

Supplementary Material 5. Species Narratives

The species narratives present species specific results from the climate vulnerability assessment that allows for more in depth consideration of each species climate sensitivities and exposures, the identification of gaps in existing data, and potential climate adaptive management and community actions. Species narratives may also serve as the basis for future research. The interpretation of the climate sensitivity and exposure scores is aided by the attribute definitions in the supplemental information. Note that descriptions that refer to inverse scores refer to the difference between the total possible score of 5 and the actual mean score for a given climate sensitivity or exposure.

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Coastal Pelagic Species

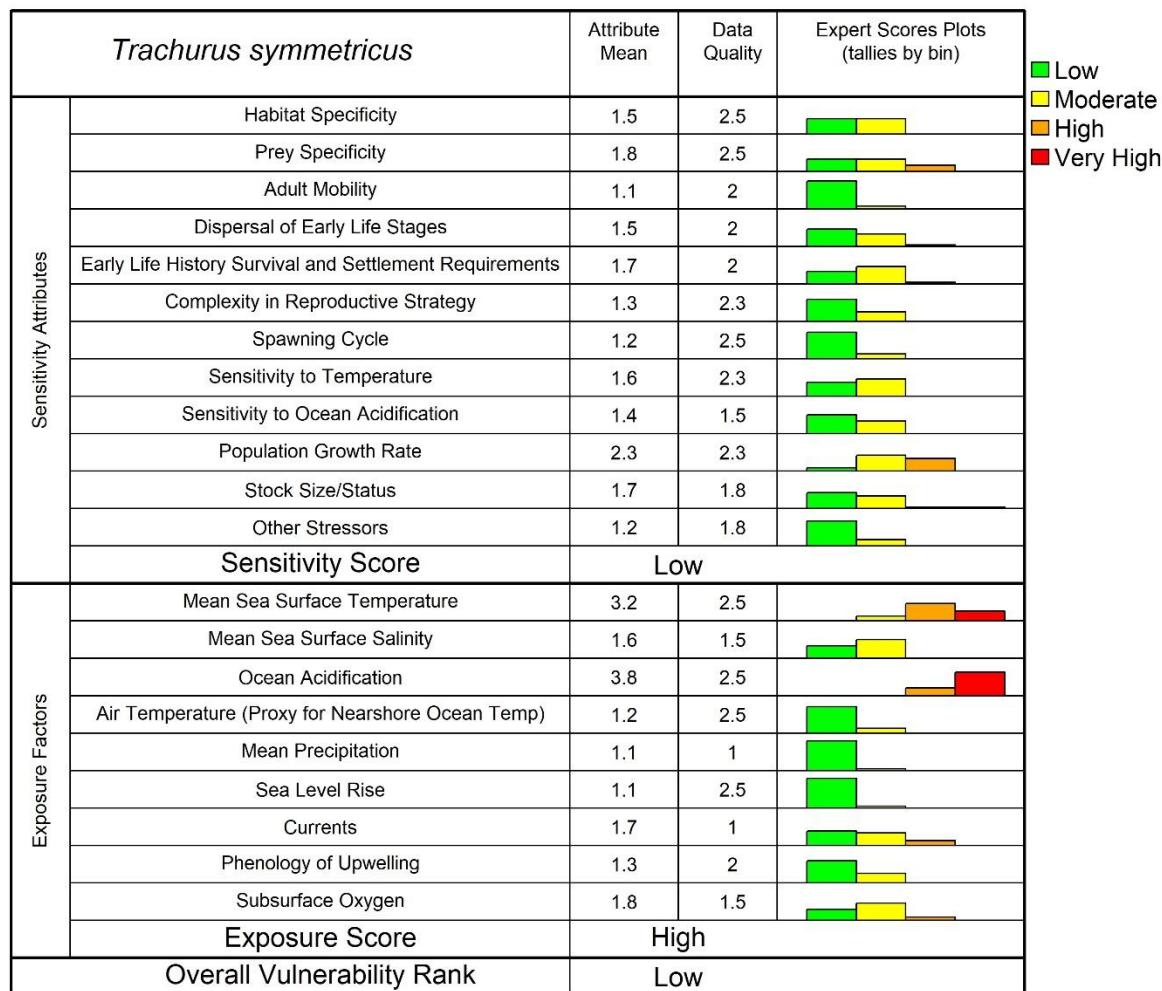
Jack Mackerel (*Trachurus symmetricus*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 67% of scores ≥ 2



Life History Synopsis

Jack mackerel juveniles are found over shallow bottoms and rocky outcrops at depths of 0-100 m. In contrast, adults are highly mobile and found throughout much of the northeast Pacific Ocean in deeper, colder water, further offshore (MacCall 1980; Nebenzahl 1997). Jack mackerel ranges from Baja California north to the Gulf of Alaska

and forages up to 1,000 miles offshore (Ahlstrom and Ball 1954; Neave and Hanavan 1960; MacCall and Stauffer 1983).

Diets include calcifying prey that may be susceptible to ocean acidification, but also fish such as myctophids. Adults eat small crustaceans found in the upper layers of the ocean (euphausiids, large copepods, and pteropods). Larger adults also feed upon juvenile squid, anchovies, and lantern fish (Fitch 1956).

Jack mackerel is a productive pelagic fish, though notably its maximum age (30) suggests the species is slightly less productive than some coastal pelagic fish. Evidence for high productivity includes early age at maturity (1-3), intermediate natural mortality rates (possibly 0.23-0.45), and a protracted spawning season during which adults can spawn up to 36 times (Theilacker 1986; Macewicz and Hunter 1993).

Climate Effects on Abundance and Distribution

Few studies have investigated climate effects on jack mackerel. In general, temperature and oceanographic conditions are expected to drive future distributions of jack mackerel in a manner similar to that of other coastal pelagic species and some highly migratory species. However, specific data on impacts to this species are not available. Jack mackerel eggs occur most frequently in waters of 14-16°C, and this narrow range suggests sensitivity of the population to future changes in sea surface temperature.

There is no direct evidence of vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items of jack mackerel do include crustaceous zooplankton that could be impacted by ocean acidification, but the direction and impact of this effect remains highly uncertain.

Climate Vulnerability Rankings

Overall vulnerability was ranked ***low*** for jack mackerel, with 100% certainty from bootstrap analysis, even though its climate exposure was ranked ***high***. This high ranking resulted from the *mean sea surface temperature* exposure score (3.2) for this mobile pelagic fish. In addition, strong expected changes in pH led to an exposure score of 3.8 for *ocean acidification*. Exposure to other attributes were scored low to moderate.

Overall biological sensitivity was ranked ***low***, with most tallies falling either in low or moderate bins. *Population growth rate* sensitivity was scored slightly higher, at 2.3 (which is still categorized as low), due to the 30-year lifespan of this fish. In general, sensitivity was primarily thought of in terms of climate effects on water temperature, spatial distribution, and larval temperature requirements.

Distributional vulnerability and directional effect

Three attributes contributed to a *very high* distributional vulnerability rank, with a high likelihood of distribution shifts resulting from high inverse sensitivity scores for *adult mobility* (3.9), *dispersal of early life stages* (3.5), and *habitat specificity* (3.5). Overall, the directional effect of climate change on jack mackerel was ranked *neutral* (0.0), primarily resulting from impacts to water temperature, spatial distribution, and larval dispersal.

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Jacksmelt (*Atherinopsis californiensis*)

Overall Vulnerability Rank = Low

Habitat Sensitivity = Low

Climate Exposure = High

Data Quality = 57% of scores ≥ 2

<i>Atherinopsis californiensis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	2.5	
	Prey Specificity	1.5	1.8	
	Adult Mobility	1.5	2.3	
	Dispersal of Early Life Stages	1.8	2.3	
	Early Life History Survival and Settlement Requirements	1.8	2.3	
	Complexity in Reproductive Strategy	1.5	2.3	
	Spawning Cycle	1.4	2.5	
	Sensitivity to Temperature	2.2	2	
	Sensitivity to Ocean Acidification	1.5	1.8	
	Population Growth Rate	1.6	1.8	
	Stock Size/Status	2	1	
	Other Stressors	1.5	1.8	
	Sensitivity Score	Low		
Exposure Factors	Mean Sea Surface Temperature	3.5	2.3	
	Mean Sea Surface Salinity	1.6	1.3	
	Ocean Acidification	3.8	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.4	2.5	
	Mean Precipitation	1.4	1	
	Sea Level Rise	1.1	2.3	
	Currents	1.7	1	
	Phenology of Upwelling	2.1	2	
	Subsurface Oxygen	1.9	1.3	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Jacksmelt is a fast-growing, short-lived, coastal pelagic species distributed from Santa Maria Bay, Baja California (Mexico) north to Yaquina Bay, Oregon (Miller and Lea 1972; Eschmeyer et al. 1983). Maximum observed size approximates 445 mm, and the species may live 9-11 years (Clark 1929; Miller and Lea 1971; Baxter 1974). On average, jacksmelt may grow 90 mm in length during the first 2 years (Clark 1929).

Jacksmelt utilizes shallow habitats in estuaries and bays, kelp canopy, and sandy beaches (Gregory 1992). Juveniles and adults primarily school in nearshore waters at depths of 1.5-15 m, although they can be found at depths of up to 29 m (Baxter 1974; DeLéon 1999). Consequently, few fish are collected in midwater trawls during the *Daily Egg Production Method* surveys, which mostly operate in offshore waters deeper than 50 m. During 2013-2016, fish sampled by *Daily Egg Production Method* surveys measured 240-320 mm fork length. They were caught in salinities ranging 33.3-33.9 ppt and sea surface temperatures between 11.8 and 12.9°C.

Adults reach sexual maturity at 2-3 years (> 140 mm) and migrate into bays and estuaries to spawn. Jacksmelt uses estuaries and bays as primary spawning and nursery grounds (Baxter 1974; DeLéon 1999). Off California, spawning occurs from October to March, peaking in winter (Clark 1929; Ganssle 1966; Middaugh et al. 1990). Jacksmelt is a batch spawner and spawns more than once during the breeding season (Clark 1929). Eggs are laid close to submerged vegetation and hydroids, forming large clusters by attaching their filament to these substrates (Frey 1971; DeLéon 1999; Wang 2010).

Eggs may hatch within 7 days in salinities as low as 5 ppt and at temperatures of 10-12°C (Middaugh et al. 1990). However, in suboptimal conditions, egg stage duration can last 19 days (Caillet 2000). Larvae are distributed in the surface waters of estuaries and nearshore habitats. During CalCOFI cruises from 1964 to 2015, 95% of larvae collected in bongo nets were captured in either winter or spring, suggesting little spawning occurs in summer and fall.

Larvae feed on copepods, diatoms and bivalve veligers in southern California (Watson and Davis 1989). Although temperature and salinity tolerances are not well specified, Middaugh et al. (1990) determined that jacksmelt larvae may achieve optimal growth at salinities between 10 and 20 ppt. Juveniles and adults are believed to be omnivores (Boothe 1967; Baxter 1974; Ruagh 1976; Horn et al. 2006) but feed mostly on gammarid amphipods, detritus, and algae (Barry et al. 1996; Horn et al. 2006).

Jacksmelt is a non-target species infrequently caught by the coastal pelagic fishery off California. However, it is an important recreational species, with major contributions to the pier and shore angler catch (Gregory 1992; CDFW 2013). The stock is not under federal management, and has not been assessed by NOAA Fisheries. In 2010, the Pacific Fishery Management Council added jacksmelt to the *Ecosystem Component* category of its coastal pelagic species management plan (SAFE 2020).

Climate Effects on Abundance and Distribution

No studies have examined the effects of climate change on jacksmelt, and temperature and salinity tolerances are not well specified for this species. However, Middaugh et al. (1990) reported that larvae achieved optimal survival rates at salinities of

10 ppt and highest growth rates between 10 and 20 ppt (Middaugh et al. 1990). Trends in ocean warming that lead to *sea level rise* will in turn affect the distribution and size of estuaries. Increasing temperature may also force jacksmelt to occupy upstream habitats in estuaries.

There is no direct evidence of jacksmelt vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items of jacksmelt do include crustaceous zooplankton that could be impacted by ocean acidification. Although the direction and impact of this effect remains highly uncertain, productivity may be indirectly affected by decreased abundance of crustaceans negatively affected by ocean acidification.

Climate Vulnerability Rankings

For jacksmelt, overall climate vulnerability was ranked ***low***, with 100% certainty from bootstrap analysis. Nevertheless, two attributes contributed to a ***high*** rank for climate exposure: *mean sea surface temperature* (3.5) and *ocean acidification* (3.8). Exposure to these two factors occurred during all life stages.

Nine sensitivity attributes contributed to the ***low*** ranking for jacksmelt biological sensitivity: *adult mobility* (1.5), *complexity in reproductive strategy* (1.5), *dispersal of early life stages* (1.8), *habitat specificity* (1.8), *population growth rate* (1.6), *prey specificity* (1.5), *ocean acidification* (1.5), *spawning cycle* (1.4), and *other stressors* (1.5). Little was known about the fluctuation of jacksmelt abundance because the population has not been assessed. Hence, interactions between jacksmelt and its food web were not well understood, nor were the effects of environmental conditions on its life history traits.

Distributional vulnerability and directional effect

Jacksmelt is an estuarine-dependent species (Yoklavitch et al. 1991), and three attributes contributed to its ***high*** rank for vulnerability to distributional shift: inverse scores for *habitat specificity* (3.2) *dispersal of early life stage* (3.2), and *adult mobility* (3.5) were high or very high. Jacksmelt larvae are pelagic and distributed from inshore to open waters (Wang 2010). At nearshore CalCOFI stations, larvae are most abundant in winter and spring, and both juveniles and adults are highly mobile.

The overall directional effect of climate change on jacksmelt was ranked ***neutral*** (-0.31). Productivity may increase with increasing temperature because the species has adapted to a wide range of salinities (5-34 ppt). Adult distribution may be affected by nearshore stressors, leading to an increase in estuary residence times.

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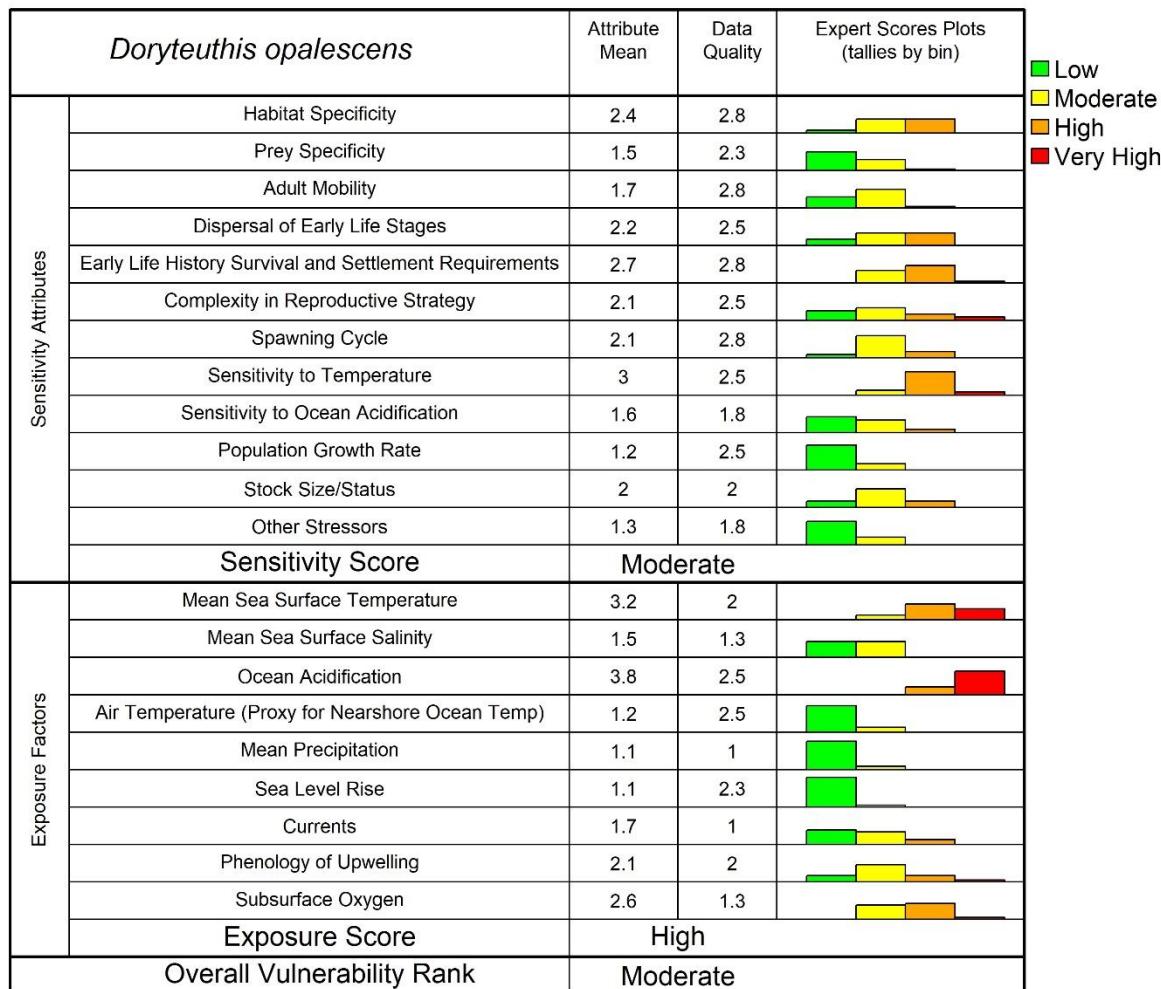
Market Squid (*Doryteuthis opalescens*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2



Life History Synopsis

Market squid is a fast-growing, short-lived, coastal pelagic species distributed from Baja California, Mexico, north to British Columbia, Canada (Hixon 1983, Field 1965). This species occurs in a wide range of temperatures (9-23°C), depending on life stage, but is most productive in waters offshore from California (Macewicz et al. 2004, Dorval et al. 2013, Ralston et al. 2018). Market squid is semelparous and may live less

than one year, although most individuals recruit to the fishery at about six months of age (Butler et al. 1999). Daily natural mortality rates may vary from 0.01 in juveniles to 0.45 in adults (Macewicz et al. 2004; Maxwell et al. 2005, Dorval et al. 2013).

