Eastern Bering Sea Pacific cod − *Gadus macrocephalus*

Overall Vulnerability Rank = Low

Biological Sensitivity = Low

Climate Exposure = Low

Sensitivity Data Quality = 83% of scores ≥ 2

Exposure Data Quality = 56% of scores ≥ 2

	Gadus macrocephalus	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.2	2.1	
	Prey Specificity	1.1	2.5	
	Adult Mobility	1.3	2.5	
	Dispersal of Early Life Stages	1.2	2.1	
	Early Life History Survival and Settlement Requirements	2.4	1.8	
	Complexity in Reproductive Strategy	1.7	2.1	
	Spawning Cycle	2.8	2.2	
	Sensitivity to Temperature	1.7	2.5	
	Sensitivity to Ocean Acidification	2.1	1.7	
	Population Growth Rate	2.3	2.5	
	Stock Size/Status	1.1	2.5	
	Other Stressors	1.0	2.4	
	Sensitivity Score	Low		
Exposure factors	Sea Surface Temperature	2.0	2.5	
	Sea Surface Temperature (variance)	1.5	2.5	
	Bottom Temperature	2.0	3.0	
	Bottom Temperature (variance)	1.8	3.0	
	Salinity	1.2	2.0	
	Salinity (variance)	2.2	2.0	
	Ocean Acidification	4.0	3.0	
	Ocean Acidification (variance)	1.3	3.0	
	Phytoplankton Biomass	1.3	1.2	
	Phytoplankton Biomass (variance)	1.5	1.2	
	Plankton Bloom Timing	1.4	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	1.5	1.0	
	Mixed Layer Depth (variance)	1.9	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

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Pacific cod (*Gadus macrocephalus*)

Overall Climate Vulnerability Rank: **Low**. (97% 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: **Low**. Spawning cycle (2.9) was ranked as “moderate” sensitivity, and all other sensitivity attributes were ranked as “low” sensitivity.

Potential for distribution change: **Very High** (98% 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 cod, with 82% certainty in expert scores.

Data Quality: 83% 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:

Several studies have demonstrated an impact of temperature on survival and hatching of eggs and development of embryos and larvae (e.g., Laurel et al. 2008, Hurst et al. 2010, Laurel et al. 2011, Laurel et al. 2012, Bian et al. 2014, Bian et al. 2016). Temperature has been (negatively) related to recruitment of Pacific cod (e.g., Doyle et al. 2009, Hurst et al. 2012). Shimada and Kimura (1994) and Neidetcher et al. (2014) speculated that variations in spawning time may be temperature-related.

Under elevated CO_2 levels, 2-week-old larvae exhibited lower lipid levels and 4-week-old larvae exhibited stronger phototaxis than under ambient CO_2 levels, while older fish did not exhibit either response, suggesting a stage-specific sensitivity of Pacific cod to both the direct and interactive effects of ocean acidification (Hurst et al., 2017). Juveniles rely heavily upon copepods and euphausiids (e.g., Abookire et al. 2007, Moss et al. 2016, Strasburger et al. 2014, Farley et al. 2016), which have calcareous exosketetons, further indicating potential sensitivity to ocean acidification.

However, climate effects on abundance and distribution may be mitigated to some extent by the generalist nature of the species. For example, Hurst et al. (2015) state, “The ability to utilize a mosaic of habitats as nursery areas may contribute to the persistence of the Pacific cod population in the Bering Sea.”

Life History Synopsis:

Range

As a species, Pacific cod range from Santa Monica Bay, California northward along the North American coast; across the Gulf of Alaska and Bering Sea north to Norton Sound; and southward along the Asian coast from the Gulf of Anadyr to the northern Yellow Sea (Ketchen 1961, Bakkala et al. 1984). The species occurs in 14 of the provinces identified by Spalding et al. (#14 and #45-57). Within the EBS, Pacific cod are widely distributed over the shelf and upper slope, to depths of 500 m (Bakkala 1984), and are routinely captured in every stratum of the annual EBS shelf bottom trawl survey. However, EBS bottom trawl survey catch rates in excess of 50 kg/ha are seldom observed inside the 0 degree bottom temperature isotherm (http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm).

