Puget Sound coho

Overall vulnerability—High (8% Moderate, 92% High)
Biological sensitivity—High (7% Moderate, 93% High)
Climate exposure—High (1% Moderate, 99% High)
Adaptive capacity—High (2.1)
Data quality—89% of scores ≥ 2

	Puget Sound Coho	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Early life history	2.1	2.8	
	Juvenile freshwater stage	3.1	2.8	
	Estuary stage	2	2.8	
	Marine stage	3.1	2.3	
	Adult freshwater stage	1.9	3	
	Cumulative life-cycle effects	1.9	2.3	
	Hatchery influence	2.9	2.8	
	Other stressors	3.3	2.8	
	Population viability	2.1	3	
	Ocean acidification sensitivity	1.9	1	
	Sensitivity Score	High		
Exposure variables	Stream temperature	3.2	2.8	
	Summer water deficit	2.7	2	
	Flooding	1.8	2	
	Hydrologic regime	3.1	2.8	
	Sea level rise	2.5	2	
	Sea surface temperature	2.9	2.5	
	Ocean acidification exposure	3.9	3	
	Upwelling	1.5	2	
	Ocean currents	1.8	1	
	Exposure Score	High		
	Overall Vulnerability Rank	High		

Life History Synopsis

Puget Sound coho adults migrate relatively short distances (<1-150 km) upstream to spawning grounds. Migration begins in late summer or early fall and is often timed with rain events. Coho take advantage of shallower floodplain channels to spawn (Weitkamp et al. 1995). Most coho smolts migrate at age 1+, but a significant proportion may migrate in spring or fall at age 0+. Subyearling coho may rear in estuaries, but employ several strategies. Some may rear in the estuary of the natal river and then move to nearshore areas or migrate back upstream. Others leave as fry and find small, non-natal rearing streams. Average rearing time for age 1+ fish is less than one week, while rearing time is likely more than 4-10 weeks for subyearlings (Beamer et al. , Koski 2009, Jones et al. 2014).

Most Puget Sound coho move directly into deeper waters of Puget Sound and out to coastal waters from Oregon to northern British Columbia (Morris et al. 2007, Van Doornik et al. 2007). However, some may rear for an extended time within Puget Sound and may be captured in deeper waters of the sound into November. Most fish migrate relatively short distances in the ocean, and maturing fish are caught in fisheries from Vancouver Island to the Washington coast and within the Salish Sea (Weitkamp et al. 1995). Early marine climate signals explain a large proportion of the variation in total return rate (Beamish et al. 2000, Beamish and Mahnken 2001, Zimmerman et al. 2015a). Almost all females return after 2 winters at sea, although males may return as jacks (Weitkamp et al. 1995).

Climate Effects on Abundance and Distribution

Few studies have examined the effect of climate factors on the population productivity of Puget Sound coho. In colder systems, some juveniles migrate at age 2+ (Zimmerman et al. 2015a) Rearing in rivers is likely limited by low flows in summer. High flows in winter may also impact survival, particularly in areas with few floodplains, side channels, or off-channel rearing areas. This was reflected in a ***high*** sensitivity score for the *juvenile freshwater stage*. Summer temperature barriers exist in some lowland river systems, and these conditions are likely to worsen under climate change. This DPS also received ***high*** exposure scores for *stream temperature* and *hydrologic regime* shift, causing the *juvenile freshwater stage* to qualify as a ***highly vulnerable life stage***. About 10% of the spawning habitat is expected to shift from transitional to rain dominated by 2080, and 2% from snow dominated to transitional, based on our analysis (Appendix S2). Yearling fry do not rear extensively in estuaries, except as refuges during large floods.

Climate change will likely reduce summer rearing capacity as a result of low flows and high water temperatures, thereby shifting more juvenile migrants to the estuarine-dependent type. However, rearing in estuaries is likely already temperature-limited in late spring and summer (Miller and Sadro 2003, Hall et al. 2018). Delayed rainfall can interrupt adult migration and extend exposure of adults to mortality risk within Puget Sound, as well as present spawn timing challenges (Weitkamp et al. 1995). This could greatly impact marine survival. Early marine climate signals (temperature, upwelling, Pacific Decadal Oscillation) explain a large proportion of the variation in total return rate, suggesting climate change may have significant impacts to this DPS (Beamish et al. 2000, Beamish and Mahnken 2001, Zimmerman et al. 2015a). These risks were reflected in a ***high*** sensitivity score for *marine stage*.