Upon maturity, market squid moves from deep waters (Ralston et al. 2015) to shallow nearshore habitats where adults aggregate for about 2 weeks before spawning (Maxwell et al. 2005, Perretti et al. 2015). Spawning females lay gelatinous egg capsules (200-300 eggs) for 2-3 d and then die, presumably owing to high-energy expenditures (Hixon 1983, Macewicz et al. 2004, Foote et al. 2006).

Ninety seven percent of egg capsules are laid on sandy bottom and about 2% on low-relief hard substrate (Zeidberg et al. 2012). Thus, most spawning aggregations are concentrated in Southern California and Monterey Bay, where sandy bottoms are more common. Egg capsules are deposited at depths of 20-93 m in Southern California and 13-61 m in Monterey Bay. Egg densities are typically greater in habitats at depths of 20-70 m and water temperatures of ~10-12°C (Zeidberg et al. 2012).

Two seasonal spawning peaks of market squid have been identified in coastal waters off California: a minor peak during spring (April-May) in Monterey Bay and a major peak during fall-to-winter in Southern California (Reiss et al. 2004, Dorval et al. 2013). Market squid paralarvae, planktonic stages, hatch within 43-74 days of egg capsule deposition, depending on water temperature (Zeidberg et al. 2011). In waters of low pH and low oxygen, the duration of embryonic development may be extended by up to one week (Navarro et al. 2016).

After hatching, paralarvae enter the water column as plankton, but are retained in nearshore areas (1-3 km; close to the Channel Islands) by tidally reversing currents. Neritic currents further from shore may also play a role in dispersing older paralarvae within the Southern California Bight (Zeidberg and Hamner 2002).

Paralarvae depend on upwelling to fuel zooplankton blooms and to maintain cool water temperatures in nearshore habitats. Consequently, during warm and low-nutrient events such as El Niño, paralarval abundance typically collapses off California (Reiss et al. 2004, Koslow and Allen 2011, van Noord and Dorval 2017). Older paralarvae (30+ days old) and juveniles move to deeper waters, where they reside to maturity and return to spawn as adults (180 days old on average) in shallow waters.

Market squid feed on crustacea (euphausiid and mysids), which may account for 73% of juvenile diet and 7% of adult diet (Fields 1965). The population exhibits a high level of genetic homogeneity from Canada to Mexico (Reichow and Smith 2001) and is managed as a single stock by the Pacific Fisheries Management Council. The fishery exploits spawning aggregations during the two recruitment peaks, and hence operates in Monterey Bay during spring-summer and in southern California during fall-winter.

Although market squid stocks from these regions are not spatially different, genetically different cohorts have been identified within regions (Cheng 2015). The fishery is currently monitored by the California Department of Fish and Wildlife using weekend closures, marine protected areas, and catch limits. These restrictions are intended to achieve 30% of egg escapement on average (CDFW 2005; Dorval et al. 2013).

Climate Effects on Abundance and Distribution

No studies have directly examined the effects of climate change on market squid. However, market squid exhibit large population fluctuations in relation to the El Niño Southern Oscillation. Little production occurs during El Niño years, but abundance typically rebounds in La Niña years. The collapse in abundance may be consistent along the U.S. Pacific coast in some El Niño years, for example, in 1997-1998 (Reiss et al. 2004). However, in other years, such as the 2015-2016 El Niño, the population may shift northward while declining in southern habitats.

An age-based, temperature-dependent model predicted bimodal recruitment with periods of 5 and 7 months (Reiss et al. 2004). A multi-year projection from this model consistently shows that the broader recruitment period peaked in late winter and was more than twice as long as the summer recruitment.

Moderately significant relationships are found between the Pacific Decadal Oscillation and market squid productivity, but these impacts remain secondary compared to the effects of the El Niño Southern Oscillation on stock abundance (Koslow and Allen 2011). Market squid abundance fluctuates highly with water temperature, causing the population to bust during El Niño years and boom during La Niña years (Reiss et al. 2004; Koslow and Allen 2011; van Noord and Dorval 2017).

Climate Vulnerability Rankings

Overall climate vulnerability for market squid was ranked ***moderate*** with 93% certainty from bootstrap analysis, and with the remaining 7% ranking ***low***. Climate exposure attributes ranked ***high***, with *mean sea surface temperature* (3.2) and *ocean acidification* (3.8) contributing high scores. Exposure to these two factors occurred during all life stages. Biological sensitivity was ranked ***moderate*** overall, with two sensitivity attributes contributing to this score: *early life history survival and settlement requirements* (2.7) and *sensitivity to temperature* (3.0).

Distributional vulnerability and directional effect

Distributional vulnerability was ranked ***moderate*** for market squid. Three attributes were scored as moderate, with only the inverse score for *adult mobility* scoring high (3.3). Embryonic development contributed to a moderate inverse score for *habitat*

specificity (2.7) because egg capsules were mostly deposited on sandy bottom. Newly hatched paralarvae have moderate dispersal capability, producing an inverse score of 2.8 for *early life stage dispersal*. Paralarvae are mostly retained by the currents around islands offshore from California. *Sensitivity to temperature* was moderate at all life stages (3.0).

The directional effect of climate change on market squid was projected to be **negative** (-0.38). Recruitment will likely decrease as temperature increases within the more suitable spawning habitats located off California. Adult distribution may shift northward, but overall stock productivity was expected to decrease coast-wide.

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Northern Anchovy (*Engraulis mordax*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2

<i>Engraulis mordax</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.6	3	 
	Prey Specificity	1.5	2.5	 
	Adult Mobility	1.5	2.8	 
	Dispersal of Early Life Stages	1.6	3	 
	Early Life History Survival and Settlement Requirements	1.9	2.5	  
	Complexity in Reproductive Strategy	1.5	2.5	 
	Spawning Cycle	1.2	2.8	 
	Sensitivity to Temperature	2.8	2.8	 
	Sensitivity to Ocean Acidification	1.7	1.8	 
	Population Growth Rate	1.3	2.5	 
	Stock Size/Status	2.4	2.3	  
	Other Stressors	1.4	1.5	 
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.4	2.3	  
	Mean Sea Surface Salinity	1.3	1.3	 
	Ocean Acidification	3.8	2.5	  
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.2	2.3	 
	Mean Precipitation	1.5	1	  
	Sea Level Rise	1.1	2.3	 
	Currents	1.7	1	  
	Phenology of Upwelling	2.3	2	  
	Subsurface Oxygen	1.9	1.5	  
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Anchovy is a planktivorous, small epipelagic fish with population biomasses that are notoriously variable over time. Anchovy is considered “r-selected,” capable of fast population growth, high fecundity, and high mortality. Age at maturity is 1-2 years (Hunter and Macewicz 1980; Butler 1987), with a maximum lifespan of 7 years (Baxter 1967; Butler 1987), and a natural mortality rate that suggests high productivity (0.6-1.06)

(Methot 1986; Butler 1987). Anchovy, like sardine and other small pelagic fish in the California Current, have fluctuated strongly in abundance over the past 500 to 1700 years (Baumgartner et al. 1992, McClatchie et al. 2017).

Anchovy is a serial spawner, and eggs and larvae are found every month of the year. However, peak spawning occurs in late winter and early spring. Spawning locations are typically in inshore waters over the continental shelf, but may be found further offshore during cold periods or periods of high population biomass. Eggs and larvae are pelagic with developmental rates that are temperature sensitive. Eggs hatch between 1.4 and 4 days after spawning, and larvae have a similar yolk-sac stage duration. Metamorphosis occurs after about 1-3 months. Anchovy feeds on both phytoplankton and zooplankton; although phytoplankton may compose a large portion of the diet by volume, most of the nutritional value in the diet is likely derived from crustaceous zooplankton (Miller et al. 2010).

Stock structure is not well defined, though some have reported two stocks: one ranging from Baja California to Central California and a second ranging from Northern California to British Columbia (MacCall et al. 1983; Parrish et al. 1985; Fielder 1988). Stock status is not currently assessed, but a recent interpretation of ichthyoplankton abundance as sampled by CalCOFI suggests that population size was low (MacCall et al. 2016), though in 2016 and 2017 there were signs of stock recovery (Zwolinski et al. 2017, Dorval et al. 2018).

Climate Effects on Abundance and Distribution

Changes in the distribution of northern anchovy are associated with variability in ENSO, with a distribution closer to the coast during El Niño events and offshore during La Niña events. Additionally, observations indicate that during periods of low biomass, the population tends to retract toward estuaries. The impact of anthropogenic climate change on the distribution is not well known. Despite this sensitivity and observed large-scale variability in populations, the species is considered resilient to change with the ability to recover from periods of anomalous climate conditions (though this recovery may take place over decades).

The net effect of future climate change on northern anchovy is uncertain. Historical observations document a negative relationship between the population biomass and regional temperature (Lindegren et al. 2013). The mechanisms responsible for this relationship are not certain, but the temperature may be a proxy for the strength of wind-driven upwelling (Rykaczewski and Checkley 2008) and the subsequent availability of larger phytoplankton consumed by anchovy. Changes in the supply of new nutrients (either by upwelling or by rivers) may influence population productivity, but future trends in these factors are uncertain.

Checkley et al. (2017) identified vulnerabilities of anchovy to global change,

including potential for poleward shifts, changes in quality of source water (i.e. nutrient concentrations in the California Current), ocean acidification impacts on plankton, and changes in plankton community composition. Poleward shifts are expected for many small pelagic fish under climate change, as modeled by Cheung et al. (2015).

There is no direct evidence of vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items of northern anchovy do include crustaceous zooplankton that could be impacted by ocean acidification, but the direction of this effect and the impact remains highly uncertain.

Climate Vulnerability Rankings

For northern anchovy, overall climate vulnerability was ranked ***low*** with 68% certainty and ***moderate*** with 32% certainty from bootstrap analysis. Climate exposure was ranked ***high***, in part due to the broad distribution of northern anchovy, with its core population in the Southern California Bight and its relative coastal affinity as compared to other coastal pelagic species, as well as spawning typically occurring inshore over the continental shelf. Exposure attributes scored high due to projected changes in *sea surface temperature* (3.4) and *ocean acidification* (3.8) expected throughout the northeastern Pacific.

Overall biological sensitivity was ranked ***low***. The anchovy population was believed to be sensitive to factors associated with changes in temperature (2.8), likely mediated through high impacts on early life-history stages (Fiedler et al. 1986). Effects of temperature on egg distribution were documented by multiple studies, including Reiss et al. (2008) and Weber and McClatchie (2010). Recruitment was highly variable, and survival of larvae to the juvenile stage was believed to be dependent on the availability and vertical distribution of planktonic prey (1.9; Lasker 1975). Northern anchovy has been monitored but no formal assessment has been conducted since 1995 (Jacobson et al. 1995).

Recent interpretation of ichthyoplankton abundance as sampled by CalCOFI suggested population size declined to below 20,000 mt during 2009-2011 (*stock size/status* score of 2.4; MacCall et al. 2016). However, a Daily Egg Production Method survey conducted in spring 2017 found that productivity of the Central Stock of northern anchovy has since rebounded, with female spawning stock biomass estimated to be within the range of 171,689 mt (CV=0.35) to 238,877 (CV=0.69), depending on the method used (Dorval et al. 2018).

Distributional vulnerability and directional effect

Adult northern anchovy was considered ***high*** in vulnerability to distributional shift based on inverse scores for *adult mobility* (3.5) and *habitat specificity* (3.4). As

broadcast spawners with planktonic durations on the order of several weeks to about two months (Lo 1983; Butler et al. 1993), sensitivity of the population to *dispersal of early life stages* was considered high (3.4). However, the population had an inverse score for *sensitivity to temperature* of 2.2. Predicted directional effect on northern anchovy was *neutral* (-0.19).

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Pacific Chub Mackerel (*Scomber japonicus*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2

<i>Scomber japonicus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.3	2.5	 
	Prey Specificity	1.5	2.3	 
	Adult Mobility	1.2	2.5	 
	Dispersal of Early Life Stages	2	2.8	  
	Early Life History Survival and Settlement Requirements	1.9	2.3	  
	Complexity in Reproductive Strategy	1.2	2	 
	Spawning Cycle	1.4	2.5	 
	Sensitivity to Temperature	2.2	2.3	  
	Sensitivity to Ocean Acidification	1.4	1.8	 
	Population Growth Rate	1.4	2.3	 
	Stock Size/Status	1.3	2.3	 
	Other Stressors	1.3	1.5	 
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.4	2.5	  
	Mean Sea Surface Salinity	1.6	1.5	 
	Ocean Acidification	3.8	2.5	  
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.2	2.5	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1.1	2.5	
	Currents	1.7	1	  
	Phenology of Upwelling	1.4	2	 
	Subsurface Oxygen	1.7	1.8	  
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Pacific chub mackerel is a broadly distributed and highly mobile pelagic species, ranging from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California. This species is common from Monterey Bay, California, to Cabo San Lucas, Baja California, but is most abundant south of Point Conception, California. Adults are highly mobile, occupying more northern habitats (up to British Columbia) in

summer to fall, and southern habitats in winter to spring (Southern California to Baja California). Adults undergo large seasonal feeding and spawning migrations along the North American Pacific coast. Pacific chub mackerel usually occurs within 30 km of shore, but has been captured as far as 400 km offshore (Crone et al. 2006, 2009). Egg and larval duration is relatively short, approximately 3 weeks, ranging from 33 h at 23°C to 117 h at 14°C (Hunter and Kimbrell 1980).

Pacific chub mackerel is a fast-growing, highly fecund, and short-lived species. Individuals may live up to 14 years, although most commercially caught fish are less than 4 years old. The species realizes 50% of its total growth in length by 1.5 years, when growth slows down, adding a few cm per year up to a maximum length of 39 cm by age 6-8 (Crone and Hill 2015).

Pacific chub mackerel is a batch spawner and matures by age 1-3 years. Females spawn up to 8 times per year, producing batches of 68,000 eggs on average (Dickerson et al. 1992). Eggs and larvae are pelagic, and larval distribution is associated with oceanic currents, e.g. geostrophic flow (Matsuura and Hewitt 1994; Weber and McClatchie 2011). Egg and larval stage durations depend on temperature (Hunter and Kimbrell 1980).

Pacific chub mackerel spawns over a broad geographic range, from Point Conception to Cabo San Lucas and from 3 to over 300 km offshore (Moser et al. 1993). The spawning season is prolonged, with peaks during March–October in the Southern California Bight, during late fall to early spring off Cabo San Lucas, and year-round off central Baja California (Fritzsche 1978; Moser et al. 1993; Crone et al. 2011).

Stock biomass was assessed at 120,435 t in 2015, higher than in the early 2000s but substantially lower than the high abundances of over 1 million t in the early 1980s (Crone and Hill 2015). However, analysis of mackerel scale deposition (Soutar and Isaacs 1974) in the Santa Barbara Basin showed that periods of high abundance, such as during the 1930s and 1980s, are relatively rare events that may be expected to occur on a 60-year cycle (MacCall et al. 1985). Hence, like many other coastal pelagic species, Pacific chub mackerel stock productivity appears to fluctuate with large-scale environmental factors. Natural mortality ranges 0.3-0.5 (Parish and MacCall 1978), but was assumed to be 0.5 in the last full stock assessment, given current productivity of the stock (Crone and Hill 2015).

