Sockeye salmon – *Oncorhynchus nerka*

Overall Vulnerability Rank = Low

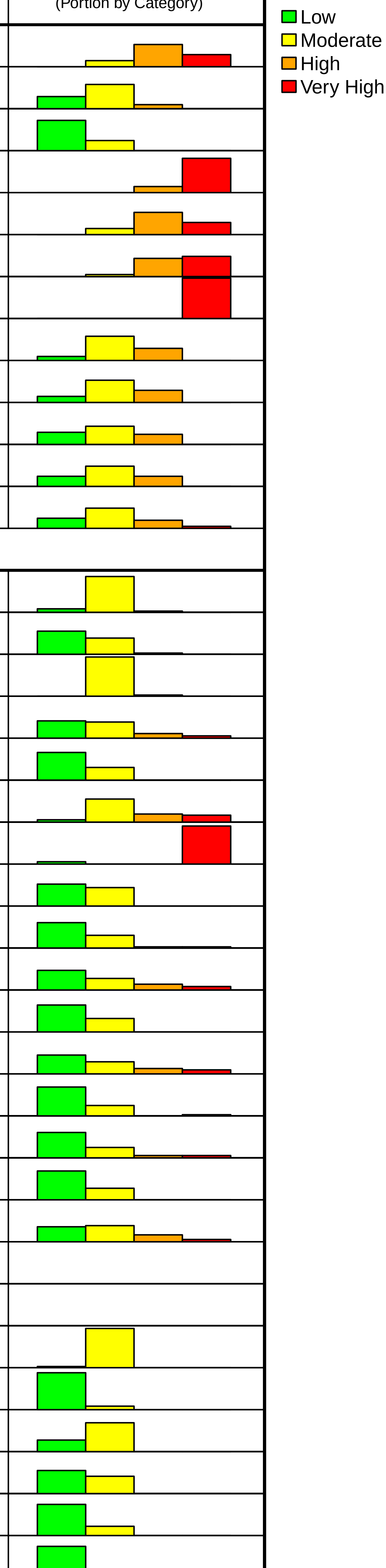
Biological Sensitivity = High

Climate Exposure = Low

Sensitivity Data Quality = 75% of scores ≥ 2

Exposure Data Quality = 64% of scores ≥ 2

	Oncorhynchus nerka	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	3.1	2.5	
	Prey Specificity	1.8	2.8	
	Adult Mobility	1.2	2.5	
	Dispersal of Early Life Stages	3.8	2.8	
	Early Life History Survival and Settlement Requirements	3.1	2.0	
	Complexity in Reproductive Strategy	3.4	2.5	
	Spawning Cycle	4.0	2.8	
	Sensitivity to Temperature	2.2	2.2	
	Sensitivity to Ocean Acidification	2.1	1.8	
	Population Growth Rate	1.9	2.2	
	Stock Size/Status	2.0	1.8	
	Other Stressors	2.0	1.8	
	Sensitivity Score	High		
Exposure factors	Sea Surface Temperature	1.9	2.5	
	Sea Surface Temperature (variance)	1.5	2.5	
	Bottom Temperature	2.0	2.5	
	Bottom Temperature (variance)	1.8	2.5	
	Salinity	1.3	2.0	
	Salinity (variance)	2.5	2.0	
	Ocean Acidification	3.8	2.5	
	Ocean Acidification (variance)	1.5	2.5	
	Phytoplankton Biomass	1.5	1.2	
	Phytoplankton Biomass (variance)	1.8	1.2	
	Plankton Bloom Timing	1.3	1.0	
	Plankton Bloom Timing (variance)	1.9	1.0	
	Large Zooplankton Biomass	1.3	1.0	
	Large Zooplanton Biomass (variance)	1.5	1.0	
	Mixed Layer Depth	1.3	1.0	
	Mixed Layer Depth (variance)	1.9	1.0	
	Currents	NA	NA	
	Currents (variance)	NA	NA	
	Air Temperature	2.0	2.5	
	Air Temperature (variance)	1.1	2.5	
	Precipitation	1.7	2.0	
	Precipitation (variance)	1.4	2.0	
	Sea Surface Height	1.2	2.5	
	Sea Surface Height (variance)	1.3	2.5	
	Exposure Score	Low		
Overall Vulnerability Rank		Low		



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Sockeye salmon (*Oncorhynchus nerka*)

Overall Climate Vulnerability Rank: **Low**. (31% certainty from bootstrap analysis).

