Sockeye Salmon (*Oncorhynchus nerka*)

Snake River sockeye

Overall vulnerability—Very high (57% High, 43% Very high)
Biological sensitivity—Very high (91% moderate, 9% low)
Climate Exposure –High (99% High)
Adaptive capacity—Low (1.4)
Data quality—79% of scores ≥ 2

	Snake River Sockeye	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Early life history	2.1	2.8	
	Juvenile freshwater stage	2.9	2.8	
	Estuary stage	1.7	2.3	
	Marine stage	2.4	2.3	
	Adult freshwater stage	3.5	2.8	
	Cumulative life-cycle effects	3.6	2	
	Hatchery influence	2	2.5	
	Other stressors	3.1	2.5	
	Population viability	3.7	2.5	
	Ocean acidification sensitivity	2.3	1.8	
	Sensitivity Score	Very High		
Exposure variables	Stream temperature	3.6	2.8	
	Summer water deficit	2.4	2	
	Flooding	2.8	1.8	
	Hydrologic regime	3	2.8	
	Sea level rise	1.3	2	
	Sea surface temperature	3.2	2.3	
	Ocean acidification exposure	3.9	3	
	Upwelling	1.7	1.8	
	Ocean currents	1.8	1	
	Exposure Score	High		
	Overall Vulnerability Rank	Very High		

Life History Synopsis

Snake River sockeye salmon has the longest freshwater migration (1500 km) to the highest elevation (2000 m above sea level) of any sockeye DPS. Adults enter fresh water from mid-June to mid-July and typically arrive at Redfish Lake, Idaho or nearby lakes in the second half of August. Adults reside in the relatively cool, deep, lake water until they spawn in October. Spawning occurs along edges of the lake and near the mouths of some tributaries. Natural-origin juveniles typically rear in lakes for a year, although a small proportion may stay longer. Smolts migrate rapidly with the spring freshet and are thought to pass quickly through the Columbia

River estuary. Although population sizes are too low to be well-documented in marine sampling programs, they likely move relatively quickly northward toward the Gulf of Alaska (Tucker et al. 2015) to offshore feeding grounds (Farley et al. 2018). The majority of Redfish Lake sockeye return to spawn after 2 years at sea, although return migrations after 1-6 years in the ocean can also occur (Crozier et al. 2015).

Climate Effects on Abundance and Distribution

Life-stage sensitivity attributes for this DPS were scored ***very high*** for the *adult freshwater stage*, which essentially caused the ***very high*** score in *cumulative life-cycle effects*. Rates of adult and juvenile migration survival are strongly correlated with temperature in the Columbia River, and catastrophic effects of temperature on the adult migration have been observed recently. Adult migration survival to spawning grounds ranged from 1% in the extremely warm year of 2015 to 60% in the more average year 2010 (Crozier et al. 2015, Crozier et al. 2018). The anadromous run essentially disappeared altogether in the early 1990s, and has rebounded somewhat in recent years due to large releases of captive broodstock and improved ocean survival (Williams et al. 2014, Ford et al. 2015). Ocean survival is well predicted by environmental climate indices, particularly upwelling and the Pacific Northwest Index (Williams et al. 2014). However, the impact of climate change specifically on marine survival is uncertain, leading to a ***moderate*** score for the *marine stage*.

Snake River sockeye was scored ***low*** in *estuary stage* sensitivity because of its rapid migration from fresh water to the early marine stage. Risk during *early life history* was also scored ***low*** because of the high elevation and relatively stable lake temperatures that influence the egg stage. Scores for the *juvenile freshwater stage* were spread across many bins (sd = 0.89) due to uncertainty in how juvenile rearing and migration would be affected by climate change. The primary rearing lake is likely to remain suitable for sockeye, but the long-distance migratory stage is sensitive to reduced freshets that will result from reduced snowpack. Because smolt production is now dependent on hatchery releases, there is great uncertainty in how management and fish condition will change in the future. Many juveniles are transported past the eight dams along their migration route, which improves juvenile survival but has negative effects on marine survival and adult migration success (Crozier et al. 2015, Crozier et al. 2018). All these anthropogenic influences make predictions about wild sockeye difficult.

In exposure attributes, this DPS was scored ***very high*** for *stream temperature* and *ocean acidification* and ***high*** for *hydrologic regime* and *sea surface temperature*.