Climate Effects on Abundance and Distribution

Temperature and oceanographic conditions are expected to drive future distributions of Pacific chub mackerel, similar to other pelagic fish species. There is some evidence that abundance of larvae is correlated with physical habitat and prey fields such as geostrophic flow (Matsuura and Hewitt 1994; Weber and McClatchie 2011), zooplankton displacement volume, and temperature (Weber and McClatchie 2011) in the

California Current, but the exact mechanisms are unknown.

There is no direct evidence of vulnerability to ocean acidification for Pacific chub mackerel. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). This species may be sensitive to ocean acidification, since its diet includes calcifying prey; however, the diet also includes a broad range of non-calcifying prey. Adult Pacific chub mackerel feed on small fish, fish larvae, squid, and pelagic crustaceans, such as euphausiids (Clemmens and Wilby 1961; Turner and Sexsmith 1967; Fitch 1969; Fitch and Lavenberg 1971; Frey 1971; Hart 1973; Collette and Nauen 1983). Thus, the direction and impact of this effect remain highly uncertain.

Climate Vulnerability Rankings

Overall vulnerability was ranked **low** for Pacific chub mackerel, with 100% certainty from bootstrap analysis, even though its climate exposure was ranked **high**. Two attributes contributed to the **high** exposure score: *mean sea surface temperature* (3.4) and *ocean acidification* (3.8). Exposure to these two factors occurs during all life stages. Strong expected changes in pH led to a score of **very high** for *ocean acidification*. Exposure to other attributes was low to moderate.

Biological sensitivity was ranked **low** for Pacific chub mackerel, with nine sensitivity attributes contributing to this score: *adult mobility* (1.2), *complexity in reproductive strategy* (1.2), *habitat specificity* (1.3), *population growth rate* (1.4), *prey specificity* (1.5), *ocean acidification* (1.4), *spawning cycle* (1.4), and *other stressors* (1.3). *Sensitivity to temperature* was still low but slightly higher (2.2), followed by *dispersal of early life stages* (2.0) and *early life history survival and settlement requirements* (1.9).

Distributional vulnerability and directional effect

Two attributes contributed to the **high** predicted vulnerability to distributional shift for Pacific chub mackerel: **very high** inverse scores for *adult mobility* (3.8) and *habitat specificity* (3.7). The inverse score for *dispersal of early life stages* was also **high** (3.0). The predicted directional effect of climate change on Pacific chub mackerel was **neutral** (-0.25). Distribution of the spawning stock may generally shift northward in spring, summer and fall, but stock productivity is likely to be moderately affected.

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Pacific Herring (*Clupea pallasii*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2

<i>Clupea pallasii</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	2.5	
	Prey Specificity	1.5	2.5	
	Adult Mobility	1.6	2.8	
	Dispersal of Early Life Stages	2.5	2.5	
	Early Life History Survival and Settlement Requirements	2.6	2.3	
	Complexity in Reproductive Strategy	2.6	2.8	
	Spawning Cycle	2.3	2.5	
	Sensitivity to Temperature	1.8	2.5	
	Sensitivity to Ocean Acidification	1.7	1.8	
	Population Growth Rate	1.6	1.5	
	Stock Size/Status	1.5	2	
	Other Stressors	2.6	2.5	
	Sensitivity Score	Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.2	2.3	
	Mean Sea Surface Salinity	1.4	1.3	
	Ocean Acidification	3.8	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.4	2.3	
	Mean Precipitation	1.9	1	
	Sea Level Rise	1.7	2.3	
	Currents	1.7	1	
	Phenology of Upwelling	2.1	2	
	Subsurface Oxygen	1.8	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Pacific herring is a small schooling species that ranges from Baja California to Alaska in the North Pacific (CDFW 2015, Stick and Lindquist 2009, Barnhart 1988, Beacham et al. 2008, Hay et al. 2001, Miller and Schmidtke 1956). This forage fish is a pelagic, highly mobile species that utilizes nearshore waters for feeding and growth and then migrates into bays/estuaries for spawning (Barnhart 1988, Stick and Lindquist 2009,

CDFW 2015).

Reduced salinity and temperatures above 6°C may cue spawning (Hay and Kronlund 1987, Griffin et al. 1998, Haegele and Schweigert 1985). California populations spawn from October to April with a peak in January and February, while Washington populations spawn from February to March (Spratt 1981, Haegele and Schweigert 1985, Barnhart 1988). Adults move from the open ocean into the bays and estuaries around 2-3 weeks before spawning (Barnhart 1988, Stick and Lindquist 2009, CDFW 2015).

They form large spawning aggregations for one week and spawn adhesive demersal eggs onto marine vegetation or rocky intertidal substrates in calm and protected waters (Brown et al. 1996, McGurk and Brown 1996, Norcross et al. 1996, Griffin et al. 1998, Carls et al. 2002). After spawning, Pacific herring leave the spawning grounds immediately and return to the ocean coastal zone (Barnhart 1988, Stick and Lindquist 2009, CDFW 2015).

Optimal egg development occurs at salinities of 8-24 ppt (Brown et al. 1996, McGurk and Brown 1996, Norcross et al. 1996, Griffin et al. 1998, Carls et al. 2002). Eggs hatch after 10-24 d, depending on water temperature, and the planktonic larvae are retained in bays and estuaries for their 10-12 week larval duration (Brown et al. 1996, CDFW 2015). Larval survival does depend on salinity and temperature: large larval dispersion has occurred with temperatures around 10°C and salinities around 28 ppt (CDFW 2015, Stick and Lindquist 2009, Barnhart 1988, Alderdice and Houston 1985).

Juveniles also utilize bays/estuaries and coastal waters, where adult spawning occurs. In bays and estuaries, juveniles feed on molluscan larvae and other zooplankton (Barnhart 1988; Haegele 1997, Stick and Lindquist 2009, CDFW 2015). Adults reach sexual maturity at 2-3 years and typically live 7-9 years (Stick and Lindquist 2009, CDFW 2015). Adults are found in nearshore ocean waters where their principal prey item is macrozooplankters, such as copepods and euphausiids (Haegele 1997).

Stock size and status is undetermined, but there is a herring roe and limited commercial herring fishery in San Francisco. There are large fluctuations in the herring population, likely due to environmental conditions (Ware 1985, Small et al. 2005, O'Connell et al. 1998). Other potential stressors include suspended sediment pollution from dredge operations, oil spills, and run-off into bays/estuaries (Brown et al. 1996, Carls et al. 2002, McGurk and Brown 1996, Norcross et al. 1996, CDFW 2015). Additionally, Pacific herring is affected by diseases, which have occasionally caused local massive mortalities (Stick and Lindquist 2009).

Climate Effects on Abundance and Distribution

No studies have examined the effect of climate change on the Pacific herring. However, there are dramatic fluctuations in herring populations due to climatic regime

shifts (Benson and Trites 2002). A mechanistic model demonstrates that Pacific herring growth across the Pacific is controlled by water temperature and zooplankton availability (Ito et al. 2015). In California, Pacific herring growth appears to be directly associated with zooplankton abundance. After the 1976-1977 regime shift, zooplankton abundance decreased with increasing water temperature. As a result, herring growth and abundance decreased in the eastern North Pacific.

The reverse trend is found in northern latitudes: in Sitka Sound, herring responded positively to warming temperatures; increased temperatures led to earlier spawning so larvae had a better chance of encountering a phytoplankton bloom (Benson and Trites 2002). Therefore, Pacific herring may do best in intermediate temperatures.

There is no direct evidence of vulnerability to ocean acidification for Pacific herring; however, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items of Pacific herring do include crustaceous zooplankton that could be impacted by ocean acidification, but the direction of this effect and the impact remains highly uncertain.

Climate Vulnerability Rankings

Overall vulnerability was ranked ***moderate*** for Pacific herring, with 97% certainty from bootstrap analysis. Two attributes contributed to a ***high*** score for climate exposure: *mean sea surface temperature* (3.2) and *ocean acidification* (3.8). Biological sensitivity was scored ***moderate***, with three sensitivity attributes contributing to this score: *early life history survival and settlement requirements* (2.6), *complexity in reproductive strategy* (2.6), and *other stressors* (2.6).

Distributional vulnerability and directional effect

Predicted vulnerability to distributional shift was ***high*** for Pacific herring. Two inverse scores contributed to this ranking: *adult mobility* (3.4) and *habitat specificity* (3.0). Directional effect of climate change on Pacific herring was projected to be ***negative*** (-0.56) based on the relative complexity of its spawning strategy in estuaries and bays, which are affected by nearshore stressors and sea level rise. Herring growth and abundance may also be negatively affected by sensitivity to temperature (Ito et al. 2015).

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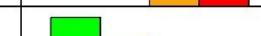
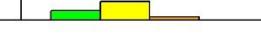
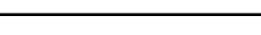
Pacific Sardine (*Sardinops sagax*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Sardinops sagax</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.6	3	
	Prey Specificity	1.4	2.5	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	1.7	3	
	Early Life History Survival and Settlement Requirements	1.8	2.5	
	Complexity in Reproductive Strategy	1.4	2.3	
	Spawning Cycle	1.3	3	
	Sensitivity to Temperature	2.5	2.8	
	Sensitivity to Ocean Acidification	1.4	1.5	
	Population Growth Rate	1.4	2.8	
	Stock Size/Status	3.1	2.5	
	Other Stressors	1.2	2	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.4	2.5	
	Mean Sea Surface Salinity	1.7	1.5	
	Ocean Acidification	3.8	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.2	2.5	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1.1	2.5	
	Currents	1.7	1	
	Phenology of Upwelling	2.1	2	
	Subsurface Oxygen	1.8	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Sardine is a relatively fecund, short-lived, epipelagic, species, with few individuals older than 10 years of age. Sardine is an r-selected species with early age at maturity (0.5-1.5 years). Like anchovy and other small pelagic fish in the California Current, sardine has fluctuated strongly in abundance over the past 500 to 1700 years (Baumgartner et al. 1992, McClatchie et al. 2017).

The northern subpopulation of Pacific sardine ranges from northern Baja California, Mexico (30°N) to southeastern Alaska (57°N) in waters from the continental shelf to several 100 km offshore (Hill et al. 2017). Female ovarian development is fully initiated above 12°C , and optimal spawning occurs at sea surface temperatures of $12\text{-}15^{\circ}\text{C}$ (Hill et al. 2017; Lo et al. 2011; Demer et al. 2012; Clark and Janssen 1945; Janssen 1938). Spawning begins in January off northern Baja California and ends by late fall off the Pacific Northwest (Oregon, Washington, Vancouver Islands). The peak of the spawning season is generally March to April off central and southern California, and while spawning off the Pacific Northwest may occur, the intensity is highly variable.

Eggs and larvae are pelagic. At $13\text{-}16^{\circ}\text{C}$, duration of egg development to hatching is 2-3 d, at which larvae of 2-3 mm have unpigmented eggs, unformed mouth, and a large yolk-sac. Larval duration is another 30-80 d.

Survival of eggs and larvae are dependent on the availability of planktonic food, and these prey items may provide productive conditions and increase survivorship (Logerwell and Smith 2001). Adults are highly mobile, and individuals greater than about 20 cm in length may undergo seasonal migrations from springtime spawning areas in Southern California to summertime feeding areas in the Northern California Current (Lo et al. 2010).

Climate Effects on Abundance and Distribution

Changes in the distribution of sardine are associated with variability in the El Niño-Southern Oscillation, with distribution closer to the coast during El Niño events and further offshore during La Niña events. During periods of low biomass in the 1960s-1980s, observations indicate that the population retracted toward the southern California Bight (MacCall 1990). However, in recent years (2015-2017) the spawning stock was mostly concentrated off northern California and Oregon (Dorval et al. 2017).

The impact of anthropogenic climate change on the distribution of Pacific sardine is not well known. Historical observations document a positive relationship between the population biomass and regional temperature (Lindegren et al. 2013), but the mechanisms responsible for this relationship are not well understood. Changes in the supply of new nutrients (either by coastal or curl-driven upwelling) may influence population productivity, but future trends in these factors are uncertain (Checkley et al. 2017).

There is no direct evidence of vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items do include crustaceous zooplankton that could be impacted by ocean acidification, but the direction and impact of this effect remains highly uncertain.

Climate Vulnerability Rankings

For Pacific sardine, overall climate vulnerability was ranked **low** with 54% certainty and **moderate** with 46% certainty from bootstrap analysis. Climate exposure was ranked **high** due to projected changes in *mean sea-surface temperature* (3.4) and *ocean acidification* (3.8) that are expected throughout the northeastern Pacific. The distribution of Pacific sardine was broad, ranging from northern Baja California, Mexico to southeastern Alaska. Pacific sardine had a coastal affinity relative to other coastal pelagic species, with spawning occurring both nearshore and offshore.

Biological sensitivity was ranked **low** for Pacific sardine although sardine biomass was low relative to the historical population size, contributing to a **high** score in sensitivity to *stock size/status* (3.1). In 2016, a full stock assessment suggested that the population spawning stock biomass remained at about 10% of the size documented only 9 years ago (Hill et al. 2016).

Distributional vulnerability and directional effect

Projected vulnerability to distributional shift was ranked **high** for Pacific sardine. Sardine had a **very high** inverse score for *adult mobility* (3.8) and a high inverse score for *habitat specificity* (3.4), due to low reliance on a specific type of habitat (Hill et al. 2017; Lo et al. 2011; Demer et al. 2012; Clark and Janssen 1945; Janssen 1938). As broadcast spawners with planktonic durations on the order of several weeks to nearly 3 months (Silliman 1943; Emmett et al. 2005; Lo et al. 2010; Weber et al. 2015), the inverse score for sensitivity of the population to change in larval distribution from *dispersal of early life stages* was **high** (3.3). The combination of these factors suggested **high** potential for a distributional shift. The forecast net directional effect of future climate change on sardine was **neutral** (-0.13).

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Elasmobranchs

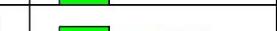
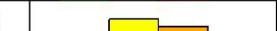
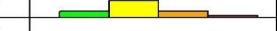
Leopard Shark (*Triakis semifasciata*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 62% of scores ≥ 2

<i>Triakis semifasciata</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	2.8	
	Prey Specificity	1.2	2.8	
	Adult Mobility	1.6	2.8	
	Dispersal of Early Life Stages	1.6	2.5	
	Early Life History Survival and Settlement Requirements	1	2.8	
	Complexity in Reproductive Strategy	1.7	2.8	
	Spawning Cycle	2.5	2.5	
	Sensitivity to Temperature	1.7	2.3	
	Sensitivity to Ocean Acidification	1.1	2	
	Population Growth Rate	3.7	2.8	
	Stock Size/Status	2.1	0	
	Other Stressors	1.7	1.8	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.6	1.8	
	Mean Sea Surface Salinity	1.3	1	
	Ocean Acidification	4	2.3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1.8	2.3	
	Currents	2.1	1.5	
	Phenology of Upwelling	2.1	1.3	
	Subsurface Oxygen	2.3	1.3	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Leopard shark (*Triakis semifasciata*) is widely distributed in a broad range of habitats from Samish Bay, Washington, to Mazatlán, Mexico. Adults generally occupy benthic habitats of kelp beds, open sand, and mud flats in shallow bays and estuaries, but also venture into midwater and nearshore regions (kelp forests) ranging 1-156 m in depth (Compagno 1984; Ebert 2003; Love 2011). Adult leopard sharks occur in temperatures as low as 7°C, and temperatures of 10-12°C trigger entrance to and eventual departure

from bays and estuaries (Love 2011). Adult females in California have restricted home ranges (typically 0.1-1.0 km²), with total distances traveled of about 10-45 km/day (Carlisle and Starr 2009; Nosal et al. 2013). Juveniles occur in shallow, inshore regions such as bays, sloughs, and tidal creeks often in association with sandy or muddy flats, cobble bottoms, rocky reefs, eelgrass beds, and kelp beds (Compagno 1984).

There is some evidence for seasonal movements as advanced juveniles and adults enter embayments and inshore waters in spring and remain throughout fall, then retreat to deeper waters with some individuals remaining inshore year-round (Carlisle and Starr, 2009, 2010). These inshore regions and embayments are used for both feeding and reproductive activity such as mating and rearing.

Leopard shark group mating consists of small aggregations (10 or less) and female aggregating behavior reduces the frequency of polyandry compared to non-aggregating females (Nosal et al. 2013; Smith 2005). The location of female aggregations is affected by temperature, where aggregations occur in shallow, warm thermal refuges during the day (Hight and Lowe 2007). This behavior results in elevated core body temperatures that likely enhance pup development.

Leopard sharks typically feed in benthic and demersal habitats, although they are found throughout the water column, especially at night (Love 2011), and diet varies with size. Adults eat a wide variety of prey items including fishes, fish eggs, echinoids, crabs, ghost shrimp, clam siphons, polychaetes, squid, octopi, eelgrass, and algae (Ebert and Ebert 2005; Love 2011). Small juveniles feed heavily on crabs, whereas larger juveniles eat a wide variety of other prey items including echinid worms, sculpin, atherinids and their eggs, sardines, and surf perches (Love 2011; Talent 1976; Barry et al. 1996; Ebert 2003).

