Upper Willamette River steelhead

Overall vulnerability—High (47% Moderate, 51% High, 2% Very high)
Biological sensitivity—High (51% High, 49% Moderate)
Climate exposure—High (95% High, 5% Very high)
Adaptive capacity—Moderate (1.8)
Data quality—84% of scores ≥ 2

	Upper Willamette River Steelhead	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Early life history	1.5	2.8	
	Juvenile freshwater stage	2.4	2.8	
	Estuary stage	1.6	2.3	
	Marine stage	2	2	
	Adult freshwater stage	1.6	2.8	
	Cumulative life-cycle effects	2.5	2	
	Hatchery influence	3	2.5	
	Other stressors	3.2	2.5	
	Population viability	2.4	2.8	
	Ocean acidification sensitivity	1.9	1.8	
	Sensitivity Score	High		
Exposure variables	Stream temperature	3.7	2.5	
	Summer water deficit	2.9	2	
	Flooding	2.5	2	
	Hydrologic regime	2.1	2.8	
	Sea level rise	1.4	2	
	Sea surface temperature	3.2	2.3	
	Ocean acidification exposure	3.9	3	
	Upwelling	1.8	1.8	
	Ocean currents	1.8	1	
	Exposure Score	High		
	Overall Vulnerability Rank	High		

Low
Moderate
High
Very High

Life History Synopsis

Upper Willamette River steelhead is an ocean-maturing phenotype with adults entering fresh water from late winter to early spring (March-April). Adults spawn within a few weeks of freshwater entry (April-June), with eggs incubating in stream gravels through mid-summer (Busby et al. 1996). Juveniles generally spend 2-3 years in fresh water prior to migration, and in the Willamette and other systems, some individuals complete the life cycle entirely within fresh water (Kendall et al. 2015). Migrating steelhead juveniles are believed to spend little time in the Columbia River estuary and move directly offshore to feeding areas across the subarctic Pacific Ocean (Light et al. 1989, Daly et al. 2014).

Climate Effects on Abundance and Distribution

For upper Willamette River steelhead, two of the three contributors to ***high*** exposure scores were attributes of the marine environment: *ocean acidification* and *sea surface temperature*. Sensitivity of upper Willamette River steelhead to *ocean acidification*, however, was ranked just below ***moderate***. Similarly, sensitivity of upper Willamette River steelhead to *sea surface temperature* was ranked ***moderate***. Data quality for sensitivity attributes indicated that information is lacking.

The most important freshwater exposure factor was *stream temperature*, which is important because steelhead juveniles generally rear for one or more years in fresh water before migrating (Busby et al. 1996). Of the four recognized populations of winter steelhead in the Upper Willamette River Basin (Myers et al. 2006), all drain the west slope of the Cascade Range, but only the North Santiam River extends in the high Cascades region where snow melt and ground water contribute significantly to stream flows (Chang et al. 2018). Access to much of the higher elevation historical spawning habitat in the North Santiam is blocked by impassable dams (Ford et al. 2015). In studies of steelhead in other basins, warmer summer temperatures are associated with development of anadromy, whereas a resident life history was more prevalent in streams with colder summer water temperatures (McMillan et al. 2012). In contrast, the distribution of native steelhead in the upper Willamette Basin is not cleanly associated with gradients in summer stream temperatures.

In the Willamette River Basin, native late-winter migrating populations occur in watersheds draining the Cascade Mountains on the eastern edge of the basin. Interestingly, native steelhead populations are not believed to occur in the upper extremes of the basin, nor in the tributaries on its western edge that drain the Coastal Range, though it is well-known that steelhead migrate much longer distances to reach spawning grounds in other watersheds (Busby et al. 1996). In other systems, longer steelhead migrations are associated with much earlier (months earlier) timing of adult returns relative to the spring spawn timing of upper Willamette River steelhead. Thus, the late winter entry of Willamette River steelhead, which is believed to be an adaptation to allow historical passage over Willamette falls (Busby et al. 1996), may pose a temporal constraint on the migration distance that native steelhead can attain prior to spawning. Such time constraints may be more important than temperature in terms of the distribution of steelhead in the Willamette Basin.

Extrinsic Factors

One of the most important factors driving sensitivity of upper Willamette River steelhead was *hatchery influence*, which was ranked ***high***. Though hatchery propagation of this lineage is no longer occurring, there are established populations of nonnative winter-run steelhead, active hatchery summer-run steelhead production, and feral natural production of non-native summer- and winter-run steelhead in the basin (Busby et al. 1996, Van Doornik et al. 2015). There is also a potential legacy of stocking non-native hatchery rainbow trout to support recreational harvest in reservoirs and rivers.

