collections used in this study.

We used various indicators of river, estuary, and ocean climate during juvenile emigration for comparison with juvenile attributes and overall survival, including river discharge, metrics of the Columbia River plume environment, and two basin-scale ocean indices—the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). Data on daily discharge in the lower river were obtained from the United States Geological Survey (Site 14246900 at 46°N, 123°W). For plume metrics, we used the output of simulation databases to characterize the variability in plume size (area of the plume surface and volume of the 3D plume) and location (expressed in terms of coordinates of the centroid of the surface plume; Zhang et al. 2004; Zhang and Baptist 2008). We defined the plume using a cutoff salinity of 28 psu. The simulation databases are a component of a modeling system, known as the "Virtual Columbia River" (www.stccmop.org/datamart/virtualcolumbiariver), which is anchored by 3D unstructured-grid numerical models of water circulation. Burlap et al. (2010) demonstrated that the majority of variation in the coastal surface salinity field is accounted for by variation in river discharge (43%) and prevailing winds (21%).

To provide an indication of interannual variation in coastal productivity, we used the Copepod Community Index (CCI). The CCI is a numerical representation of all copepod species that are present in more than 5% of the samples collected biweekly 9 km offshore of Newport, Oregon, using a 50-cm diameter, 202-μm mesh ring net towed vertically from 5 m above the sea floor to the surface. The values are rotated Axis 1 scores of a non-metric multidimensional scaling ordination of species abundance by sample date from 1996 to 2010 (Morgan et al. 2003; Hoof and Peterson 2006). During spring and summer, negative CCI values indicate the presence of a "northern community" comprised of cold-water neritic taxa that are large and lipid-rich, whereas positive values indicate the presence of an "offshore or southern community" comprised of

smaller, relatively lipid-poor species (Keister et al. 2011). The CCI may be indicative of the nutritional quality of the food web supporting juvenile salmon and their prey. Therefore, we determined if juvenile Chinook salmon marine growth rates and size at capture were related to the CCI. Finally, we used a multi-model inference approach to assess the ability of the physical and biological variables to account for variation in juvenile attributes during early marine residence and interannual variation in SARs. Survival rates were obtained from the Fish Passage Center (http://www.fpc.org/). For analyses that included juvenile Chinook salmon, we included eight years (1999-2000, 2002-2004, and 2006-2008). The years 2001 and 2005 were removed from analysis due to low number of yearlings collected (n < 10). For comparisons between SARs and physical (river discharge, plume size and position, PDO, and NPGO) and biological (CCI) metrics, we included data from 1999 to 2008 (n = 10 years).

Overall, mean annual timing of juvenile emigration ranged from 6 May to 18 May and all juveniles emigrated between 20 April and 19 June with a shift toward later emigration in 2006-2008. Individual residence in coastal waters prior to capture ranged from 1 to 81 days. Mean annual marine growth rate mean ranged from 0.47% day^{-1} in 2002 to 0.83% day^{-1} in 2000. We determined that estimated size at marine entry displayed negative, non-significant trends with survival. However, marine growth and length and mass at capture, which occurred an average of 20 days after marine entry, were strongly, positively related to survival (r > 0.73). Yearlings grew faster and attained larger sizes during early marine residence in years in which the plume was larger, the NPGO index was more positive, the PDO index more negative, and the copepod community was dominated by northern, boreal species. In terms of accounting for interannual variation in juvenile size after early marine residence, the model that incorporated a local index (plume area) was 1.4 to 2.5 times more likely than the models with basin-scale indices (NPGO and PDO), given the data and family of models. For emigration years 1999 to 2008, interannual variation in SARs was well-described by physical and biological conditions during emigration, including yearling marine density, NPGO, PDO, and the CCI. The most parsimonious hindcast model included NPGO and yearling marine density (R^2 = 0.85, n = 10). A comparison of the relative importance of model parameters indicated the yearling marine density in June, which represents cohort abundance after an average of 20 days in the ocean, was generally the most important variable in accounting for variation in SARs. The relatively high survival of the cohort that emigrated in 2001, a year with extremely low river discharge and a relatively small plume, may have been due to very good survival conditions in the ocean as indicated by the NPGO and PDO. These data indicate that ocean conditions favorable for survival may modulate poor river conditions.