Leopard shark populations have not been assessed, but some studies suggest an increase in population size following the closure of the nearshore net fisheries in California waters (Pondella and Allen 2008). Recent mass mortality events in San Francisco Bay may have depressed population sizes in central and northern California. Predators include marine mammals and other sharks. There is currently no commercial fishing for leopard sharks, but poaching occurs. Inshore waters that are important for shark feeding and reproductive purposes are susceptible to environmental change and degradation. For instance, most of the wetlands in California and Mexico have been severely degraded or destroyed, and estuarine habitats have been highly modified.

Climate Effects on Abundance and Distribution

No studies examine the effect of climate factors on population abundance or distribution of Leopard sharks. Given their distribution in warm temperate and subtropical waters, it is likely that the thermal habitat will shift to the north (Love 2011).

Changes in food web dynamics associated with climate change (e.g. less coastal productivity, Guinder and Molinero 2014) could significantly affect leopard shark populations, especially during early life stages, when foraging occurs largely in shallow inshore habitats. While there is no direct evidence of leopard shark vulnerability to ocean acidification, acidification affects odor tracking and foraging behavior of some sharks (Dixon et al. 2015; Rosa et al. 2014).

Although there is no stock assessment for leopard sharks, there is concern about the impact of nearshore net fisheries on the population prior to their ban in the early 1990s. Some suggest an increase in the population (Pondella and Allen 2008). Concerns about spawning cycle center on internal fertilization and the need for warm nearshore habitat for gestating females (Hight and Lowe 2007; Nosal et al. 2013).

Climate Vulnerability Rankings

Overall vulnerability for leopard shark was ranked ***low*** with 58% certainty and ***moderate*** with 42% certainty from bootstrap analysis, although climate exposure was ranked ***high***. Two exposure attributes contributed to a high exposure score: *ocean surface temperature* (3.6), and *ocean acidification* (4.0). Changes in temperature may be even higher in estuarine areas (common habitat for juvenile leopard sharks) than model results indicated for coastal habitats.

Although of lower magnitude, there was some concern about the potential impacts of changing *currents* (2.1), the *phenology of upwelling* (2.1) and *subsurface oxygen* (2.3). These exposure attributes were linked to the distributional patterns of the leopard shark, which spends its entire life in near-shore waters, where these processes are likely to have the greatest impact (Compagno 1984; Love 2011; Ebert 2003; Carlisle and Starr 2009; Nosal et al. 2013).

Biological sensitivity was ranked ***low*** for the leopard shark, as the only attribute score above 2.5 was *population growth rate* (3.7). All attributes used to characterize population growth rates were conservative when compared with most other species, including maximum growth rate (0.067), von Bertalanffy k ($0.04\text{-}0.16 \text{ yr}^{-1}$), age at maturity (7-10 years), maximum age (26+ years) and natural mortality ($0.14\text{-}0.28 \text{ yr}^{-1}$) (Cailliet 1992; Kusher et al. 1992; Smith 2001; Smith and Abramson 1990). *Stock size/status* (2.1) and *spawning cycle* (2.5) were elevated compared to other sensitivity attributes.

Distributional vulnerability and directional effect

Inverse scores of three attributes indicated ***high*** vulnerability to change in distribution for leopard shark: *adult mobility* (3.4), *dispersal of early life stages* (3.4), and *habitat specificity* (3.3). While restricted to the shallow waters of the inner shelf, leopard shark has a relatively high potential for movement across life history stages, and

is found over a broad region and range of habitats (Nosal et al. 2013; Compagno 1984; Love 2011; Ebert 2003; Carlisle and Starr 2009; 2010).

A combination of factors related to climate change will likely reduce productivity in the California Current. This expected reduction in productivity led to a projected **negative** directional effect (-0.44) of climate change on leopard shark populations (Ainsworth et al. 2011; Donly et al. 2012; Guinder and Molinero 2014). The core of leopard shark populations may shift north as a warming temperature, declining oxygen and pH make southern estuaries less habitable.

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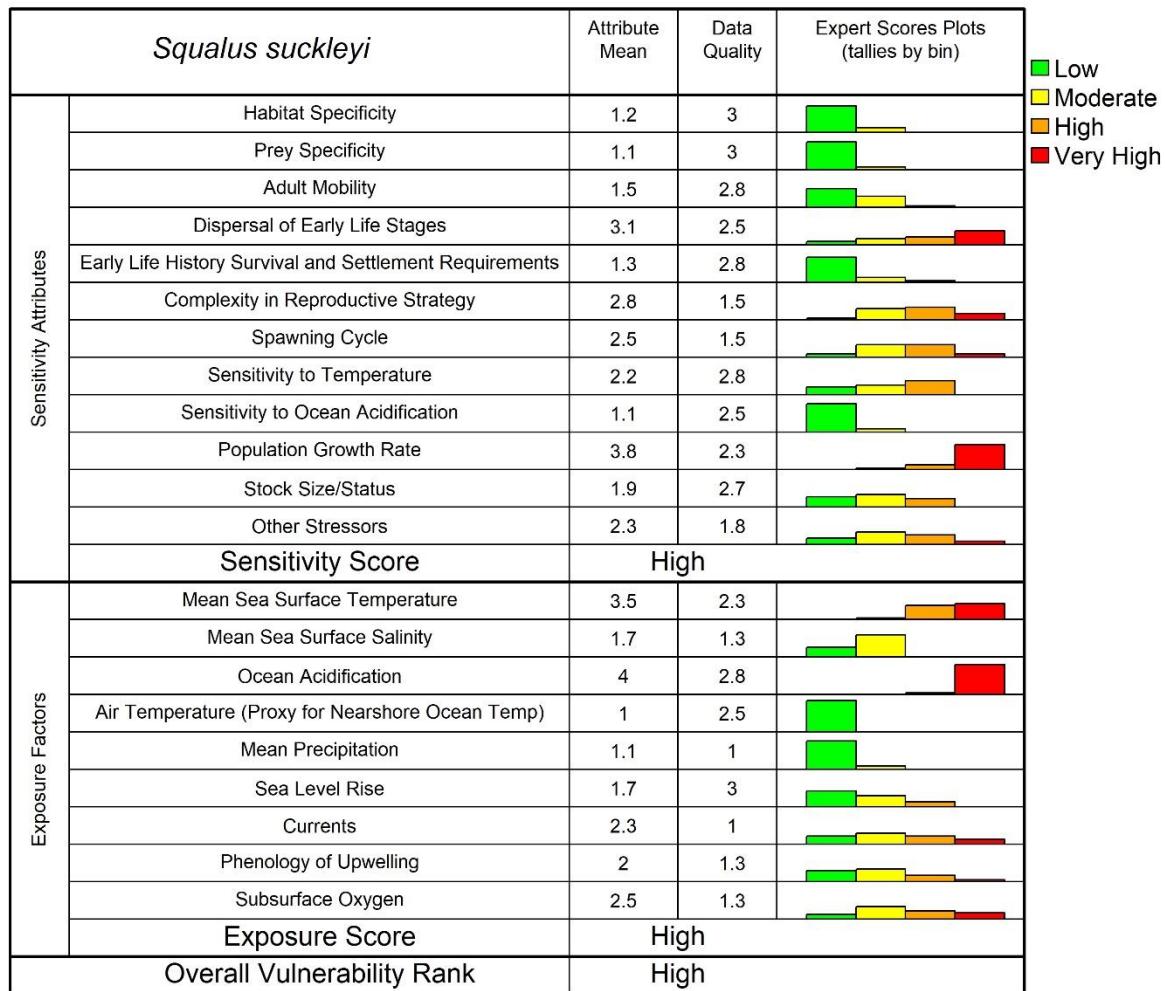
Pacific Spiny Dogfish (*Squalus suckleyi*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 62% of scores ≥ 2



Life History Synopsis

Pacific spiny dogfish (*Squalus suckleyi*) is a small-to-medium sized cartilaginous fish generally found from inshore areas to offshore depths of at least 1200 m (Ebert 2003). The species can reach 100 cm in length (Gertseva and Taylor 2012); with maximum age estimated to be between 71 and 90 years (Taylor et al. 2013).

While frequently observed as solitary individuals, spiny dogfish also form large localized schools of hundreds if not thousands of individuals that are often sex- and size-specific (Ebert 2003; Taylor et al. 2013). There is some separation of habitat use by age, with younger individuals concentrating in pelagic waters and moving to demersal habitats when mature (Beamish and Sweeting 2009). However, exposure to changing climate occurs during all life stages. This shark appears to prefer water temperatures in the 5-15°C range, and often makes latitudinal and depth migrations to follow this temperature gradient (Brodeur et al. 2009; McFarlane and King 2003). There is also evidence of seasonal movement along the coast (Ketchen 1986). One estimate of the seasonal movement along the Pacific coast is a North-South shift of about 600 km from winter to summer (Taylor 2008).

Spiny dogfish have internal fertilization and ovoviparous development. This species is long lived and extremely late maturing, with 50% female maturity reported at 35.5 years (Saunders and McFarlane 1993; Taylor 2008). Internal development in spiny dogfish takes place over 22-24 months, the longest gestation period known for sharks. The number of pups in each litter ranges between 5 and 15 individuals depending on the size of the female, with larger females bearing more pups (Campana et al. 2009; Di Giacomo et al. 2009; Tribuzio et al. 2009). Size at birth is generally 20-30 cm for both sexes. Male spiny dogfish grow faster than females, but females reach larger sizes.

This species is an opportunistic feeder that consumes a wide range of prey. Schooling pelagic fish, such as herring, make up the majority of its diet. Spiny dogfish also feed on invertebrates such as shrimp, crab and squid. In turn, spiny dogfish are preyed upon by large cod, hake and other spiny dogfish. Large-bodied shark species, seals, and killer whales also consume dogfish (Beamish et al. 1992; Brodeur et al. 2009).

Climate Effects on Abundance and Distribution

Taylor and Gallucci (2009) compared demographic parameters of Pacific spiny dogfish in the Northeast Pacific between the 1940s and 2000s. They reported a significant change in growth, decline in age at 50% maturity, and increased average number of embryos per litter for a 100-cm dogfish. It is estimated that these changes could lead to an increase in population growth rate of about 1%. Although changes in parameters are primarily attributed to fishing pressure on this species, changes in climate could have also contributed to the aggregated result.

Little is known about the effects of ocean acidification on sharks and other cartilaginous fish. However, recent studies suggest that ocean acidification may have effects on growth and aerobic potential, as well as behavior of sharks, including hunting and prey detection (Rosa et al. 2017).

Spiny dogfish is a migratory shark species with a broad latitudinal distribution, from the Gulf of Alaska to southern Baja California (Ebert 2003). This suggests that

spiny dogfish are able to utilize a range of habitats in the marine environment and shift distribution in response to climate change.

Climate Vulnerability Rankings

Overall vulnerability to climate change of Pacific spiny dogfish was ranked **high** with 66% certainty and **moderate** with 34% certainty from bootstrap analysis. Climate exposure was ranked **high**, with two exposure factors contributing heavily to this score: *mean sea surface temperature* (3.5) and *ocean acidification* (4.0). Biological sensitivity was ranked **high**, with four sensitivity attributes contributing heavily to this score: *population growth rate* (3.8), *dispersal of early life stages* (3.1), *complexity in reproductive strategy* (2.8) and *spawning cycle* (2.5).

Distributional vulnerability and directional effect

Two attributes indicated a **high** likelihood of a change in distribution for Pacific spiny dogfish: **very high** inverse scores for *adult mobility* (3.5) and *habitat specificity* (3.8). For Pacific spiny dogfish shark, the directional effect of climate change was predicted to be **neutral** (-0.25). This prediction reflected the capacity of this species to redistribute to preferred environmental conditions via the long-distance movement and broad depth range of adults.

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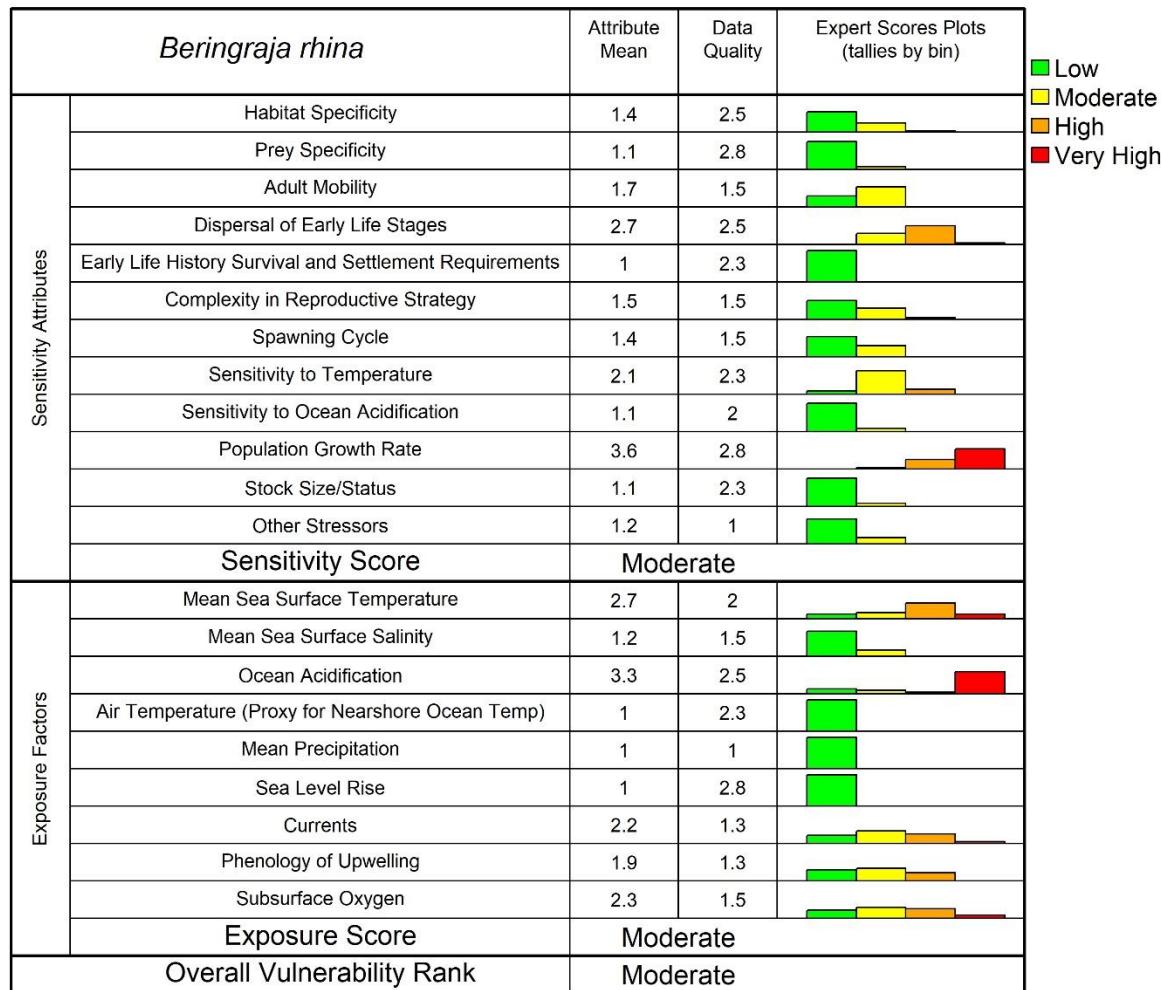
Longnose Skate (*Beringraja rhina*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = Moderate 

Data Quality = 57% of scores ≥ 2



Life History Synopsis

Longnose skate is a coastal species primarily found south of the Alaskan Peninsula; however, the species ranges from the Southeastern Bering Sea to Punta San Juanico (southern Baja California, Mexico) and into the Gulf of California (Love 2011). Juveniles and adults are solitary and demersal, found most commonly on low-relief, mixed rock, and soft-sediment seafloor habitats across a broad depth range (9-1,294 m),

though most commonly at depths of 50-200 m (Love 2011). Most life stages occur primarily in association with mixed (rock in a soft sediment matrix), and to a lesser degree, completely soft sediment (sand, mud) habitats. Occasional occurrence in association with high-relief rock has been documented (Bizzarro et al. 2014).

Longnose skates live in waters that range 2.0-12.3°C but have a preferred temperature range of 5.2-10.0°C (Love 2011; Bizzarro 2015). Movement patterns of longnose skates are not well documented. This is one of the largest skate species in the eastern North Pacific, reaching a maximum total length of 189 cm (Department of Fisheries and Oceans Canada, unpubl. data).

Longnose skates mature late, with few females maturing by 5 years and most by 14 years, but some remaining immature at 20 years. Off British Columbia, Canada, maximum age is estimated at 26 years and age of 50% maturity at 9 years for males and 13 years for females (McFarlane and King 2006). Along the U.S. Pacific Coast, length at 50% maturity is estimated at 120 cm TL for females (Gertseva and Schirripa 2008). In the Gulf of Alaska, total length at 50% maturity is estimated at 102.9 cm for males, and 113.1 cm for females (McFarlane and King 2006; Ebert et al. 2008).