There may be linkages between declining adult body size, egg size, and juvenile size at migration, leading to life-cycle based shifts in total mortality (Holtby et al. 1990). Some of these shifts may be the consequence of marine or incubation thermal regimes (Quinn et al. 2004). Nonetheless, the imminent risk of *cumulative life-cycle effects* was considered relatively ***low***.

Sea level rise is affecting the amount of rearing habitat, possibly offset in some places by higher sedimentation rates. Exposure to *sea level rise* ranked ***moderate***. Juvenile coho consume marine arthropods including crab larvae, krill, and amphipods. Some crabs, including

Dungeness crab are thought to be sensitive to direct effects of ocean acidification (Busch and McElhany 2016), as well as to indirect effects of ocean acidification on the benthic food web (Marshall et al. 2017, Hodgson et al. 2018). As with all DPSs, exposure to *ocean acidification* ranked ***very high***. Fish larvae (possibly physiologically sensitive to ocean acidification) are also an important food source (Daly et al. 2009, Sweeting and Beamish 2009).

Extrinsic Factors

Some regions of Puget Sound are experiencing losses in primary production and increases in eutrophication, possibly due to anthropogenic nutrient inputs (Snover et al. 2005). These can be exacerbated by higher temperatures and increased stratification, and could impact fish via losses in secondary production and hypoxia (Snover et al. 2005). In addition, when high flow events are preceded by extended dry periods, non-point source pollutants may accumulate rapidly in streams and cause pre-spawn, egg, and juvenile mortality (Scholz et al. 2011). These factors contributed to an overall ranking for *other stressors* as ***high***.

Puget Sound coho is not presently protected under the Endangered Species Act, and sensitivity to *population viability* was ranked ***low***. However, populations of this DPS historically have low abundance, particularly those in south Puget Sound. Likely this is a result of lost or degraded spawning habitat in small creeks, as well as loss of floodplains in larger rivers (Pess et al. 2002, Zimmerman et al. 2015b).

Adaptive Capacity

Adaptive capacity was ranked ***high*** for Puget Sound coho. Climate change will likely reduce summer rearing capacity as a result of lower flows and higher temperatures, but coho retain the capacity to shift to a more estuarine-dependent life history type. Similarly, coho in Puget Sound historically had protracted spawn timing, extending to March in some rivers; under higher winter flood scour conditions, this later timing might be more successful. (Weitkamp et al. 1995). Adults also display climate-sensitive plasticity in run timing, which might allow them to avoid high temperature stress in streams prior to spawning and subsequent maladaptive early emergence of fry.

Literature Cited

Beamer, E., R. Henderson, and K. Wolf. Juvenile salmon, estuarine, and freshwater fish utilization of habitat associated with the fisher slough restoration project, Washington 2009 Skagit River System Cooperative, La Conner, WA.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Oceanography **49**:423-435.

Beamish, R. J., D. J. Noakes, G. A. McFarlane, W. Pinnix, R. Sweeting, and J. King. 2000. Trends in coho marine survival in relation to the regime concept. Fish Oceanogr **9**:114-119.

Busch, D. S., and P. McElhany. 2016. Estimates of the direct effect of seawater pH on the survival rate of species groups in the California Current ecosystem. PLoS ONE **11**:e0160669.

Daly, E. A., R. D. Brodeur, and L. A. Weitkamp. 2009. Ontogenetic shifts in diets of juvenile and subadult Coho and Chinook salmon in coastal marine waters: Important for marine survival? Trans Am Fish Soc **138**:1420-1438.

Hall, J. E., T. P. Khangaonkar, C. A. Rice, J. Chamberlin, T. Zackey, F. Leonetti, M. Rustay, K. Fresh, A. Kagley, and M. Rowse. 2018. Characterization of salinity and temperature patterns in a large river delta to support tidal wetland habitat restoration. Northwest Sci **92**:36-52.