In the Willamette Basin, historically introduced, nonnative steelhead with earlier winter run-timing have established to varying degrees in west-side tributaries that drain the Oregon Coast Range (Busby et al. 1996). Recent analyses indicate these nonnative steelhead are genetically distinct from native populations to the east (Van Doornik et al. 2015). Results of this work also indicate that native steelhead and resident rainbow trout in the upper Willamette Basin are distinctive, yet form a definable lineage relative to nonnative winter and nonnative summer-run steelhead. Genetic analyses of native rainbow trout and native winter steelhead in the basin does not indicate a substantial level of introgression (Van Doornik et al. 2015). However, genetic analysis of fish from the nearby Sandy River suggests that non-native hatchery rainbow trout do not readily hybridize with native winter steelhead (Winans et al. 2018).

Ecological effects from this suite of nonnative, hatchery-derived populations of summer and winter steelhead and rainbow trout are a concern, though not well understood, partly because they can be extremely difficult to rigorously quantify (Weber and Fausch 2003). This applies to largely unquantified direct and indirect effects, such as attraction of very large numbers of anglers to harvest nonnative steelhead and trout (and other salmonids, such as hatchery spring Chinook). These popular river and reservoir fisheries may lead to incidental mortality of native juvenile and adult winter steelhead. Such effects can be magnified in locations where access of native fish is constrained by the presence of impassible dams (Sheer and Steel 2006).

In addition to nonnative salmonids, there are growing numbers of nonnative fishes spreading throughout the basin, and the effects of these species may equal or exceed threats from nonnative salmonids (Williams 2014). Most of these species are tolerant of much warmer water temperatures than salmonids, and climate warming could lead to their increased dominance over, or consumption of, upper Willamette River steelhead (Carey et al. 2011, Lawrence et al. 2012).

The Willamette River Basin supports the highest human population densities in the state of Oregon, and there are a variety of growing threats related to urbanization and water quality. These threats include unknown levels of pollution from a host of personal care and pharmaceutical products that are difficult to detect, often unregulated, and biologically active at extremely low concentrations (Yeakley et al. 2014).

Therefore, *other stressors* (which include non-native fish species and human caused habitat degradation) was ranked ***high***, and was the highest-ranking climate sensitivity attribute for upper Willamette River steelhead.

Adaptive Capacity

Winter steelhead in the upper Willamette River have an extended freshwater residency, and the majority of naturally produced smolts migrate during their second spring (Keefer and Caudil 2010). Although it is possible for winter steelhead to complete the life cycle as resident *O. mykiss*, there is little information on the frequency of this life history trajectory, and it is not thought to be common among naturally produced fish. While juvenile winter steelhead will redistribute themselves during freshwater residency, cooler, higher-elevation rearing habitat is

not present in tributary basins (Molalla and Calapooia River), inaccessible due to impassable dams (North Santiam, Brietenbush, and Middle Santiam River), or severely degraded (South Santiam River). There is considerable flexibility in juvenile migration timing (Keefer and Caudil 2010) and adult return timing (Jepson et al. 2015) to adapt to changing temperature extremes. There has been no hatchery-supplementation of winter run steelhead since the late 1990s, and with the exception of hybridization with non-native summer-run and early-winter run steelhead, the genetic integrity of this DPS is thought to be relatively intact (Van Doornik et al. 2015). Adaptive capacity for Upper Willamette steelhead was ranked ***moderate***.

Literature Cited

Information summarized in this narrative is provided in greater depth in a 5-year status review for Upper Willamette Basin steelhead (Ford et al. 2011) and in a literature review by Keefer and Caudil (2010).

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. U.S. Dep Commerce NOAA Tech Memo NMFS-NWFSC-27, Seattle, WA.

Carey, M. P., B. L. Sanderson, T. A. Friesen, K. A. Barnas, and J. D. Olden. 2011. Smallmouth bass in the Pacific Northwest: a threat to native species; a benefit for anglers. Rev Fish Sci **19**:305-315.

Chang, H., E. Watson, and A. Strecker. 2018. Climate change and stream temperature in the Willamtette River basin: implication for fish habitat. Pages 119-132 *in* H.-S. Jung and B. Wang, editors. Bridging Science and Policy Implication for Managing Climate Extremes. World Scientific Publishing, Toh Tuck Link, Singapore.

Daly, E. A., R. D. Scheurer, R. D. Brodeur, L. A. Weitkamp, B. R. Beckman, and J. A. Miller. 2014. Juvenile steelhead distribution, migration, feeding, and growth in the Columbia River estuary, plume, and coastal waters. Mar Coast Fish **6**:62-80.