Females likely produce relatively few offspring per year, although their fecundity has not been adequately measured. Offspring hatch from egg cases deposited on the seafloor (Ebert et al. 2008; Gertseva and Schirripa 2008; Love 2011). Egg cases are found in dense aggregations, such as on rocky outcrops at 130 m in Southern California (Love et al. 2008). Gastropod predation on skate egg cases can reach up to 40% on some nursery grounds (Love et al. 2008).

Longnose skate is a trophic generalist, with pronounced differences in diet composition and predatory role between populations in central California and the Gulf of Alaska (Robinson et al. 2007; Bizzarro 2015). In both regions, juveniles feed mainly on crustaceans, especially shrimp. However, the contribution of fish to juvenile diets is far greater off California, and cephalopods are a supplemental dietary component in this region. In the Gulf of Alaska, crabs are of secondary importance and cephalopods are trivial diet components. In Alaska, longnose skate feed heavily on tanner crab, but are broad generalists, consuming the most common and abundant local species including fishes, various crabs and shrimps, squid, and octopus (Robinson et al. 2007; Love 2011; Bizzarro 2015).

Longnose skate is actively managed under the Pacific Coast Groundfish Fishery Management Plan. The initial stock assessment suffered from a problematic catch reconstruction, so resulting population estimates are considered unreliable (Gertseva and Schirripa 2008). A new assessment was conducted during the 2019 stock assessment cycle.

Climate Effects on Abundance and Distribution

No studies directly examine the effect of climate factors on population productivity, abundance or distribution of longnose skate. Longnose skate has a preferred temperature range of 5.2-10.0°C. As oceans warm, their distributions may shift northward. It is also possible that they will seek temperature refugia in deeper waters.

Climate Vulnerability Rankings

Overall climate vulnerability was ranked **moderate** with 82% and **low** with 18% certainty from bootstrap analysis. Overall climate exposure was ranked **moderate**. Primary drivers of exposure included scores for *mean sea surface temperature* (2.7) and *ocean acidification* (3.3). Juvenile and adult stages of this demersal nearshore species are exposed to projected increases in both these attributes. Biological sensitivity was also ranked **moderate** for Longnose skate. Primary drivers of sensitivity included *dispersal of early life stages* (2.7) and *population growth rate* (3.6). Females are oviparous and produce relatively few young each year, hence the low rate of population growth.

Distributional vulnerability and directional effect

A **high** likelihood of distributional shift was projected for Longnose skate, reflecting high inverse scores for adult mobility (3.3) and habitat specificity (3.6). Directional effect of climate change was predicted to be **neutral** for longnose skate on the U.S. Pacific Coast Shelf (-0.31). This ranking reflected the capacity of this species to redistribute to preferred environmental conditions via the long-distance movement and broad depth range of adults.

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Groundfish Species

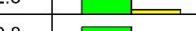
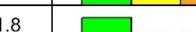
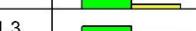
Arrowtooth Flounder (*Atheresthes stomias*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = Moderate 

Data Quality = 67% of scores ≥ 2

<i>Atheresthes stomias</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.2	2.8	 (Legend: Low = green, Moderate = yellow, High = orange, Very High = red)
	Prey Specificity	1.2	2.8	
	Adult Mobility	1.9	2	
	Dispersal of Early Life Stages	1.2	1.8	
	Early Life History Survival and Settlement Requirements	2	1	
	Complexity in Reproductive Strategy	1.5	2	
	Spawning Cycle	1.7	2.5	
	Sensitivity to Temperature	1.7	2.8	
	Sensitivity to Ocean Acidification	1.3	2	
	Population Growth Rate	2.9	2.8	
	Stock Size/Status	1.2	2.3	
	Other Stressors	1.4	1.3	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3	2.5	
	Mean Sea Surface Salinity	1.3	1.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1	2.8	
	Currents	2	1	
	Phenology of Upwelling	1.7	2	
	Subsurface Oxygen	2.3	1.8	
	Exposure Score	Moderate		
Overall Vulnerability Rank		Low		

Life History Synopsis

Arrowtooth flounder is a batch spawning species (Rickey 1995), utilizing waters of at least 200 m in depth during fall through early spring (Zimmerman and Goddard, 1996). Throughout its range, spawning adults have been observed during almost all months of the year: during March and from May to September (Hirshberger and Smith

1983), as well as during January to February in the Gulf of Alaska (Blood et al. 2007); in December off the coast of Washington (Rickey 1995); and from September to March in the Bering Sea (Pertzeva 1961).

Whether there are temperature effects on reproduction is not known, but it is possible that temperature plays a role. Blood et al. (2007) hypothesized that males migrate to shallower water and females move to deeper water to meet for spawning from 400-500 m depth. The temperature range for spawning adults is 4.3-5.4°C (Blood et al. 2007). Additional observations have identified the optimal temperature range for adults at 3-4°C (Zimmerman and Goddard 1996).

Larvae settle to the bottom after 1-4 months in the water column during late winter and early spring (Fargo and Starr 2001). Juvenile arrowtooth flounder are typically found in waters less than 200 m in depth, on sand or sandy gravel substrate (NOAA 1990). Larvae eat crustaceous zooplankton (Brodeur et al. 1995), and juveniles and adults feed on euphausiids and other crustaceans, worms, and fish (Hart 1973; Love 1996). Diet studies of Oregon and Washington arrowtooth flounder found an assortment of hake, unidentified gadids, herring, mesopelagics, rex sole, slender sole and other small flatfish, pandalid shrimp and euphausiids (Buckley et al. 1999). There is some evidence that diet composition varies seasonally based on the changing availability of suitable prey items (Smith 1991).

Adults are found in the same regions as late juveniles, and are abundant from Northern California through the Bering Sea at depths ranging 5-800 m (Kaplan and Hesler 2007). Adult arrowtooth flounder are associated with soft sediment substrate (Demory et al. 1976). They exhibit a strong migration from shallow-water feeding grounds on the continental shelf in summer to deep-water spawning grounds over the continental slope (NOAA 1990). Dark and Wilkins (1994) noted a tendency for Arrowtooth flounder to move into deeper waters with increasing age.

Climate Effects on Abundance and Distribution

Arrowtooth flounder occurs in temperatures of 0-9°C, with optimal temperatures hypothesized at 3-4°C (Zimmerman and Goddard 1996). The species is found from approximately 37 to 60°N latitude. Given the wide range of environmental conditions under which Arrowtooth thrive, the high availability of preferred substrate, and its ability to switch between prey types, concern for the population under climate change is relatively low. Some evidence supports an inverse relationship between the cold pool in the Bering Sea and the distribution of arrowtooth flounder (Spencer et al. in press), but this positive relationship between summertime temperature and distributional area may not be generalizable to the entire distribution along the West Coast.

There is no direct evidence of vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al.

2012, Munday et al. 2009). Prey items of arrowtooth flounder do include crustaceous zooplankton that could be impacted by ocean acidification, but the direction and impact of this effect remains highly uncertain.

Climate Vulnerability Rankings

Overall climate vulnerability was ranked **low** with 100% certainty from bootstrap analysis. Given the wide distribution of arrowtooth flounder and the magnitude of projected changes in climate and ecosystem properties, the species had a **moderate** exposure to future climate change. This rating was due primarily to exposure to *ocean acidification* (4.0) and *sea surface temperature* (3.0), which are both expected to show significant change throughout the northeastern Pacific.

Arrowtooth flounder had **low** biological sensitivity to climate attributes. The species is a generalist predator found in non-specific sandy or gravel habitats (Rickey 1995; Zimmerman and Goddard 1996; Fargo and Starr 2001). Of the sensitivity attributes considered, *population growth rate* was the only one scored in the moderate range (2.9), as the species has a relatively late age at maturity (>7 years; Stark 2012).

Distributional vulnerability and directional effect

For arrowtooth flounder, the potential for distributional change was influenced by a high inverse score for *dispersal of early life stages* (3.8). Arrowtooth flounder is a broadcast spawner, with larval planktonic durations of several months (Bouwens et al. 1999). Inverse scores for *adult mobility* (3.1) and *habitat specificity* (3.8) were also considered relatively high, as this species uses a variety of habitat types (Demory et al. 1976; Kaplan and Hesler 2007). The combination of these attributes suggested that potential for distributional shift was **high**. The predicted directional effect of climate change on arrowtooth flounder was **positive** (0.38).

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Aurora Rockfish (*Sebastes aurora*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 52% of scores ≥ 2

<i>Sebastes aurora</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.1	3	 
	Prey Specificity	1.4	2	 
	Adult Mobility	2.6	1	 
	Dispersal of Early Life Stages	1.3	1.5	 
	Early Life History Survival and Settlement Requirements	2.8	1	  
	Complexity in Reproductive Strategy	2.8	1	  
	Spawning Cycle	2.2	2.8	 
	Sensitivity to Temperature	2.2	2.5	  
	Sensitivity to Ocean Acidification	1.9	2	  
	Population Growth Rate	4	2.8	
	Stock Size/Status	1.5	2.5	  
	Other Stressors	1.3	1	 
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.4	2.8	 
	Mean Sea Surface Salinity	1.6	1.3	 
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1	1	
	Sea Level Rise	1	3	
	Currents	2.2	1	   
	Phenology of Upwelling	2.2	1	  
	Subsurface Oxygen	3.2	1.3	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Aurora rockfish occur from Queen Charlotte Islands (British Columbia, Canada) south to mid-Baja California (Mexico) and probably farther south. They are common across their range, but are most abundant in the area around Point Conception, California. Love (2011) summarized the life history of aurora rockfish. Like most rockfishes (*Sebastes*), aurora rockfish is long-lived, with a lifespan of up to 125 years (Hamel et al.

2013). These benthic fish have internal fertilization, allowing the female to incubate the tiny embryos until larvae can actively swim. Although females with developed embryos have been observed from March to June, larvae have been encountered throughout the year, with the highest densities of larvae from January to June. Thompson and Hannah (2010) reported the age at 50% maturity for female aurora rockfish at 12.6 years. Aurora rockfish exhibit both spatially varying and sexually dimorphic growth, with asymptotic size and size at age decreasing with latitude, and with females achieving a larger size than males (Thompson and Hannah 2010).

Aurora rockfish co-occurs with other groundfish targeted in commercial fisheries such as Dover sole, sablefish, and hake; aurora is the most numerous as bycatch in the splitnose rockfish fishery (Thompson and Hannah 2010). Aurora rockfish feeds on crustaceans and small fishes and is prey for fish, marine mammals, squid, and birds (Love 2011). Aurora rockfish is commonly caught from central California to Oregon, although it remains a largely non-targeted member of the slope rockfish fishery.

Climate Effects on Abundance and Distribution

Climate effects on aurora rockfish are not well studied. However, aurora rockfish will probably not be affected by changes in ocean temperatures during the next 40-50 years due to occurrence on the continental slope. Changes in abundance are likely to be small, depending on change in ocean productivity and transport. Survival, transport and settlement of young rockfishes are generally influenced by the timing of parturition and localized oceanographic features. These include relaxed upwelling and onshore transport, as well as change in temperature.

In the early life-history stages, pelagic rockfish are thought to be sensitive to physical conditions. Hypotheses include advection towards and availability of food sources, as well as eddies and gyres that maintain retention and concentrate food (Moser and Boehlert 1991; Ralston and Howard 1996; Field and Ralston 2005). Size and age of pelagic juveniles can also influence the timing of active onshore movement and settlement.

Climate Vulnerability Rankings

For aurora rockfish, overall climate vulnerability was ranked ***moderate*** with 86% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***, with four attributes contributing to this high score: *sea surface temperature* (3.4), *ocean acidification* (4.0), *subsurface oxygen* (3.2), and *currents* (2.2).

Biological sensitivity was ***moderate***, with both low and high attributes contributing to this rank. Aurora rockfish are long-lived with high fecundity, so have considerable potential for *population growth rate* (4.0), assuming good recruitment and the absence of heavy fishing. *Early life history survival and settlement requirements* and

complexity in reproductive strategy were also scored high (2.8). Environmental conditions influence the spawning success and survival of larvae and juvenile rockfish, including aurora rockfish. These life-stages are likely affected by zooplankton abundance, variability in water temperature and currents, distribution of prey and predators, and strength and phenology of upwelling. *Habitat specificity* was low (1.1); benthic adults are found on mixed hard and soft bottoms. They have a broad depth range (81-893 m), but are typically found deeper than many other rockfish species (>260 m). *Prey specificity* (1.4), *dispersal of early life stages* (1.3), and *other stressors* (1.3) were all scored low.

Distributional vulnerability and directional effect

Potential change in aurora rockfish distribution was ranked **high** based on a high inverse score for *habitat specificity* (3.9) and a moderate inverse score for *adult mobility* (2.4). Overall directional effect of climate change on aurora rockfish was predicted to be **negative** (-0.44).

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Black Rockfish (*Sebastes melanops*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 62% of scores ≥ 2

<i>Sebastes melanops</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	3	  
	Prey Specificity	1.2	2.8	 
	Adult Mobility	2.2	3	  
	Dispersal of Early Life Stages	1.4	2	 
	Early Life History Survival and Settlement Requirements	3.1	1.3	  
	Complexity in Reproductive Strategy	2.9	1.5	  
	Spawning Cycle	2.3	2.8	 
	Sensitivity to Temperature	2.7	2.8	 
	Sensitivity to Ocean Acidification	1.8	2.5	  
	Population Growth Rate	3.4	2.9	  
	Stock Size/Status	2.3	2.3	   
	Other Stressors	1.6	1	 
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.5	2.5	 
	Mean Sea Surface Salinity	1.6	1	 
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	 
	Mean Precipitation	1.1	1	 
	Sea Level Rise	1.2	3	 
	Currents	2.2	1	   
	Phenology of Upwelling	2.2	1	  
	Subsurface Oxygen	2.4	1.3	   
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Black rockfish spawn timing is consistent from Alaska through California. Fertilized eggs are found from August to January, peaking around January in California. Spawning females are present from January through May, with peaks identified from January through April (Dunn & Hitz 1969; Hart 1973; Wyllie Echeverria 1987; O'Connell 1987; Stein & Hassler 1989; Houk 1992; Reilly et al. 1994; Lea et al. 1999;

Love et al. 2002). Larvae and juveniles inhabit the pelagic environment for at least 2 months, and settle into nearshore areas at sizes of 30-50 mm (Moser 1996; Krigsman 2000). Young black rockfish show some ontogenetic shifts to deeper waters with increasing age, though they remain a relatively nearshore, midwater schooling species (Love et al. 2002).

Black rockfish mature at 5-8 years of age and can live to over 50 years (Cope et al. 2015), though older individuals tend to be males. An interesting phenomenon, also seen in canary and yellowtail rockfishes, is that females are rarely caught once they age into the 20s; this lack of older females sampled in the fishery samples remains a mystery. Black rockfish research also demonstrates older individuals produce more robust offspring (Bobko and Berkeley 2004; Berkeley et al. 2004; Sogard et al. 2008).

Climate Effects on Abundance and Distribution

Black rockfish is highly associated with nearshore kelp forests and rocky reefs (Pearcy and Myers 1974; Dewees and Gotshall 1974; Gascon and Miller 1981; Rosenthal et al. 1982; Gascon and Miller 1982; Grossman 1982; Anderson 1983; Carr 1983; Boehlert and Yoklavich 1984; Yoshiyama et al. 1986; Stein and Hassler 1989; Love et al. 1991; Moser and Boehlert 1991; Carr 1991; Ventresca et al. 1996; Bloeser 1999; Calliet et al. 2000; Love et al. 2002; Love 2011). Given that kelp forest habitats can fluctuate as the environment changes (Bodkin 1986; Bodkin 1988; Krumhansl et al. 2016), black rockfish may be displaced under circumstances where kelp forests are reduced, potentially if temperatures in nearshore waters become too warm to support them.

Early life history stages of black rockfish are also generally thought to be susceptible to changes in the environment. Rockfish larval pelagic stages are believed to be sensitive to physical conditions, with hypotheses to this sensitivity including advection to and availability of food sources, as well as eddies and gyres that retain and concentrate food (Moser and Boehlert 1991; Ralston and Howard 1996; Field and Ralston 2005).

Zooplankton make up a large portion of the diet during early life stages, so anything affecting zooplankton distribution and abundance would in turn affect black rockfish larval and pelagic juvenile dynamics. Growth may also be affected by sensitivity to temperature, particularly in California, as optimal temperature for newly settled juveniles was identified at 18°C (Boehlert 1981; Boehlert and Yoklavich 1983).