Habitat use

Habitat within the water column: The stock utilizes various depths within the water column, both at various stages in life history and also on a diel basis. Eggs are demersal (Thomson 1963), but larvae quickly migrate to surface waters (Rugen and Matarese 1988, Hurst et al. 2009). Juveniles tend to settle near the seafloor (Abookire et al. 2007, Laurel et al. 2007). Nichol et al. (2013) observed frequent diel vertical migration. Patterns varied significantly by location, bottom depth, and time of year, with daily depth changes averaging 8 m.

Juveniles: Juveniles occur mostly over the inner continental shelf at depths of 60 to 150 m. Adults occur in depths from the shoreline to 500 m, although occurrence in depths greater than 300 m is fairly rare. Preferred substrate is soft sediment, from mud and clay to sand. Average depth of occurrence tends to vary directly with age for at least the first few years of life. Some studies of Pacific cod in the Gulf of Alaska and also some studies of Atlantic cod suggest that young-of-the-year cod are dependent on eelgrass, but this does not appear to be the case in the EBS. In contrast to other parts of the range of Pacific cod, where sheltered embayments are key nursery grounds, Hurst et al. (2015) found that habitat use of age 0 Pacific cod in the EBS occurs along a gradient from coastal-demersal (bottom depths < 50 m) to shelf-pelagic (bottom depths 60-80 m), with densities near the coastal waters of the Alaska peninsula much higher than elsewhere. Hurst et al. (2012) and Parker-Stetter et al. (2013) also observed age 0 Pacific cod in the shelf-pelagic zone. Hurst et al. (2012) found evidence of density-dependent habitat selection at the local scale, but no consistent shift in distribution of juvenile Pacific cod in response to interannual climate variability. Habitat for juvenile Pacific cod in the EBS is abundant. The coastal-demersal part of the habitat has been disturbed to some extent by fishing activity, while the shelf-pelagic part of the habitat would best be described as undisturbed.

Adults: Adult Pacific cod are widely distributed across the EBS, to depths of 500 m (Bakkala 1984), and are routinely captured in every stratum of the annual EBS shelf bottom trawl survey (http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm). Habitat for adult Pacific cod in the EBS is abundant. Adult Pacific cod in the EBS are strongly associated with the seafloor (Nichol et al. 2007), suggesting that fishing activity has the potential to disturb habitat, although the effect of fishing upon EBS Pacific cod habitat was rated as minimal and temporary in the most recent EFH 5-year review (NPFMC 2010).

Diet

Juveniles: Abookire et al. (2007) found that young-of-the-year Pacific cod near Kodiak Island fed mainly on small calanoid copepods, mysids, and gammarid amphipods. Moss et al. (2016) found that age 0 Pacific cod in the central Gulf of Alaska consumed mostly copepods and amphipods. Poltev and Stominok (2008) found that young-of-the-year walleye pollock played a major role in the diet of juvenile Pacific cod near the Kuril Islands and Kamchatka. Strasburger et al. (2014) found that age 0 (juvenile) Pacific cod in the southeastern Bering Sea consumed primarily euphausiids, snow and Tanner crab larvae, amphipods, sea snails, and arrow worms. Farley et al. (2016) found that diet of age 0 (juvenile) Pacific cod in the EBS varied with temperature, with high proportions of age 0 walleye pollock during warm years and a shift to euphausiids and large copepods during cool years.

Adults: Albers and Anderson (1985) found that adult Pacific cod in Pavlof Bay in the western Gulf of Alaska consumed primarily pandalid shrimp, capelin, and walleye pollock. In terms of weight, Yang (2004) found that adult Pacific cod in the same area consumed primarily eelpouts, Tanner crab, crangonid shrimp, hermit crab, and polychaetes; and attributed differences from the results of Albers and Anderson (1985) to climate change. Livingston (1989) found that adult Pacific cod were significant predators of snow and Tanner crab in the eastern Bering Sea. Lang et al. (2005) examined stomach contents of adult Pacific cod sampled in annual EBS shelf bottom trawl surveys from 1997-2001, and found that hermit crab, snow crab, Tanner crab, walleye pollock, eelpout, and fishery offal all contributed at least 5% of the diet by weight in at least one survey year, with walleye pollock being by far the most important prey item by weight (average across years = 45%).

