Pacific halibut − *Hippoglossus stenolepis*

Overall Vulnerability Rank = Low

Biological Sensitivity = Moderate

Climate Exposure = Low

Sensitivity Data Quality = 100% of scores ≥ 2

Exposure Data Quality = 56% of scores ≥ 2

	Hippoglossus stenolepis	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.5	3.0	
	Prey Specificity	1.5	2.8	
	Adult Mobility	1.3	3.0	
	Dispersal of Early Life Stages	1.1	2.8	
	Early Life History Survival and Settlement Requirements	2.6	2.2	
	Complexity in Reproductive Strategy	2.2	2.4	
	Spawning Cycle	2.8	2.6	
	Sensitivity to Temperature	1.8	2.8	
	Sensitivity to Ocean Acidification	1.8	2.8	
	Population Growth Rate	3.8	2.8	
	Stock Size/Status	1.4	3.0	
	Other Stressors	2.2	2.4	
	Sensitivity Score	Moderate		
Exposure factors	Sea Surface Temperature	2.1	2.5	
	Sea Surface Temperature (variance)	1.3	2.5	
	Bottom Temperature	2.1	3.0	
	Bottom Temperature (variance)	1.7	3.0	
	Salinity	1.5	2.0	
	Salinity (variance)	2.5	2.0	
	Ocean Acidification	4.0	3.0	
	Ocean Acidification (variance)	1.3	3.0	
	Phytoplankton Biomass	1.7	1.2	
	Phytoplankton Biomass (variance)	1.7	1.2	
	Plankton Bloom Timing	1.5	1.0	
	Plankton Bloom Timing (variance)	1.9	1.0	
	Large Zooplankton Biomass	1.5	1.0	
	Large Zooplanton Biomass (variance)	1.6	1.0	
	Mixed Layer Depth	1.3	1.0	
	Mixed Layer Depth (variance)	1.6	1.0	
	Currents	1.3	2.0	
	Currents (variance)	1.5	2.0	
	Air Temperature	NA	NA	
	Air Temperature (variance)	NA	NA	
	Precipitation	NA	NA	
	Precipitation (variance)	NA	NA	
	Sea Surface Height	NA	NA	
	Sea Surface Height (variance)	NA	NA	
	Exposure Score	Low		
Overall Vulnerability Rank		Low		

Low
Moderate
High
Very High

Pacific halibut (*Hippoglossus stenolepis*)

Overall Climate Vulnerability Rank: **Low**. (63% certainty from bootstrap analysis).

Climate Exposure: **Low**. With the exception of ocean acidification (4.0), all exposure factors had scores less than 2.5.

Biological Sensitivity: **Moderate**. Population growth rate (3.8) was ranked as "very high" sensitivity, and spawning cycle (2.8) and early life history survival (2.6) were ranked as "moderate" sensitivity.

Potential for distribution change: **Very High** (57% certainty from bootstrap analysis). Three attributes (adult mobility, dispersal of early life stages, and habitat specificity) indicated very high 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 Pacific halibut, with 95% certainty in expert scores.

Data Quality: 100% of the sensitivity attributes, and 56% 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:

For Pacific halibut, the positive phase of the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) and subsequent recruitment of juveniles into the commercial fishery appears to be correlated (Clark and Hare 2002, Clark et al. 1999, Stewart and Martell 2016). It is unknown whether this correlation is related to temperature, currents, or other environmental conditions. Recent trends in the PDO time series represent one of the few pieces of information related to juvenile Pacific halibut abundance prior to their entry into the commercial fishery at around 8 to10 years, and the historical correlation is used in stock assessment modelling or recruitment strengths.

Older juvenile and adult Pacific halibut have a relatively wide temperature tolerance range, occupying temperatures from 1-12°C, and are found most commonly in mid-range temperatures of 4-5°C (Seitz et al. 2003, 2006, 2007; Best 1977). Less is known regarding the temperature tolerances of young juvenile Pacific halibut in the first few years following settlement. However, halibut in the egg and larval phases appear to have a much more narrow thermal tolerance than adult fish. In laboratory studies, hatching occurred between 5-8°C, but did not occur outside of this range. Additionally, for those within the tolerance range, time to hatch was more rapid at higher temperatures but size at hatch was greatest at mid-range temperatures (Forrester and Alderdice 1973, McFarlane et al. 1991, Liu et al. 1994). Therefore, wholesale increases in temperature over time as predicted with climate change could considerably impact Pacific halibut egg and larval development, survivability, and hatch size.

Pacific halibut are opportunistic feeders, but depend on shelled organisms such as gastropods, shrimp, and crabs for a substantial portion of their food intake at all life stages (St-Pierre and Trumble 2000; Livingston et al. 2017). In an acidified ocean environment where shelled organisms are compromised, halibut would depend more heavily on unshelled organisms such as fishes and it is unclear how the health, distribution, and population abundance would be affected.

There is no evidence to suggest that the Bering Sea habitat for Pacific halibut is currently degraded. However, elsewhere within the species range, specifically in the California Current system, hypoxic zones (i.e. dissolved oxygen $\leq$ 1.4 ml/L), which have been observed to some extent off Washington in the historical record dating back to 1950, have intensified since the early 2000s to include the coast of Oregon as well as Washington at greater extent and severity than previously observed (Connelly et al. 2010, Chan et al. 2008, Grantham et al. 2004). In that region, dissolved oxygen concentration of about 0.9 ml/L and lower appears to cause an exodus of Pacific halibut from the hypoxic area thus affecting distribution. At levels > 0.9 ml/L, but still hypoxic or near-hypoxic, feeding behavior of older juvenile and adult fish may be reduced (Sadorus et al. 2014).