Climate Vulnerability Rankings

Overall climate vulnerability was ranked ***high*** with 79% certainty and ***moderate*** with 21% certainty from bootstrap analysis. Overall climate exposure ranked ***high***, with two exposure attributes contributing to this score: high *mean sea surface temperature* (3.5) and very high *ocean acidification* (4.0). These two factors had consistent scoring, with all values in the *high* to *very high* bins. For overall biological sensitivity, four

attribute scores contributed to a **high** rank: high *population growth rate* (3.4) and *early life history requirements* (3.1) and moderate *complexity in reproductive strategy* (2.9) and *sensitivity to temperature* (2.7). Each of these attributes had some uncertainty, as expert scores varied among three scoring bins, however, none had a score in the *low* bin.

Distributional vulnerability and directional effect

Two attributes influenced the **high** rank for black rockfish in vulnerability to distribution shift as a response to climate change: a **very high** inverse score for *dispersal of early life stages* (3.6) and a **high** inverse score for *habitat specificity* (3.3). Directional effect of climate change on black rockfish was expected to be **negative** (-0.56).

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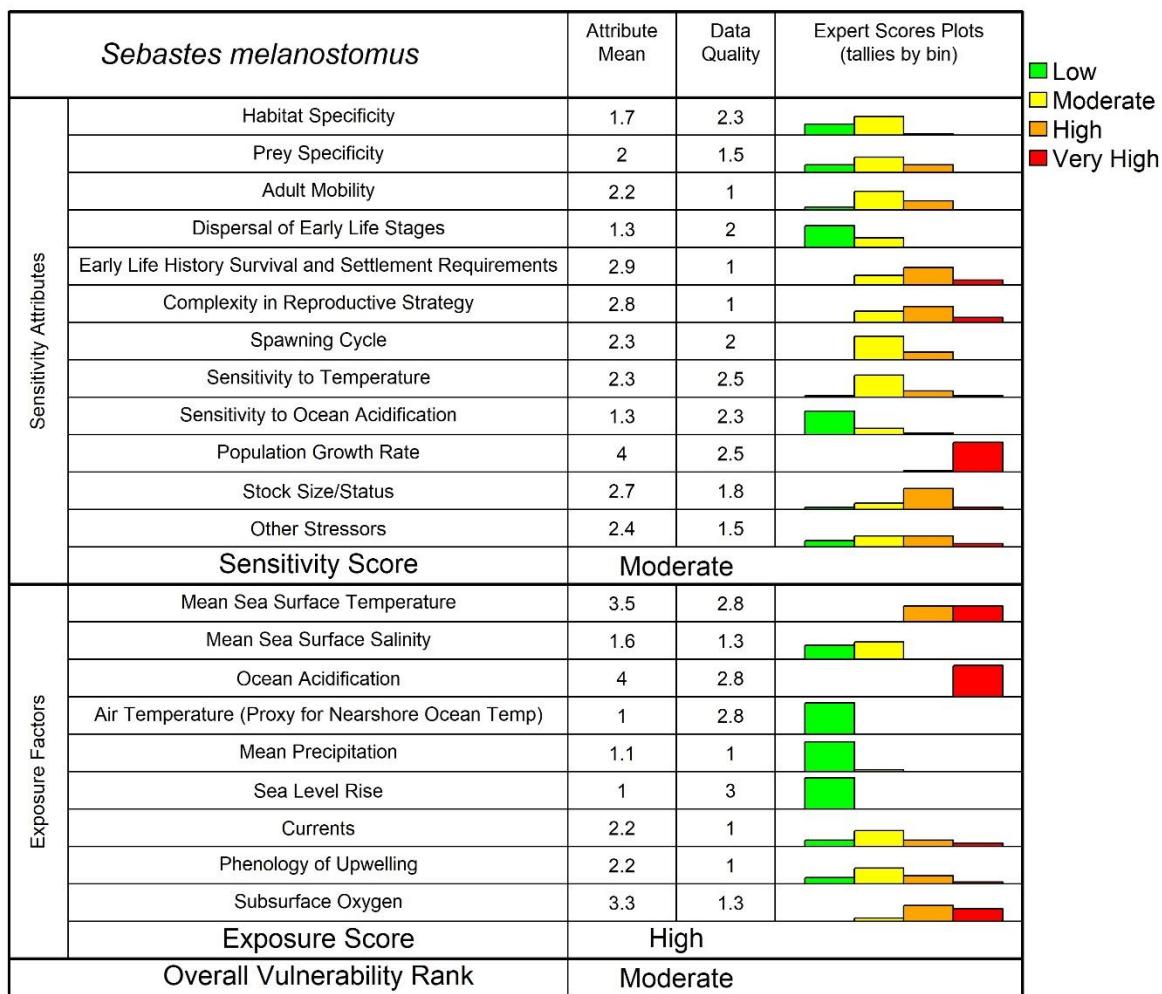
Blackgill Rockfish (*Sebastodes melanostomus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 48% of scores ≥ 2



Life History Synopsis

Blackgill rockfish is long-lived, viviparous, and grows slowly, reaching sexual maturity at around 17 years for males and 21 years for females (Butler et al. 1998; Andrews et al. 2005; Field and Pearson 2011). Females grow slower than males but grow to a larger size. Blackgill rockfish live up to 90 years (Andrews et al. 2005), reproducing once a year (Love et al. 1990). Parturition of live larvae occurs from

December through June in southern California and around February in northern California (Moser and Ahlstrom 1978; Love 2011; Lefebvre and Field 2015). Larval and pelagic juvenile stages are estimated to last 3 to 4 months total, though durations as long as 7 months have been reported (Moser and Ahlstrom 1978; Love et al. 1990). Planktonic larvae may travel on the order of tens to hundreds of kilometers based on ichthyoplankton and juvenile fish distribution (Moser et al. 2001).

Blackgill rockfish occur from Queen Charlotte Islands (British Columbia, Canada) south to mid-Baja California (Mexico), although they typically occur from northern to southern California. The species is not highly mobile, but schools are thought to move, although the extent of movement is poorly understood. Adult blackgill are found on high-relief rocky outcrops at depths of 87-768 m, and are most abundant on the continental slope at 250-600 m. Smaller individuals tend to be encountered at shallower depths than larger individuals. They utilize caves and crevices found on the reefs and may also be encountered midwater above the reefs (Field and Pearson 2011; Love 2011).

Climate Effects on Abundance and Distribution

Survival, transport, and settlement of young rockfishes are influenced by the timing of parturition and localized oceanographic features such as relaxed upwelling and onshore transport, and by characteristics such as changes in temperature. Size and age of pelagic juveniles also could influence the timing of active onshore movement and settlement. Environmental conditions influence the spawning success and survival of larval and juvenile rockfish. These life-stages are likely affected by zooplankton abundance, variability in water temperature and currents, distribution of prey, predators, and strength and phenology of upwelling.

Blackgill reside in deep waters at the edge of the O₂ minimum zone. As the O₂ minimum zone continues to shoal, this species may face habitat loss. Hypoxia has been documented in 37% of deep-water habitats within the depth range that blackgill typically inhabit; hypoxia could extend to up to 55% of deep-water habitat within 15 years if present trends continue (Bograd et al. 2008; McClatchie et al. 2010).

Blackgill is a long-lived species with high fecundity, and thus has considerable potential for population growth in the absence of heavy fishing. Slow adult growth and late maturation increase vulnerability to fishery exploitation, potentially magnifying climate effects at low stock sizes. Blackgill is one of the most deeply-distributed rockfish of any *Sebastodes* species in the California Current region.

Climate Vulnerability Rankings

Overall climate vulnerability was ranked ***moderate*** with 59% certainty, ***high*** with 39% certainty, and ***very high*** with 2% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***, with three attributes contributing to this score: *sea surface*

temperature (3.5), *ocean acidification* (4.0), and *subsurface oxygen* (3.3). Overall biological sensitivity was ranked **moderate**. Both low and high sensitivity attributes contributed to this score. *Early life history survival and settlement requirements* and *complexity in reproductive strategy* scored high (2.9 and 2.8, respectively). *Habitat specificity* was moderate-low (1.7). *Population growth rate* (4.0) was the highest.

Distributional vulnerability and directional effect

Potential for change in blackgill rockfish distribution was ranked **high** as determined by relatively low inverse scores for *habitat specificity* (3.3) and broad *dispersal of early life stages* (3.7). Directional effect of climate change on blackgill was expected to be **negative**, with moderate certainty (-0.44).

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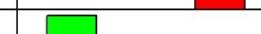
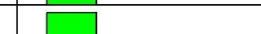
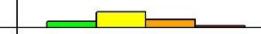
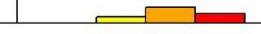
Bocaccio Rockfish (*Sebastodes paucispinis*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 57% of scores ≥ 2

<i>Sebastodes paucispinis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.6	2.3	
	Prey Specificity	1.8	2	
	Adult Mobility	2.2	2	
	Dispersal of Early Life Stages	1.3	1.8	
	Early Life History Survival and Settlement Requirements	2.9	1.3	
	Complexity in Reproductive Strategy	2.9	0.5	
	Spawning Cycle	2.2	2.3	
	Sensitivity to Temperature	2.1	2.5	
	Sensitivity to Ocean Acidification	1.6	2.3	
	Population Growth Rate	2.8	3	
	Stock Size/Status	2.9	2.3	
	Other Stressors	2.1	0.8	
	Sensitivity Score	Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.4	2.8	
	Mean Sea Surface Salinity	1.6	1.3	
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1	3	
	Currents	2.2	1	
	Phenology of Upwelling	2.2	1	
	Subsurface Oxygen	3.1	1.3	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Bocaccio rockfish typically mate during September and October, although some evidence suggests that spawning season varies with latitude. Fertilization is often delayed, and embryonic development takes at least one month to complete, with larvae hatching internally and females releasing larvae during the winter months. Bocaccio is among the rockfishes (*Sebastodes spp.*) that produce multiple broods per year, especially in

the south, where the spawning season may be more protracted (Moser 1967; Wyllie Echeverria 1987; Moser and Boehlert 1991; Beyer 2015). In closely related species, such as chilipepper rockfish, interannual variability in egg production and frequency of multiple broods is likely linked to female condition and oceanographic conditions (Beyer et al. 2015).

Duration of the planktonic larval stage is about 150 d (Moser and Boehlert 1991; Woodbury and Ralston 1991), with larvae eventually metamorphosing to pelagic juveniles. Bocaccio rockfish probably move on the order of tens to thousands of kilometers, inferred from ichthyoplankton and juvenile fish distribution.

Pelagic age-0 juveniles typically recruit to shallow habitats, and juvenile bocaccio are more common in shallower water than adults, with average size notably larger at greater depths. Strong year classes frequently lead to high densities and high catches of young bocaccio from piers and other shore structures from early summer through winter of the first year of life (Love et al. 2006; Field et al. 2009; Field et al. 2010).

Half of bocaccio mature by age-3 in California waters (He et al. 2015), and maximum age varies with latitude, from 37 years along the U.S. West coast to 52 years along the Canadian coast (Andrews et al. 2005; Piner et al. 2006; Stanley et al. 2009; He et al. 2015). Adults are not highly mobile, but evidence suggests that large fish move to deeper waters, as juveniles are more common than adults in shallower water; with a clear trend toward larger fish at greater depths as well as at higher latitudes (Harmann 1987; Starr et al. 2002; Field et al. 2009). Adult bocaccio are typically described as occurring in a broad range of habitats and depths; they can develop large mid-water aggregations, although most tend to be associated with benthic habitat. Larger individuals and higher densities tend to be associated with more complex substrates.

Juvenile bocaccio are omnivores, known to prey on other age-0 rockfish, surfperch, jack mackerel and other small inshore fish species (Phillips 1964). This piscivorous tendency may begin during the pelagic stage, when age-0 bocaccio tend to feed on larger prey items relative to other age-0 pelagic rockfish species, including other larval and juvenile fishes (Philips 1964; Nelson 2001; Reilley et al. 1992). Adult bocaccio are piscivorous, typically feeding on small rockfish, Pacific hake, young sablefish, anchovies, mesopelagic fishes, and squids, particularly California market squid (Philips 1964; Nelson 2001).

Climate Effects on Abundance and Distribution

No formal studies have been reported on climate change effects on bocaccio rockfish. Bocaccio is found from Stepovac Bay on the Alaska Peninsula to Punta Blanca in central Baja California, consistent with broad temperature tolerances. However, bocaccio occurs in deeper waters in the south than in the north (Love et al. 2002), suggesting a behavioral response to temperature. Bocaccio is abundant off southern and

central California, uncommon between Cape Mendocino and the Oregon-Washington border, and moderately abundant from the Oregon-Washington border into Queen Charlotte Sound and Hecata Strait, British Columbia (Miller and Lea 1972; Eschmeyer et al. 1983; Love et al. 2002). Genetic analyses have suggested three general populations of bocaccio: a Queen Charlotte Island population, a second from Vancouver Island to Point Conception, and a third south of Point Conception (Matala et al. 2004).

Larvae are more common in cooler, chlorophyll-rich western waters of the southern California Current. Bocaccio recruitment is higher during cold phases of the Pacific Decadal Oscillation, when upwelling is stronger (Tolimieri and Levin 2005; Zabel et al. 2011; Love et al. 2002). Larval abundances for other species show correlations with environmental conditions such as sea-level anomaly and near shore temperature. Rockfish larvae in general can be more common near oceanic fronts in the vicinity of pycnoclines. Onshore advection of surface waters may also be important in some years. Rockfish larvae from the Washington and Oregon coasts may be transported to the Aleutian Islands (Hitchman et al. 2012; Tolimieri and Levin 2005; Zabel et al. 2011; Laidig et al. 2007; Bjorkstedt et al. 2002; Yoklavich et al. 1996; Orlov 2001).

Climate Vulnerability Rankings

Overall climate vulnerability was ranked **moderate** with 74% certainty and **high** with 26% certainty from bootstrap analysis. Climate exposure was ranked **high**, with three exposure attributes contributing to this score: high *mean sea-surface temperature* (3.4), very high *ocean acidification* (4.0), and high *subsurface oxygen* (3.1). Two exposure attributes were particularly uncertain: *currents*, and *phenology of upwelling*, both with scores distributed from low to very high. Biological sensitivity was ranked **moderate** overall with four sensitivity attributes contributing to this score: *early life history requirements* (2.9), *complexity in reproductive strategy* (2.9), *population growth rate* (2.8) and *stock size/status* (2.9), all of which scored moderate. *Other stressors* was particularly uncertain, with scores distributed from low to very high.

Distributional vulnerability and directional effect

Two inverse attribute scores indicated **high** vulnerability to distributional shift as a response to climate change, with respective scores of very high and high: *dispersal of early life stages* (3.8) and lack of *habitat specificity* (3.4). Directional effect of climate change on bocaccio rockfish was predicted to be **negative** (-0.38).