Extrinsic Factors

This DPS is listed as endangered under the U.S. Endangered Species Act, and natural production remains extremely low. Spatial diversity is limited to two main spawning areas within one lake, although some spawning occurs in other locations. Finally, genetic diversity has been maintained through careful breeding, but ultimately stems from very few anadromous individuals collected in the 1990s and a residual resident population that has continued to

produce smolts. Thus Snake River sockeye salmon was scored ***very high*** for the *population viability* attribute.

The *other stressors* attribute was also ranked ***high*** due mainly to the hydrosystem and associated impacts on the migratory stage. Spawning and rearing habitat for this DPS is pristine in high-elevation wilderness area. Although historic mining and forestry has affected the spawning gravel in Redfish Lake, and sediment in spawning areas has caused spawning locations to change over time, ongoing habitat threats are minimal.

This DPS has been totally dependent on a conservation hatchery using captive broodstock derived from a handful of Redfish Lake anadromous sockeye combined with residuals, or resident sockeye (Ford et al. 2015). The long-term sockeye reintroduction plan for the Stanley Basin is organized around three phases 1) genetic conservation of the natal stock, 2) lake recolonization and 3) promoting natural adaptation (Kline and Flagg 2014). A large-scale hatchery facility specifically designed to accommodate levels of production projected for phases 2 and 3 is now in operation. The score associated with *hatchery influence* for this DPS is ***moderate***. Best practices in maintaining this captive broodstock have proven that a conservation hatchery is capable of re-establishing an anadromous run, even after a devastating period of unsuccessful migration.

Adaptive Capacity

Snake River sockeye salmon scored ***low*** in adaptive capacity. Sockeye is unlikely to respond to climate change by changing its life-history characteristics, other than reverting to a fully freshwater life history, which would constitute the complete loss of a fundamental characteristic of this DPS. It is possible that the resident population in Redfish Lake has already contributed significantly to the present anadromous broodstock.

Furthermore, little potential habitat exists that might improve in suitability. Low population abundance and spatial diversity suggest limited genetic heterogeneity that would support rapid adaptation. Adult migration spans a broad temporal window (April to mid-August), which might contract to avoid high temperatures and low flows in summer, as has been observed in the larger Okanogan and Wenatchee sockeye DPSs (Crozier et al. 2011).

Literature Cited

Crozier, L. G., B. J. Burke, B. Sandford, G. Axel, and B. L. Sanderson. 2015. Passage and survival of adult Snake River sockeye salmon within and upstream from the Federal Columbia River Power System: 2014 Update. U.S. Dep Commerce NOAA Fisheries Northwest Fisheries Science Center, Seattle, WA.

Crozier, L. G., M. D. Scheuerell, and R. W. Zabel. 2011. Using time series analysis to characterize evolutionary and plastic responses to environmental change: A case study of a shift toward earlier migration date in sockeye salmon. Am Nat **178**:755-773.

Crozier, L. G., L. Wiesebron, J. E. Siegel, B. J. Burke, T. M. Marsh, B. P. Sandford, and D. Widener. 2018. Passage and survival of adult Snake River sockeye Salmon within and upstream from the Federal Columbia River Power System from 2008-2017 U.S. Dep Commerce NOAA Fisheries Northwest Fisheries Science Center, Seattle, WA.

Farley, E. V., T. D. Beacham, and A. V. Bugaev. 2018. Ocean ecology of sockeye salmon.*in* R. J. Beamish, editor. The ocean ecology of Pacific salmon and trout. American Fisheries Society, Bethesda, MD.

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.

Kline, P. A., and T. A. Flagg. 2014. Putting the red back in Redfish Lake, 20 years of progress toward saving the Pacific Northwest's most endangered salmon population. Fisheries **39**:488-500.

Tucker, S., M. E. Thiess, J. F. T. Morris, D. Mackas, W. T. Peterson, J. R. Candy, T. D. Beacham, E. M. Iwamoto, D. J. Teel, M. Peterson, and M. Trudel. 2015. Coastal distribution and consequent factors influencing production of endangered Snake River sockeye salmon. Trans Am Fish Soc **144**:107-123.

Williams, J. G., S. G. Smith, J. K. Fryer, M. D. Scheuerell, W. D. Muir, T. A. Flagg, R. W. Zabel, J. W. Ferguson, and E. Casillas. 2014. Influence of ocean and freshwater conditions on Columbia River sockeye salmon *Oncorhynchus nerka* adult return rates. Fish Oceanogr **23**:210-224.