Climate Exposure: **Low**. With the exception of ocean acidification (3.8), all exposure factors had scores less than 2.5.

Biological Sensitivity: **High**. Spawning cycle (4.0) and dispersal of early life stages (3.9) were ranked as "very high" sensitivity and complexity in reproductive strategy (3.5), early life history survival (3.2), and habitat specificity (3.2) were ranked as "high" sensitivity.

Potential for Distribution Change: **Low** (98% certainty from bootstrap analysis). Adult mobility indicated a very high potential for distribution change, whereas the remaining three distribution attributes indicated low potential for distribution change.

Directional Effect in the Eastern Bering Sea: Projected climate change in the eastern Bering Sea is expected to have a neutral effect on sockeye salmon, with an 81% certainty in expert scores.

Data Quality: 75% of the sensitivity attributes and 64% of the exposure factors had average data quality scores of 2 or greater (indicating at least "moderate" data quality).

Climate Effects on Abundance and Distribution:

Bristol Bay supports the worlds' largest and primary run of sockeye salmon that enters the eastern Bering Sea from western Alaska river systems (Irvine and Ruggerone 2016). Stock productivity (returns per spawner) increased with the cool to warm regime shift in the late 1970s (Adkison et al. 1996). Changes in survival rates of sockeye salmon were related to freshwater and early marine processes (Peterman et al. 1998).

Stock productivity of western Alaska sockeye salmon was positively correlated to scale growth during the first and second year at sea (Ruggerone et al. 2007). Larger juvenile sockeye salmon had higher marine survival rates than smaller juvenile sockeye salmon in the eastern Bering Sea (2000-2002; Farley et al. 2007a). Abundance of juvenile sockeye salmon in the eastern Bering Sea during late summer increased with warming sea temperatures (2002-2016; Yasumiishi et al. 2017). Currently, warmer summer sea temperatures appears to favor the production of sockeye salmon in the eastern Bering Sea.

Body weight of adult sockeye salmon captured in Bristol Bay commercial fisheries increased from early 1980 to the mid-2000s (Helle et al. 2007). From the mid-1990s to 2014, average body weight declined for sockeye salmon from the Kuskokwim River but not from Norton Sound or Bristol Bay. Growth rate potential (mm/day) was lower during cooler years and higher during warmer years for juvenile sockeye salmon in the Bering Sea as indicated by bioenergetics modeling (Farley and Trudel 2009). Total length of juvenile sockeye salmon back-calculated from adult scales was positively correlated with sea temperatures during the first year at sea (Yasumiishi et al. 2016).

Time of outmigration from fresh water to salt water is influenced by water temperature in the lakes, wind direction, number of lake systems for a particular river system, size and/or age, and time of day (Quinn 2005, Burgner 1991). The positive influence of spring lake temperature on the size of juvenile sockeye salmon in Lake Iliamna exceeded negative effects caused by increases in population density (Rich et al. 2009). Larger smolts have more locomotory abilities that may decrease their predation risk in comparison to smaller smolts; on the other hand, their larger size may increase their visibility to predators, thus increasing their predation risk.

Timing of the spawning migrations of Bristol Bay sockeye salmon was earlier in June when sea surface temperatures were warmer (Kvichak River), lake levels were lower (Wood River) (Hodgson and Quinn 2006), and fishing effort was reduced on the early part of the run (Quinn et al. 2007).