<u>Life History Synopsis:</u>

Pacific halibut range from northern California northward to the Gulf of Alaska and Bering Sea and westward to Russia and Japan (Thompson and Van Cleve 1936). In the Bering Sea, halibut are typically found as far north as Norton Sound in summer and were recorded once in 1998 just north of the Bering Strait in the Chukchi Sea (Fair and Nelson 1999). They can grow to be 500 pounds, although weights less than 50 pounds are more typical, and the longest living specimens recorded to date for both males and females were 55 years old. Growth is sexually dimorphic with females growing faster and larger than males. Age at 50% maturity is currently estimated at 8 years for males and 11.5 years for females. The number of eggs spawned is correlated with size so that a 50-pound female may produce 500,000 eggs in a season whereas a 250-pound female may produce 4 million eggs (Schmitt and Skud 1978).

Mature Pacific halibut conduct a cross-shelf migration from the shallow feeding grounds of the continental shelf to the deeper water of the continental slope to spawn. Spawning in the eastern Bering Sea takes place along the continental shelf edge primarily in Bering and Pribilof Canyons (St-Pierre 1984, Sohn et al. 2016). Some halibut also execute an along-shelf migration to spawning grounds further north and west in the Gulf of Alaska (Loher and Seitz 2006). The migration from the summer feeding grounds to the spawning grounds begins in the fall and it is unclear what, if any, environmental cues trigger this migration, but the timing of the migration appears to be fairly consistent throughout the species range (Loher 2011). Spawning takes place November to March with the peak of spawning occurring in late December to early January (St-Pierre 1984). Spawning adults tagged with pop-up satellite tags have been observed performing abrupt vertical rises during spawning which are hypothesized to be deliberate placement of fertilized eggs into the water column for transport (Loher and Seitz 2008, Loher 2011).

The eggs and larvae are carried by ocean currents away from the spawning grounds north and westward (Skud 1977). During the egg phase, the specific gravity decreases, allowing them to slowly float towards the surface. Once hatched, Pacific halibut larvae are bilaterally symmetrical and feed off of yolk sacs for the first several weeks (Thompson and Van Cleve 1936). They can maintain position within the water column within three weeks post-hatch (McFarlane et al.

1991). At the time of first feeding (~ 55 days post hatch) the larvae move closer to the surface (Sohn et al. 2016) and must have been successfully delivered by the ocean currents to areas with adequate food in order to survive. The halibut population releases millions of eggs over the spawning period (Schmitt and Skudd 1978) which may help buffer the population from spatial and temporal mismatches in larval food supply.

At about six months of age, the larvae undergo a metamorphosis to the asymmetrical, adult form and settle to the bottom in shallow (< 100 m depth), inshore areas of Bristol Bay and the Gulf of Alaska (Thompson and Van Cleve 1936). Between 1 and 3 years of age, Pacific halibut begin migrating to deeper habitats and disperse west and south onto the Bering Sea flats and the coastal areas of the Aleutian Islands in the Bering Sea, and eastward in the Gulf of Alaska in a migration pattern that counters the direction of larval drift. By age-6, juvenile halibut are widely dispersed on the continental shelf and upper slope occupying a variety of bottom substrates including mud, sand, gravel, and rocky (Best 1977, Sadorus et al. 2015). Older juveniles and adults can be typically found at depths as great as 500 m in summer, with greater abundance at shallower depths (< 275 m). Mature halibut can be found at depths from 200 m to more than 500 m in winter during spawning.

Both juvenile and adult Pacific halibut are opportunistic feeders. Adult halibut eat a variety of animal prey including fishes, cephalopods, crabs, shellfish, and other invertebrates. The most common food items found in halibut stomachs include pollock in all areas, along with crabs in the Bering Sea, and Atka mackerel and sculpins in the Aleutian Islands. Juvenile halibut eat animals smaller than themselves, such as small shrimp, crabs, gastropods, and fishes (St-Pierre and Trumble 2000, Livingston et al. 2017). Larval phase halibut likely eat a variety of planktonic organisms. Larval and small juvenile Pacific halibut are prey for other fishes, but eventually they grow to a size that renders them immune to most other fish predation. As larger adults, halibut are occasionally preyed upon by marine mammals and sharks.

Recruitment of Pacific halibut is naturally highly variable spatially and temporally. Natural mortality is estimated to be between 0.12 and 0.2 for females and slightly lower for males.

The Pacific halibut fishery for Canada and the United States of America has been managed by the International Pacific Halibut Commission (IPHC) since 1923. The Convention Area is divided into eight management and regulatory areas and catch limits for each of the areas are set annually by the IPHC. The Pacific halibut stock assessment provides a summary of recently collected data, and model estimates of stock size and trend. The stock assessment uses an ensemble of assessment models and reports the status of the Pacific halibut resource in the IPHC Convention Area. Currently, the resource is modelled as a single stock extending from northern California to the Aleutian Islands and Bering Sea, including all inside waters of the Strait of Georgia and Puget Sound, but excludes known extremities in the western Bering Sea within the Russian Exclusive Economic Zone (IPHC 2018).

Specific management information is summarized via a decision table reporting the estimated risks associated with alternative management actions and catch tables projecting the level of mortality for fisheries in each Regulatory Area indicated by the IPHC’s interim management procedure, as well as other alternatives (IPHC 2018). The interim management procedure for Pacific halibut uses a constant harvest rate (based on the spawning potential ratio), adjusted via a minimum biomass limit and a target threshold relative to unfished conditions. The halibut stock is currently estimated to be above the threshold level and within the historical range (Stewart and Martell 2015).

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