Ford, M. J., A. Albaugh, K. Barnas, T. Cooney, J. Cowen, J. J. Hard, R. G. Kope, M. M. McClure, P. McElhany, J. M. Myers, N. J. Sands, D. J. Teel, and L. A. Weitkamp. 2011. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest. U.S. Department of Commerce NMFS-NWFSC-113, Seattle, WA.

Ford, M. J., K. Barnas, T. Cooney, L. G. Crozier, M. Diaz, J. J. Hard, E. E. Holmes, D. M. Holzer, R. G. Kope, P. W. Lawson, M. Liermann, J. M. Myers, M. Rowse, D. J. Teel, D. M. V. Doornik, T. C. Wainwright, L. A. Weitkamp, and M. Williams. 2015. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest. U.S. Dep Commerce NOAA Fisheries Northwest Fisheries Science Center, Seattle, WA. Available from www.nwfsc.noaa.gov/publications/scipubs/searchdoc.cfm.

Jepson, M. A., M. L. Keefer, C. C. Caudill, T. S. Clabough, C. S. Erdman, T. J. Blubaugh, and C. S. Sharpe. 2015. Migratory behavior, run timing, and distribution of radio-tagged adult winder steelhead, summer steelhead, spring Chinook salmon, and Coho salmon in the Willamette River: 2011-2014. Oregon Department of Fish and Wildlife, Corvallis Research Lab, Corvallis, Oregon.

Keefer, M. L., and C. C. Caudil. 2010. A review of adult salmon and steelhead life history and behavior in the Willamette River basin: identification of knowledge gaps and research needs. University of Idaho College of Natural Resoures, Moscow, ID. Available from http://www.webpages.uidaho.edu/uiferl/pdf%20reports/2010-08_Keefer-Caudill%20WIL%20lit%20review%20(FINAL).pdf.

Kendall, N. W., J. R. McMillan, M. R. Sloat, T. W. Buehrens, T. P. Quinn, G. R. Pess, K. V. Kuzishchin, M. M. McClure, and R. W. Zabel. 2015. Anadromy and residency in steelhead and rainbow trout (*Oncorhynchus mykiss*): a review of the processes and patterns. Can J Fish Aquat Sci **72**:319-342.

Lawrence, D. J., J. D. Olden, and C. E. Torgensen. 2012. Spatiotemporal patterns and habitat associations of smallmouth bass (*Micropterus dolomieu*) invading salmon-rearing habitat. Freshwat Biol **57**:1929-1946.

Light, J. T., C. K. Harris, and R. L. Burgner. 1989. Ocean distribution and migration of steelhead (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*). Fisheries Research Institute, University of Washington, 8912, Seattle, WA.

McMillan, J. R., J. B. Dunham, G. H. Reeves, J. S. Mills, and C. E. Jordan. 2012. Individual condition and stream temperature influence early maturation of rainbow and steelhead trout, *Oncorhynchus mykiss*. Environmental Biology of Fishes **93**:343-355.

Myers, J., C. Busack, D. Rawding, A. Marshall, D. J. Teel, D. M. Van Doornik, and M. Maher. 2006. Historical population structure of Pacific salmonids in the Willamette River and Lower Columbia River Basins. U.S. Dep Commerce NOAA Tech Memo NMFS NWFSC 73, Seattle, WA.

Sheer, M. B., and E. A. Steel. 2006. Lost watersheds: barriers, aquatic habitat connectivity, and salmon persistence in the Willamette and Lower Columbia River basins. Trans Am Fish Soc **135**:1654-1669.

Van Doornik, D. M., D. M. Hess, M. A. Johnson, D. J. Teel, T. A. Friesen, and J. M. Myers. 2015. Genetic population structure of Willamette River steelhead and the influence of introduced stocks. Trans Am Fish Soc **144**:150-162.

Weber, E. D., and K. D. Fausch. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. Can J Fish Aquat Sci **60**:1018-1036.

Williams, J. E. 2014. Habitat relationships of native and non native fishes of the Willamette River, Oregon. M.S. Thesis, Oregon State University, Corvalis, OR.

Winans, G. A., M. B. Allen, J. Baker, E. Lesko, F. Shrier, B. Strobel, and J. Myers. 2018. Dam trout: Genetic variability in *Oncorhynchus mykiss* above and below barriers in three Columbia River systems prior to restoring migrational access. PLoS ONE **13**:e0197571.

Yeakley, J. A., K. G. Maas-Hebner, and R. M. Hughes. 2014. Wild salmonids in the urbanizing Pacific Northwest. Springer, New York, NY.