REFERENCES

Achord, S., B.P. Sandford, E.H. Hockersmith, M.G. Nesbit, N.D. Dumdei, J.J. Lamb, K.W. McIntyre, N.D. Paasch, S.G. Smith, and R.W. Zabel. 2011. Monitoring the migrations of wild Snake River spring/summer Chinook salmon juveniles, 2009-2010. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland. p. 123.

Barnett-Johnson, R., D.J. Teel, and E. Casillas. 2010. Genetic and otolith isotopic markers identify salmon populations in the Columbia River at broad and fine geographic scales. Environ. Biol. Fish. 89: 533-546.

Burla, M., A.M. Baptista, Y.L. Zhang, and S. Frolov. 2010. Seasonal and interannual variability of the Columbia River plume: A perspective enabled by multiyear simulation databases. J. Geophys. Res. Oceans 115: C2. doi:10.1029/2008JC004964

Daly, E.A., R.D. Brodeur, and L.A. Weitkamp. 2009. Ontogenetic shifts in diets of juvenile and subadult coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) in coastal marine waters: important for marine survival? Tran. Am. Fish. Soc. 138: 1420-1438.

Hooff, R.C., and W.T. Peterson. 2006. Copepod biodiversity as an indicator of changes in ocean and climate conditions of the northern California current ecosystem. Limnol. Oceanogr. 51(6): 2607-2620.

Kalinowski, S.T., K.R. Manlove, and M.L. Taper. 2007. ONCOR A computer program for genetic stock identification. Department of Ecology, Montana State University, Bozeman. (Available at www.montana.edu/kalinowski/Software/ONCOR.htm.)

Keister, J.E., E.D. Lorenzo, C.A. Morgan, V. Combes, and W.T. Peterson. 2011. Zooplankton species composition is linked to ocean transport in the Northern California Current. Global Change Biol. 17: 2498-2511.

Miller, J.A. 2009. The effects of temperature and water concentration on the otolith incorporation of barium and manganese in black rockfish *Sebastes melanops*. J. Fish Biol. 75: 39-60.

Miller, J.A., A. Gray, and J. Merz. 2010. Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon *Oncorhynchus tshawytscha*. Mar. Ecol. Prog. Ser. 408: 227-240.

Miller, J.A., B.L. Butler, C.A. Simenstad, D.H. Backus, and A.J.R. Kent. 2011. Life history variation in upper Columbia River Chinook salmon (*Oncorhynchus tshawytscha*): a comparison using modern and ~500-year-old archaeological otoliths. Can. J. Fish. Aquat. Sci. 68: 603-617.

Morgan, C.A., W.T. Peterson, and R.L. Emmett. 2003. Onshore-offshore variations in copepod community structure off the Oregon coast during the summer upwelling season. Mar. Ecol. Prog. Ser. 249: 223-236.

Rannala, B., and J.L. Mountain. 1997. Detecting immigration by using multilocus genotypes. Proc. Nat. Acad. Sci. USA 94: 9197-9201.

Scheuerell, M.D., R.W. Zabel, and B.P. Sandford. 2009. Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (*Oncorhynchus* spp.). J. Appl. Ecol. 46: 983-990.

Seeb, L.W., A. Antonovich, M.A. Banks, T.D. Beacham, M.R. Bellinger, S.M. Blankenship, M.R. Campbell, N.A. Decovich, J.C. Garza, C.M. Guthrie, T.A. Lundrigan, P. Moran, S.R Narum, J.J. Stephenson, K.J. Supernault, D.J. Teel, W.D. Templin, J.K. Wenburg, S.E. Young, and C.T. Smith. 2007. Development of a standardized DNA database for Chinook salmon. Fisheries 32: 540-552.

Teel, D.J., C. Baker, D.R. Kuligowski, T.A. Friesen, and B. Shields. 2009. Genetic stock composition of subyearling Chinook salmon in seasonal floodplain wetlands of the Lower Willamette River, Oregon. Trans. Am. Fish. Soc. 138: 211-217.

Zabel, R.W., and A. Achord. 2004. Relating size of juveniles to survival within and among populations of Chinook salmon. Ecology 85: 795-806.

Zhang, Y.L., and A.M. Baptista. 2008. SELFE: A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation. Ocean Model. 21(3-4): 71-96.

Zhang, Y.-L., A.M. Baptista, and E.P. Myers. 2004. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: I. Formulation and skill assessment. Cont. Shelf Res. 24: 2187-2214.