Predators

The predators of Pacific cod have been described Westrheim (1996). Predators of Pacific cod include Pacific cod, halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Calkins (1998) also showed Pacific cod to be an important winter prey item of Steller sea lions. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery has operated to some extent in the same areas used by Steller sea lion as foraging grounds (Livingston (ed.), 2002).

Reproductive biology

Pacific cod in the EBS form large spawning aggregations. Shimada and Kimura (1994) identified major spawning areas between Unalaska and Unimak Islands, and seaward of the Pribilof Islands along the shelf edge. Neidetcher et al. (2014) identified spawning concentrations north of Unimak Island, in the vicinity of the Pribilof Islands, at the shelf break near Zhemchug Canyon, and adjacent to islands in the central and western Aleutian Islands along the continental shelf. In their tagging study, Shimada and Kimura (1994) observed a few travel distances in excess of 500 nmi, with a large number of travel distances in excess of 100 nmi, which they inferred to be part of an annual migration between summer feeding grounds and winter spawning grounds. Shimada and Kimura (1994) and Neidetcher et al. (2014) speculated that variations in spawning time may be temperature-related. Pacific cod in the EBS typically spawn once per year (Sakurai and Hattori 1996, Stark 2007), from late February or early March through early to mid-April (Neidetcher et al. 2014).

Pacific cod eggs are demersal and adhesive (Thomson 1963). Eggs hatch in about 15 to 20 days. Spawning takes place in the sublittoral-bathyal zone (40 to 290 m) near bottom. Eggs sink to the bottom after fertilization and are somewhat adhesive. Optimal temperature for incubation is 3° to 6°C, optimal salinity is 13 to 23 parts per thousand (ppt), and optimal oxygen concentration is from 2 to 3 ppm to saturation. Little is known about the optimal substrate type for egg incubation.

In a laboratory study, eggs hatched between 16-28 days after spawning, with peak hatching occurring on day 21 (Abookire et al. 2007). Settlement in the Gulf of Alaska is reported to occur from July onward (Blackburn and Jackson 1982, Abookire et al. 2007, Laurel et al. 2007), which, given a mean spawning date of mid-March (Neidetcher et al 2014), and assuming that settlement occurs immediately after transformation, and subtracting about 20 days for the egg stage, implies that the larval life stage might last about 90 days. In the laboratory study by Hurst et al. (2010), postflexion larvae were all younger than 106 days post-hatching, and juveniles were all older than 131 days post-hatching, so it might be inferred that transformation typically takes place between 106 and 131 days after hatching. Alternatively, duration of the larval stage can be computed as follows: 1) Laurel et al. (2011, Figure 2) showed that it takes about 6 weeks (42 days) to reach the larval inflexion size of 8-12 mm, depending on temperature. 2) Hurst et al. (2010, Figure 2) showed that post-flexion larvae grow at rates of 0.2-0.4 mm per day, depending on temperature. 3) Matarese et al. (1989, p. 194) stated that transformation occurs at sizes between 25-35 mm. 4) Taking a value of 26 mm to represent transformation (near the lower end of the range reported by Matarese et al.), the ranges in (1) and (2) imply larval durations in the range of 77 (=42+(26-12)/0.4) to 132 (=42+(26-8)/0.2) days.

Life history parameters (growth, maturation, mortality)

Thompson (2017) lists the values of the von Bertalanffy growth function parametrs as L_∞ = 99.636, K = 0.198, and a_0 = 0.591.

Stark (2007) lists the age at 50% maturity for EBS Pacific cod at a value of 4.88 years.

Thompson (2017) lists the instantaneous per annum natural mortality rate M at a value of 0.359. According to the AFSC Age and Growth Program database, the maximum age observed for Pacific cod (out of a total sample size of 25,904 fish) is 17 years (http://www.afsc.noaa.gov/REFM/Age/Stats/max_age.htm).

Management units and status

Although the resource in the combined EBS and AI (BSAI) region had been managed as a single unit from 1977 through 2013, separate harvest specifications have been set for the two areas since the 2014 season, based largely on genetic evidence of differentiation between the two areas (Spies 2012).

Thompson (2017) projected the ratio of 2018 spawning biomass to the B_{MSY} proxy ($B_{35\%}$) at a value of 1.28. The stock is neither overfished nor being subjected to overfishing.

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