The known thermal range of sockeye salmon in the ocean are the narrowest range of all salmon species (Echave et al. 2012). In the eastern Bering Sea, sea temperature preference ranges for juvenile sockeye salmon were 7.3-14.6 °C and 7.4-14.6 °C for immature and mature salmon, respectively (Echave et al. 2012). Juvenile sockeye are distributed farther north in years with warmer sea temperatures (4.5-9.5 °C) in the eastern Bering Sea during late summer (2002-2016; Yasumiishi et al. 2017). Cooler summers were associated with the nearshore and southern migration along the Alaska Peninsula, while warmer summers were associated with an offshore migration pathway (Farley et al. 2005).

Prey quality of eastern Bering Sea sockeye salmon differed between warm and cold years. Sockeye salmon consumed lower energy prey (pollock) during warm years and higher energy prey (euphausiids) during cold years (Coyle et al. 2011). Juvenile sockeye salmon consumed sand lance during cool years and pollock during warm years (Farley 2007b). Evidence of reduced prey quality during warm years and energy depletion over winter could influence overwintering survival with increased warming (Farley et al. 2011).

<u>Life History Synopsis:</u>

Sockeye salmon generally distribute from 40° N to 66° N latitude in the eastern Pacific Ocean. In North America, sockeye salmon originate in rivers from the Columbia River in Washington State to the Mackenzie River in the Yukon Territory, Canada (Cobb 1917, Stephenson 2006). The eastern Bering Sea is used as a rearing habitat for juvenile sockeye salmon and maturing sockeye salmon on their way back to fresh water to spawn (Farley et al. 2005).

Sockeye salmon is a short-lived (<10 years), anadromous, and semelparous species. Adult salmon spawn and incubate eggs in fresh water. Sockeye alevin occupy interstitial spaces within stream bed gravel where water temperatures range from slightly above 0 °C to slightly below 12 °C (Burgner 1991). Freshwater juvenile sockeye rear in rivers, streams, sloughs, lakes, ponds, and/or estuaries (Burgner 1991). Freshwater juvenile salmon can tolerate 0-22 °C water and dissolved oxygen > 2 mg/l, but prefer >7 mg/l dissolved oxygen and 8-12 °C water (Echave et al. 2012). On the shelf, juvenile sockeye reside in waters within the top 40-60 m to 36-462 m bottom depths and 7.3 °C-14.6 °C sea surface temperatures with 22.8-32.1 ppt salinities (Echave et al. 2012). Adult sockeye salmon have the shallowest vertical distribution of all anadromous Pacific salmon.

The peak timing of upstream migration of Bristol Bay sockeye salmon is June and July (ADF&G 2018). Very few sockeye salmon reside in the Yukon and Kuskokwim rivers. Straying of adults is known to be low in sockeye salmon (0.6-5%) (Keefer and Caudill 2014).

Age at maturity of sockeye salmon has the widest range of Pacific salmon. Sockeye salmon can spend from 1 to 5 winters in fresh water and from 1 to 4 years in the ocean (Groot and Margolis 1991). Bristol Bay sockeye salmon typically spend 2 winters in fresh water and 3 to 4 winters at sea.

Diets of sockeye salmon in the eastern Bering Sea primarily consists of zooplankton and fish. Sockeye salmon (100 mm-910 mm) consumed primarily pollock during warm years (2002-2006) and euphausiids and fish during cold years (2007-2009) (Coyle et al. 2011, Farley et al. 2007b). Adult sockeye salmon consumed copepods, amphipods, squid, insects, and fish (Davis et al. 2009).

Stock productivity increased for sockeye salmon returning to western Alaska from 1952 to 2015 and remained stable following the 1976-77 regime shift (Adkison et al. 1996, Irvine and Ruggerone 2016). From 1996 to 2015, commercial harvest of sockeye salmon increased for Bristol Bay and Norton Sound, and remained stable for the Kuskokwim management area (ADFG 2017, Poetter and Tiernan 2017, Salomone et al. 2017). Total commercial harvest of sockeye salmon increased from 1996 to 2015.

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