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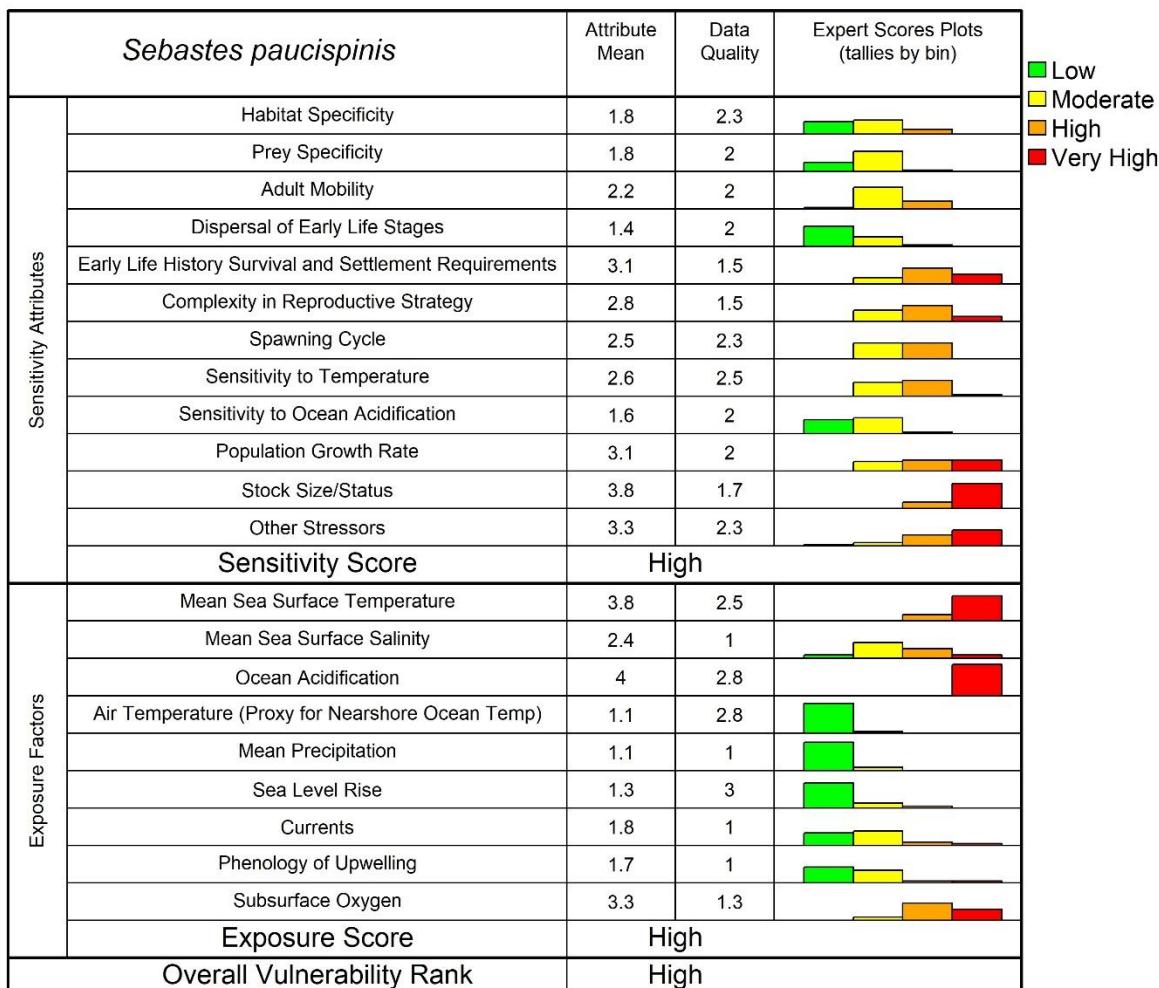
Bocaccio Rockfish (*Sebastodes paucispinis*) - Puget Sound DPS

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 62% of scores ≥ 2



Life History Synopsis

Bocaccio rockfish adults generally mate during August-November (Love et al. 2002), and eggs subsequently hatch to larvae internally as in other *Sebastodes* spp. Off Oregon and Washington respectively, females release larvae during January-February and in April (Lyubimova 1965; Moser 1967; Westrheim 1975; Wyllie-Echeverria 1987; Love et al. 2002). Most larvae remain pelagic for 3.5 months before settling to shallow

areas, although some may remain pelagic as long as 5.5 months, transforming into pelagic juveniles at 1.5-3.0 cm (Moser 1967; Matarese et al. 1989; Love et al. 2002).

Submerged vegetation provides important habitat, particularly for juveniles (Love et al. 1991). Juveniles settle to shallow, algae-covered rocky areas or biotic habitats including kelp and eelgrass (Love et al. 2002). Several weeks after settlement, they typically move to waters in the 18-30 m range with rocky reefs (Feder et al. 1974; Carr 1983; Johnson 2006; Love and Yoklavich 2008). In tagging studies, juveniles are recaptured 0.9-148 km from their tagging location (Hartman 1987; Star, et al. 2002).

Age at first maturity is 3 years for males and females off northern and central California. Half of males mature by age 3, with all mature by age 7 (55 cm); half of females mature by age 4, with all mature by age 8 (Wyllie-Echeverria 1987). Maximum age is 37-50 years (Andrews et al. 2005). Adults inhabit depths of 12-478 m but are most common at depths of 50-250 m (Feder et al. 1974; Love et al. 2002).

Like many rockfishes, adults are capable of movement but not highly mobile. While generally associated with hard substrate, adults are also typically found up to 30 m off the bottom (Love et al. 2002) and often wander onto mud flats. Some adults make daily vertical movements of about 100 m. In tagging studies, approximately half of tagged fish remained within an area of 200-400 ha, indicating low mobility. However, some fish used the entire 12-km² study area and also left the study area for extended periods (Hartman 1987; Star et al. 2002).

Pelagic juveniles are opportunistic feeders, and like adults, take fish larvae, copepods, krill, and other prey. Larger juveniles are primarily piscivores (Love et al. 2002). Chinook salmon (*Oncorhynchus tshawytscha*), terns, and harbor seals (*Phoca vitulina*) are known predators on smaller bocaccio (Love et al. 2002).

Drake et al. (2010) argued that the Puget Sound bocaccio rockfish DPS has averaged an annual decline of approximately 3% or more since the late 1960s-early 1970s, suggesting an overall decline of more than 70%. Subsequent analyses as part of the 5-year ESA status review update found a continued decline of approximately 3.8% per year during 1977-2014 (Tonnes et al. 2016; Tolimieri et al. 2017). Biomass of bocaccio in this region is estimated at 3.5% of its unfished stock size (Powles 2011), including Canadian waters outside of the Puget Sound DPS area.

Besides past fishing, key stressors to Puget Sound bocaccio rockfish include loss of biotic habitat such as eelgrass and kelp, low dissolved oxygen in some areas, and accumulated pollutants in sediments. In 2006, Puget Sound had about 20,234 ha of eelgrass, one-third of which occurred in Padilla and Samish Bays. Eelgrass coverage declined from the beginning of monitoring in 2000 until 2004, but has since stabilized for the sound as a whole, although local losses continue in some areas such as Hood Canal.

Kelp cover is variable, showing long-term declines in some regions, while increasing in areas with suitable artificial substrates (Palsson et al. 2009).

Hood Canal has seen persistent and increasing areas of low dissolved O₂ since the mid-1990s. Typically, rockfish move out of areas with dissolved O₂ less than 2 mg/L; however, when low dissolved O₂ waters were upwelled to the surface in 2003, about 26% of the rockfish population was killed (Palsson et al. 2009). In addition to Hood Canal, Palsson et al. (2009) report that periods of low dissolved oxygen are becoming more widespread in waters south of the Tacoma Narrows (Drake et al. 2010).

About 32% of sediments in the sound are moderately to highly contaminated by pollutants. Contaminants such as polychlorinated biphenyls, chlorinated pesticides (e.g., DDT), and polybrominated diphenyl ethers appear in rockfish collected in urban areas. Male rockfish collected in urban areas such as Elliot Bay, Sinclair Inlet, and Commencement Bay had high concentrations of mercury and polychlorinated biphenyls compared to rockfish in other areas and to females in the same areas (O'Neill et al. 1998; West et al. 2001; PSAT 2007). Polychlorinated biphenyl contaminants may reduce growth rates or reproductive success of rockfish. In English sole (*Parophrys vetulus*), reproductive function is reduced in animals from contaminated areas, and this effectively decreases the productivity of the species (Landahl et al. 1997).

It is not clear if the stock has experienced increased detrimental impacts from predators, competitors, or introduced species, but rockfish make up ~10% of diet by mass of lingcod in the San Juan Islands (Beaudreau & Essington 2007). Small increases in predation by lingcod, which may be increasing in marine protected areas of Puget Sound, could be sufficient to negate the benefit from cessation of fishing pressure (Ruckelshaus et al. 2009). Pinnipeds have generally increased over the last 20 years, but rockfish make up only a small proportion of the diet of harbor seal, the most abundant pinniped in Puget Sound (Lance et al. 2012). In contrast, rockfish make up 8% of Stellar sea lion diet (Lance and Jeffries 2007), suggesting scope for impact. However, whether Stellar sea lion predation is increasing in Puget Sound is not clear.

Climate Effects on Abundance and Distribution

Bocaccio abundance in Puget Sound has declined at approximately 3.8% per year since 1977 or 77% as of 2014 (Tolimieri et al. 2017). However, this decline is attributed primarily to fishing, not climate (Williams et al. 2010). Nevertheless, harmful algal blooms are one factor with potential linkages to climate that may affect future recovery or cause continued decline.

The frequency, magnitude, and geographical scope of paralytic shellfish toxins associated with harmful algal blooms have increased in Puget Sound since the 1950s (Trainer et al. 2003). There appears to be a causal link between harmful algal blooms and climate as warm air and water temperatures, low streamflow, low winds, and small tidal variability typically precede paralytic shellfish toxin events associated with the

dinoflagellate *Alexandrium catenella*, suggesting a causal link between climate and some harmful algal blooms.

Under a moderate greenhouse gas emissions scenario (i.e., A1B), the period of conditions conducive to the formation of harmful algal blooms of *Alexandrium catenella* in Puget Sound is projected to begin up to 2 months earlier and increase in duration by an average of 13 d by the end of the 21st century (Moore et al. 2009; Moore et al. 2011). Temperatures in the Puget Sound region have warmed substantially since 1980 and are expected to be at least 4.2°F warmer than at present by 2050 (Mauger et al. 2015).

As a deep-water species, bocaccio can be susceptible to low dissolved O₂ events. Hood Canal has seen persistent and increasing areas of low dissolved O₂ since the mid-1990s, and periods of low dissolved O₂ are becoming more widespread in waters south of the Tacoma Narrows (Palsson et al. 2009). Typically, rockfish move out of areas with dissolved O₂ below 2 mg/L; however, when low dissolved O₂ waters upwelled to the surface in 2003, about 26% of the rockfish population were killed (Palsson 2009).

Environmental cues that may be important to stimulate juvenile settlement are body size, photoperiod, and water temperature, the latter indicating a potential route for impacts from climate change. Additionally, ocean acidification may affect the availability of rockfish prey (Tonnes et al. 2016) and the behavior and viability of fish larvae and juveniles (Chung et al. 2014; Hamilton et al. 2014).

Climate Vulnerability Rankings

Overall climate vulnerability was ranked **high** with 95% certainty and **very high** with 5% certainty from bootstrap analysis. Three attributes contributed to a **high** overall exposure score: very high *mean sea surface temperature* (3.8) and *ocean acidification* (4.0), and high *subsurface oxygen* (3.3). The score for *mean sea surface salinity* was particularly uncertain with individual expert scores distributed from low to very high. Water temperature can affect growth rate and energy demands, while ocean acidification can influence behavior and sensory development in fish.

Four attributes contributed to a **high** score for biological sensitivity: very high *stock size/status* (3.8) and high *early life history requirements* (3.1), *population growth rate* (3.1), and *other stressors* (3.3). *Complexity in reproductive strategy* had a medium score but with some weight being placed in the very high category as well. Population levels in Puget Sound are thought to be extremely low, with bocaccio rockfish listed as *endangered* under the ESA (Tonnes et al. 2016). Recruitment for coastal populations is episodic and related to climate (Tolimieri & Levin 2005; Zabel et al. 2011).

Distributional vulnerability and directional effect

Two inverse attribute scores indicated **high** vulnerability to distributional shift as a response to climate change: very high *dispersal of early life stages* (3.6) and high *habitat specificity* (3.2). Directional effect of climate change for Puget Sound bocaccio

rockfish was predicted to be ***negative*** (-0.38).

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Calico Rockfish (*Sebastodes dalli*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 48% of scores ≥ 2

<i>Sebastodes dalli</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.2	2.8	 
	Prey Specificity	1.2	2	 
	Adult Mobility	2.3	1	 
	Dispersal of Early Life Stages	1.8	1	  
	Early Life History Survival and Settlement Requirements	3.2	1	  
	Complexity in Reproductive Strategy	2.8	1	  
	Spawning Cycle	2.3	2.8	 
	Sensitivity to Temperature	2.6	2.8	  
	Sensitivity to Ocean Acidification	2.3	2	  
	Population Growth Rate	2.9	2	 
	Stock Size/Status	2.5	0	   
	Other Stressors	1.9	0.5	   
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.6	2.5	 
	Mean Sea Surface Salinity	1.6	1	 
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1.1	1	 
	Sea Level Rise	1.2	3	 
	Currents	2.2	1	   
	Phenology of Upwelling	2.2	1	  
	Subsurface Oxygen	2.7	1.3	 
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Calico rockfish occur primarily as a solitary individuals, ranging from central Baja to San Francisco Bay. It resides at or near the bottom at depths of 15-120 m on mixed soft to rocky habitats (Mearns et al. 1980; Love et al. 2002). Calico rockfish is a single-batch spawner, with parturition occurring from January to May with a peak in February (Love et al. 2002). Pelagic larval duration is 2-3 months; however, larval

development accelerates with increased temperature. There is evidence of high interannual variability in recruitment based on oceanographic conditions (Mearns et al. 1980), and physical transport of larvae offshore can result in a significant decrease in survivorship. Pelagic larvae likely eat euphausiids and copepods (Love et al. 2002).

Juvenile calico rockfish eventually settle to mixed soft to low-relief hard substrates at depths of 20-42 m. Age at maturity is unknown, but is possibly around age-4 to -9, with a maximum at age-12 (CDFW 2001; Love et al. 2002). Adults and post-settlement juveniles are generalists that primarily eat benthic prey including crabs, krill, polychaetes, shrimp, amphipods, fish larvae, copepods, bivalves, and brittle stars (Love et al. 2002). Because of its small body size, this species is not typically targeted by sport or commercial fisheries but are caught incidentally (CDFW 2001).

Climate Effects on Abundance and Distribution

No studies examine climate change effects on calico rockfish abundance or distribution. However, recruitment is dependent on oceanographic conditions. Stock status of calico rockfish is unknown. While the species is not a common component of commercial catch, it is frequently captured in the Southern California recreational groundfish fishery. Like other rockfishes, the calico was most sensitive to environmental change during the larval stage. Calico is relatively short-lived compared to other rockfishes. Other than fisheries, the only direct, clear stressor to calico rockfish is potential exposure to upwelling-driven hypoxia at depth. According to laboratory experiments, adults prefer temperatures of 12-14°C, with a critical thermal maximum of 26°C (Shrode et al. 1982; Love et al. 2002).

Climate Vulnerability Rankings

Overall climate vulnerability was ***moderate*** with 61% certainty and ***high*** with 39% certainty from bootstrap analysis. Overall climate exposure was ranked high, with two attributes contributing to this score: *mean sea surface temperature* (3.6) and *ocean acidification* (4.0). Biological sensitivity was ranked ***moderate***, and five sensitivity attributes contributed to this score: *early life history survival and settlement requirements* (3.2), *complexity in reproductive strategy* (2.8), *sensitivity to temperature* (2.6), *population growth rate* (2.9), and *stock size/status* (2.5).

Distributional vulnerability and directional effect

Potential distributional vulnerability was ranked ***high*** as determined by inverse scores for *habitat specificity* (3.8) and *dispersal of early life stages* (3.2). Calico rockfish will likely shift from its present distribution as oceans warm because of its low site fidelity and highly mobile larvae. The expected directional effect of climate change on calico rockfish was ***neutral*** (-0.31).

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Canary Rockfish (*Sebastodes pinniger*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 57% of scores ≥ 2

<i>Sebastodes pinniger</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.9	3	  
	Prey Specificity	1.2	3	  
	Adult Mobility	2.4	2.3	 
	Dispersal of Early Life Stages	1.6	0.3	  
	Early Life History Survival and Settlement Requirements	3.1	1	  
	Complexity in Reproductive Strategy	2.8	1	  
	Spawning Cycle	2.4	2.8	 
	Sensitivity to Temperature	2.3	2.8	  
	Sensitivity to Ocean Acidification	1.6	2.3	  
	Population Growth Rate	3.7	2.5	 
	Stock Size/Status	1.8	2.3	  
	Other Stressors	1.4	1	  
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.4	2.8	 
	Mean Sea Surface Salinity	1.6	1.3	 
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1	3	
	Currents	2.2	1	   
	Phenology of Upwelling	2.2	1	  
	Subsurface Oxygen	3	1.3	  
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Canary rockfish is distributed in the northeastern Pacific Ocean from the western Gulf of Alaska to northern Baja California. The species is most abundant from British Columbia to central California (Miller and Lea 1972; Love et al. 2002). Adults are primarily found along the continental shelf at depths below 300 m, although they are occasionally observed in deeper waters (Love et al. 2002).

Canary rockfish is long-lived, with a maximum age of at least 84 years (Love et al. 2002), and a maximum size of around 70 cm. Females grow larger than males, while males reach maximum size more quickly (Love et al. 2002). Females mature at 7-14 years of age (estimates vary by latitude), while males mature at 7-9 years.

Canary rockfish is a low-productivity species with a complex reproductive cycle that entails internal fertilization of eggs and live bearing of young (Love et al. 2002). This species spawns in winter, producing pelagic larvae and juveniles that remain in the upper water column for 3-4 months (Love et al. 2002). Juveniles settle in shallow water around nearshore rocky reefs, where they may congregate for up to 3 years before moving into deeper water. Adult canary rockfish primarily inhabit areas in and around rocky habitat (Love et al. 1991).

Canary rockfish has a diverse diet. Pelagic juveniles feed on copepods, amphipods and krill eggs and larvae. Adults and subadults eat krill, small fish such as anchovies, sanddabs, shortbelly rockfish, and gelatinous zooplankton. Juvenile canary rockfish are eaten by king salmon and other fish, as well as marine birds and mammals (Love et al. 1991; Love et al. 2002; Moser and Boehlert 1991).