Hodgson, E. E., I. C. Kaplan, K. N. Marshall, J. Leonard, T. E. Essington, D. S. Busch, E. A. Fulton, C. J. Harvey, A. Hermann, and P. McElhany. 2018. Consequences of spatially variable ocean acidification in the California Current: Lower pH drives strongest declines in benthic species in southern regions while greatest economic impacts occur in northern regions. Ecol Model **383**:106-117.

Holtby, L. B., B. C. Andersen, and R. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Can J Fish Aquat Sci **47**:2181-2194.

Jones, K. K., T. J. Cornwell, D. L. Bottom, L. A. Campbell, and S. Stein. 2014. The contribution of estuary-resident life histories to the return of adult *Oncorhynchus kisutch*. J Fish Biol **85**:52-80.

Koski, K. 2009. The fate of coho salmon nomads: the story of estuarine rearing strategy promoting resilience. Ecol Soc **14**:4.

Marshall, K. N., I. Kaplan, E. E. Hodgson, A. Hermann, D. Shallin Busch, P. McElhany, T. Essington, C. J. Harvey, and E. A. Fulton. 2017. Risks of ocean acidification in the California Current food web and fisheries: Ecosystem model projections. Global Change Biol **23**:1525-1539.

Miller, B., and S. Sadro. 2003. Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Trans Am Fish Soc **132**:546–559.

Morris, J. F. T., M. Trudel, M. E. Thiess, R. M. Seeting, J. Fisher, S. A. Hinton, E. Ferguson, J. A. Orsi, E. Farley, and D. W. Welch. 2007. Stock-specific migrations of juvenile Coho salmon derived from coded-wire tag recoveries on the continental shelf of western North America. Am Fish Soc Symp **57**:81–104.

Pess, G. R., D. R. Montgomery, E. A. Steel, R. E. Bilby, B. E. Feist, and H. M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., U.S.A. Can J Fish Aquat Sci **59**:613-623.

Quinn, T. P., L. A. Vollestad, J. Peterson, and V. Gallucci. 2004. Influences of freshwater and marine growth on the egg size-egg number tradeoff in Coho and Chinook salmon. Trans Am Fish Soc **133**:55-65.

Scholz, N. L., M. S. Myers, S. G. McCarthy, J. S. Labenia, J. K. McIntyre, G. M. Ylitalo, L. D. Rhodes, C. A. Laetz, C. M. Stehr, B. L. French, B. McMillan, D. Wilson, L. Reed, K. D. Lynch, S. Damm, J. W. Davis, and T. K. Collier. 2011. Recurrent die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams. PLoS ONE **6**:e28013.

Snover, A. K., P. W. Mote, L. Whitely Binder, A. F. Hamlet, and M. N.J. 2005. Climate change and its effects on Puget Sound. A report for the Puget Sound Action Team by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA.

Sweeting, R., and R. J. Beamish. 2009. A Comparison of the Diets of Hatchery and Wild Coho Salmon (*Oncorhynchus kisutch*) in the Strait of Georgia from 1997–2007. N Pac Anadr Fish Com Bull **5**:255-264.

Van Doornik, D. M., D. J. Teel, D. R. Kuligowski, C. A. Morgan, and E. Casillas. 2007. Genetic analyses provide insight into the early ocean stock distribution and survival of juvenile Coho salmon off the coasts of Washington and Oregon. N Am J Fish Manage **27**:220-237.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Dep Commerce NOAA Tech Memo NMFS NWFSC 24, Seattle, WA.

Zimmerman, M. S., J. R. Irvine, M. O'Neill, J. H. Anderson, C. M. Greene, J. Weinheimer, M. Trudel, and K. Rawson. 2015a. Spatial and temporal patterns in smolt survival of wild and hatchery coho salmon in the Salish Sea. Mar Coast Fish **7**:116-134.

Zimmerman, M. S., C. Kinsel, E. Beamer, E. J. Connor, and D. E. Pflug. 2015b. Abundance, survival, and life history strategies of juvenile Chinook salmon in the Skagit River, Washington. Trans Am Fish Soc **144**:627-641.