Climate Effects on Abundance and Distribution

No studies examine climate change effects on canary rockfish abundance or distribution. Juvenile canary rockfish are pelagic and found in shallow, intertidal areas, while adults primarily inhabit areas in and around rocky habitat (Love et al. 2002). However, exposure to climate change factors occur during all life stages, since all life stages utilize marine habitats, and temperature affects food availability and metabolic rate of all ages. Planktivorous larvae and juveniles may be particularly sensitive to ocean acidification since they feed on invertebrates whose ability to build shells can be compromised by acidic waters.

Like many other rockfish, successful reproduction of canary rockfish depends on pelagic larval survival (the most sensitive life stage). Reproductive success is rare, and occurs with the right combination of water temperature, food supply, and upwelling intensity (Love et al. 2002).

Climate Vulnerability Rankings

Overall climate vulnerability was ranked ***high*** with 81% certainty and ***moderate*** with 19% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***, with three attributes contributing to this score: *ocean acidification* (4.0), *mean sea surface temperature* (3.4), and *subsurface oxygen* (3.0). Biological sensitivity was also ranked high, with three sensitivity attributes scoring above 2.5: *population growth rate* (3.7), *early life history survival and settlement requirements* (3.1) and *complexity in*

reproductive strategy (2.8).

Distributional vulnerability and directional effect

Inverse scores for two attributes indicated a **high** vulnerability to distributional shift as a response to climate change: *dispersal of early life stages* (3.4) and *habitat specificity* (3.1). A broad latitudinal distribution and dispersive early life stages (Love et al. 2002; Thorson and Wetzel 2016) both suggest that canary rockfish can change distribution in response to climate change. The expected directional effect of climate change on canary rockfish was **negative** (-0.38).

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Chilipepper (*Sebastodes goodei*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 67% of scores ≥ 2

<i>Sebastodes goodei</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	2.3	  
	Prey Specificity	1.8	2	 
	Adult Mobility	1.9	2	 
	Dispersal of Early Life Stages	1.6	2	 
	Early Life History Survival and Settlement Requirements	3.2	1.8	  
	Complexity in Reproductive Strategy	2.9	2	  
	Spawning Cycle	2.6	2.8	 
	Sensitivity to Temperature	2.2	2.8	 
	Sensitivity to Ocean Acidification	1.5	2	 
	Population Growth Rate	2.9	3	  
	Stock Size/Status	1.7	2.3	  
	Other Stressors	1.5	0.9	 
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.6	2.5	 
	Mean Sea Surface Salinity	1.6	1.3	 
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1	1	
	Sea Level Rise	1.1	3	
	Currents	2.2	1	   
	Phenology of Upwelling	2.2	1	  
	Subsurface Oxygen	2.8	1.3	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Chilipepper rockfish range from Vancouver Island south to Bahia Magdalena (Baja CA Sur), with the greatest abundance between Point Conception and Cape Mendocino, California (Holder and Field 2019). Chilipepper rockfish is characterized as a mobile species, but migration patterns of adults are not well studied (Love et al. 2002). There is no indication of behavioral or physical constraints on migration, but there is

some indication of seasonal movement (Love et al. 2002).

Chilipepper bear live young annually, although recruitment is highly variable, likely due to maternal effects and whether food resources and environmental conditions are favorable at the time of larval release (Bjorkstedt et al. 2002; Field et al. 2015). Females mate, and then store sperm during early egg development. Following fertilization, the gestation period may last 1-2 months depending on temperature (Love et al. 2002). Pelagic larvae are released from November through April in California (Wyllie Echeverria 1987).

Females produce one or multiple broods annually depending on environmental conditions and latitude (Love et al. 2002; Beyer et al. 2015; Lefebvre et al. 2018; Holder and Field 2019). Multiple broods are common in southern California south of Point Conception, but are less frequently observed in Central California, and have yet to be documented farther north (Beyer et al. 2015). Parturition occurs in highly-variable ocean conditions such that the timing of larval release and food variability will likely affect early survival and recruitment; larvae depend on specific physical conditions to survive (Love et al. 2002; Bjorkstedt et al. 2002).

The overall patterns and distances of movement during the pelagic larval and juvenile phases are largely unknown. Adults reproduce in deep water, and juveniles settle in shallower waters. The pelagic juvenile phase averages 3.5 months but could last up to 5.5 months (Field 2007; Love et al. 2002).

Settled juveniles tend to be found in shallow water and move to greater depths with size and age. Juveniles can be found outside of kelp beds and move to deeper habitats a few weeks after settlement (Field 2007; Love et al. 2002). Half of males and females are mature by age-2.5 to age-3, and all are mature at age-6 (males) or -7 (females). However, age at maturity likely depends on latitude and environmental conditions (Field 2007; Wyllie Echeverria 1987). Maximum reported age is 35 years (Love et al. 2002; Ralston et al. 1998).

Adult habitat includes boulder fields and other high-relief substrate and occasional low-relief cobblestones (Love et al. 2002). Adults are abundant in large schools at 100-300 m in depth, often in midwater (Field 2007).

Pelagic larvae eat copepods and small plankters (Love et al. 2002). Pelagic juveniles prey on various stages of calanoid copepods and subadult euphausiids, including eggs (Reilly et al. 1992). Adults are midwater foragers with key prey items including krill; forage fish such as anchovies, Pacific hake, mesopelagic fishes, and small squids (Love et al. 2002).

Climate Effects on Abundance and Distribution

Few studies examine the direct effect of climate factors on the abundance of chilipepper rockfish. However, changes in oceanographic conditions are likely to affect population productivity in two ways. First, interannual and spatial variability in egg production (fecundity) is likely linked to female energetic reserves and oceanographic conditions (Harvey et al. 2011; Beyer et al. 2015). Second, changes in oceanographic conditions (temperature and food availability) may also drive interannual variability in mean size-at-age of adults (Field 2007).

Climate Vulnerability Rankings

Overall climate vulnerability was ***moderate*** with 51% certainty and ***high*** with 49% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***, with two exposure factors contributing to this score: *mean sea surface temperature* (3.6) and *ocean acidification* (4.0). Two additional exposure attributes were particularly uncertain with scores distributed from low to very high: *currents* and *phenology of upwelling*. At all life stages, Chilipepper use marine habitats at all life stages.

Biological sensitivity was ranked ***moderate***, with four attributes contributing to this score: *early life history survival and settlement requirements* (3.2), *complexity in reproductive strategy* (2.9), *spawning cycle* (2.6), and *population growth rate* (2.9). Highly uncertain biological sensitivities were *habitat specificity* and *sensitivity to temperature*, with scores ranging from low to very high, but with most weight in moderate or low bins.

Distributional vulnerability and directional effect

Inverse scores from two attributes indicated ***high*** vulnerability to distributional shift as a response to climate change: *dispersal of early life stages* (3.4) and *adult mobility* (3.1). Chilipepper is mobile and has broadly dispersive early life stages. Directional effect of climate change on chilipepper was expected to be ***negative*** (-0.44).

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China Rockfish (*Sebastes nebulosus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 48% of scores ≥ 2



Life History Synopsis

China rockfish is a medium-sized, deeper-dwelling nearshore rockfish that is both recreationally and commercially prized, mainly in the live-fish fishery. China rockfish range from southern California north to the Gulf of Alaska (Love et al. 2002). Core abundance is from northern California to southern British Columbia, Canada. China rockfish is rarely encountered in the Southern California Bight (Love et al. 1998).

Available information on either stock structure or life history is limited. No genetic research has been conducted for China rockfish, and no published research indicates separate stocks along the West Coast. China rockfish does not appear to exhibit sexual dimorphism (Lenarz and Echeverria 1991), although data are limited. Fits to von Bertalanffy growth curves using age-length data from Washington, Oregon, and California indicate regional differences in growth and estimates of L-infinity (Dick et al. 2016). These data represent fish collected from the recreational and commercial sectors as well as for research.

China is among the longer-lived rockfishes and has been reported to live to at least 79 years (Love 2002). The oldest aged China rockfish from Alaska was 78 years old (Munk 2001). Recently-aged West Coast China rockfish had a maximum age of 83 years in recreation or research collections from California in 1973. Among China rockfish from the commercial dead-fish fishery off Oregon in 2003, the oldest aged fish was 79, and among those from the recreational fleet off Washington in 2000, the oldest was 77 (Dick et al. 2016).

Little is known about the maturity schedule and fecundity of China rockfish. Echeverria (1987) collected 69 China rockfish, of which the age at first maturity was 3 years for both males and females (26 cm). Both males and females exhibited 50% maturity at 4 years (27 cm) and 100% maturity at 6 years (30 cm). A study by Lea et al. (1999) off the coast of California captured females releasing larvae in April and May and spent females in April, June, and October. Echeverria (1987) identified January-June as the months of parturition for China rockfish in north-central California, with peak reproductive activity in January.

In central California, China rockfish feed predominantly on crustaceans and ophiuroids, while crustaceans and mollusks (Lea et al. 1999) dominate the diets of China rockfish in northern California. This is similar to the diet described by Love et al. (2002) of benthic organisms, including brittle stars, crabs, and shrimps. Both juvenile and adult China rockfish tend to be solitary and exhibit high site fidelity within rocky habitats. In rockfish surveys of *Nereocystis* and *Macrocystis* kelp forests, China rockfish was observed in only the *Macrocystis* kelp forests, and overall sightings within the kelp forests were rare (Bodkin 1986).

Juvenile China rockfish inhabit shallow, subtidal waters (Love et al. 2002), and an experimental study with captive China rockfish found that juveniles exhibit both site fidelity and territoriality (Lee and Berejikian 2009). A tag and recapture study by Lea et al. (1999) indicated China rockfish have high site fidelity.

Like other species in the genus *Sebastodes*, China rockfish is iteroparous with internal fertilization, and bears live young. Gestation periods range 1-2 months among

Sebastes spp., but no data specific to China rockfish are available in the literature.

Parturition by China rockfish takes place during January-June in Central California (Echeverria 1987), but the duration of pelagic larval and juvenile stages is unknown. Closely related nearshore rockfish species (e.g. gopher, black-and-yellow, kelp, and copper) recruit at small sizes (1.5-2 cm), and are thought to have short pelagic juvenile stages relative to other *Sebastes* (Anderson 1983; Love et al. 2002). Little is known about dispersal of juvenile China rockfish during the pelagic stage, and they are not captured in the Southwest Fisheries Science Center juvenile rockfish cruises.

Climate Effects on Abundance and Distribution

No studies examine climate change effects on China rockfish abundance or distribution. How climate change will affect China rockfish is not clear. However, exposure to changing ocean temperatures may result in a distribution shift. Ocean acidification will also likely have an impact on prey availability, as crustaceans seem to be one of the main food sources for China rockfish.

Climate Vulnerability Rankings

Overall climate vulnerability was ranked ***moderate*** with 61% certainty and ***high*** with 39% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***, with three exposure attributes contributing most to this ranking: high *mean sea surface temperature* (3.5) and *ocean acidification* (4.0), and moderate *subsurface oxygen* (2.8). Overall biological sensitivity was ranked ***moderate***, with four sensitivity attributes having the strongest contribution to this rank: moderate *adult mobility* (2.7), *complexity in reproductive strategy* (2.9), and *early life history survival and settlement requirements* (2.9), along with high *population growth rate* (3.3).

Distributional vulnerability and directional effect

Inverse scores for two attributes indicated ***moderate*** vulnerability to distribution shift as a response to climate change: high *dispersal of early life stages* (3.2) and moderate *habitat specificity* (2.8). Directional effect of climate change on China rockfish was expected to be ***negative*** (-0.56).

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Cowcod (*Sebastodes levis*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 52% of scores ≥ 2

<i>Sebastodes levis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.9	2.8	  
	Prey Specificity	1.6	2.5	 
	Adult Mobility	2.9	2	  
	Dispersal of Early Life Stages	1.6	2	 
	Early Life History Survival and Settlement Requirements	2.8	1	  
	Complexity in Reproductive Strategy	2.1	1.5	  
	Spawning Cycle	2.5	2.3	  
	Sensitivity to Temperature	2.3	2.5	 
	Sensitivity to Ocean Acidification	1.3	1.3	 
	Population Growth Rate	3.8	2.3	 
	Stock Size/Status	2.2	1.8	 
	Other Stressors	2.2	1.3	  
	Sensitivity Score	Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.4	2	 
	Mean Sea Surface Salinity	1.1	1	 
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	 
	Mean Precipitation	1	1	 
	Sea Level Rise	1.1	2.5	 
	Currents	1.9	1	  
	Phenology of Upwelling	1.6	1.5	 
	Subsurface Oxygen	2.9	1.8	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Cowcod life history is summarized by Love (2011) and Love et al. (2002). The most recent information regarding stock status of cowcod was reported by Dick and MacCall (2014). Cowcod is a long-lived benthic fish, with a life span of over 55 years. Like most rockfishes, cowcod has internal fertilization, allowing the female to incubate the tiny embryos until they are larvae that can actively swim. Off southern California,

cowcod releases larvae in several broods during November-May, with a peak in winter.

Back-calculated birth dates based on otolith daily growth bands indicate that parturition off central California ranges from February to August with a peak in May. Larval duration is about 30 d, and the pelagic larval and juvenile phase lasts at least 100 d before recruitment to benthic habitats. In general, estimates of larval transport (distance and path) could be made based on pelagic stage duration and magnitude and direction of currents.

Cowcod recruit to low-relief structure such as cobble, small boulders, pipelines, and shell mounds (around oil platforms), and occasionally to low-relief muddy or fine sand/clay sediments. There is an ontogenetic shift from small juveniles (5-20 cm TL) in small structure to larger juveniles (up to 45 cm) in high-relief boulder fields and rock ridges. Most observations indicate juveniles occupy physical habitat; there are a few reports of juveniles associated with metridium (anemone), sponges, and crinoids. The habitat is neither rare nor abundant.

Adults are solitary, found living on rocky reefs mainly along the coast from Baja California to southern Oregon at depths of 17-224 m. Adults are not particularly choosy about substrate, as long as they provide cover; thus, they are found around oil platforms and piles of trash, as well as boulders and cobbles. Off southern California, 50% of males are mature at 44 cm length, or about 11 years old, and all males mature at 48 cm; 50% of females are mature at 43 cm length, and all are mature at 52 cm.

Juvenile cowcod eat copepods, shrimps, mysid shrimp, gammarid amphipods, hydroids, and a few small fishes with no evidence of diet preference or prey switching (Love 2011; Love et al. 2002). Adult cowcod have a maximum length of 100 cm and have relatively large mouths. They primarily eat fish, octopuses, squids, and euphausiids (to a lesser degree) with no evidence of diet preference or prey switching (Love 2011; Love et al. 2002). They are large, sedentary fish that grow to 1 m in length and at least 13 kg in weight. Cowcod rarely moves more than a few meters above the seafloor.

Climate Effects on Abundance and Distribution

Climate effects on cowcod are unknown, but the species will probably not be affected by changes in ocean temperatures in the next 40-50 years. Distribution may shift slightly north, but changes in abundance are likely to be small, depending on changes in ocean productivity. Survival, transport, and settlement of young rockfishes are generally influenced by the timing of parturition and localized oceanographic conditions such as relaxed upwelling, onshore transport, and change in temperature. Size and age of pelagic juveniles could also influence the timing of active onshore movement and settlement. The O₂ minimum zone is expected to continue shoaling, thus cowcod may face habitat loss. Hypoxia could encompass a high proportion of deep water habitat within 15 years if present trends continue (Bograd et al. 2008; McClatchie et al. 2010).

Cowcod is a long-lived species with high fecundity, so has considerable potential for population growth in the absence of heavy fishing. However, cowcod habitat has been fished with bottom-tending gear for over 100 years. Seafloor habitats are physically disturbed with bottom-tending gear, and demersal fish community structure and food web are altered with the removal of adult predators (large fishes). Water quality is impacted with ocean acidification and warming trends. Depensation may affect the recovery of overfished species such as cowcod, such that recovery could be slower than otherwise predicted by reproductive potential (Baskett et al. 2006; O'Farrell et al. 2009).

Climate Vulnerability Rankings

Overall climate vulnerability was **moderate** with 52% certainty and **high** with 48% certainty from bootstrap analysis. Overall climate exposure was ranked **high**, with three exposure factors contributing to this score: *mean sea surface temperature* (3.4), *ocean acidification* (4.0) and *subsurface oxygen* (2.9). Biological sensitivity was ranked **moderate**. Both low and high sensitivity attributes contributed to this rank, with *population growth rate* (3.8) scoring highest. *Habitat specificity* was high (2.9), while *prey specificity* (1.6), *dispersal of early life stages* (1.6), and *sensitivity to ocean acidification* (1.3) were all low.

Distributional vulnerability and directional effect

Overall vulnerability to distributional shift was ranked **low** for cowcod. The inverse score was high for *dispersal of early life stages* (3.4), but low for all other attributes, contributing to the low overall rank. Although cowcod is mobile in its larval stage, it is territorial in later life stages and overall has a low risk of shifting distribution. Directional effect of climate change on cowcod was **negative** (-0.44).

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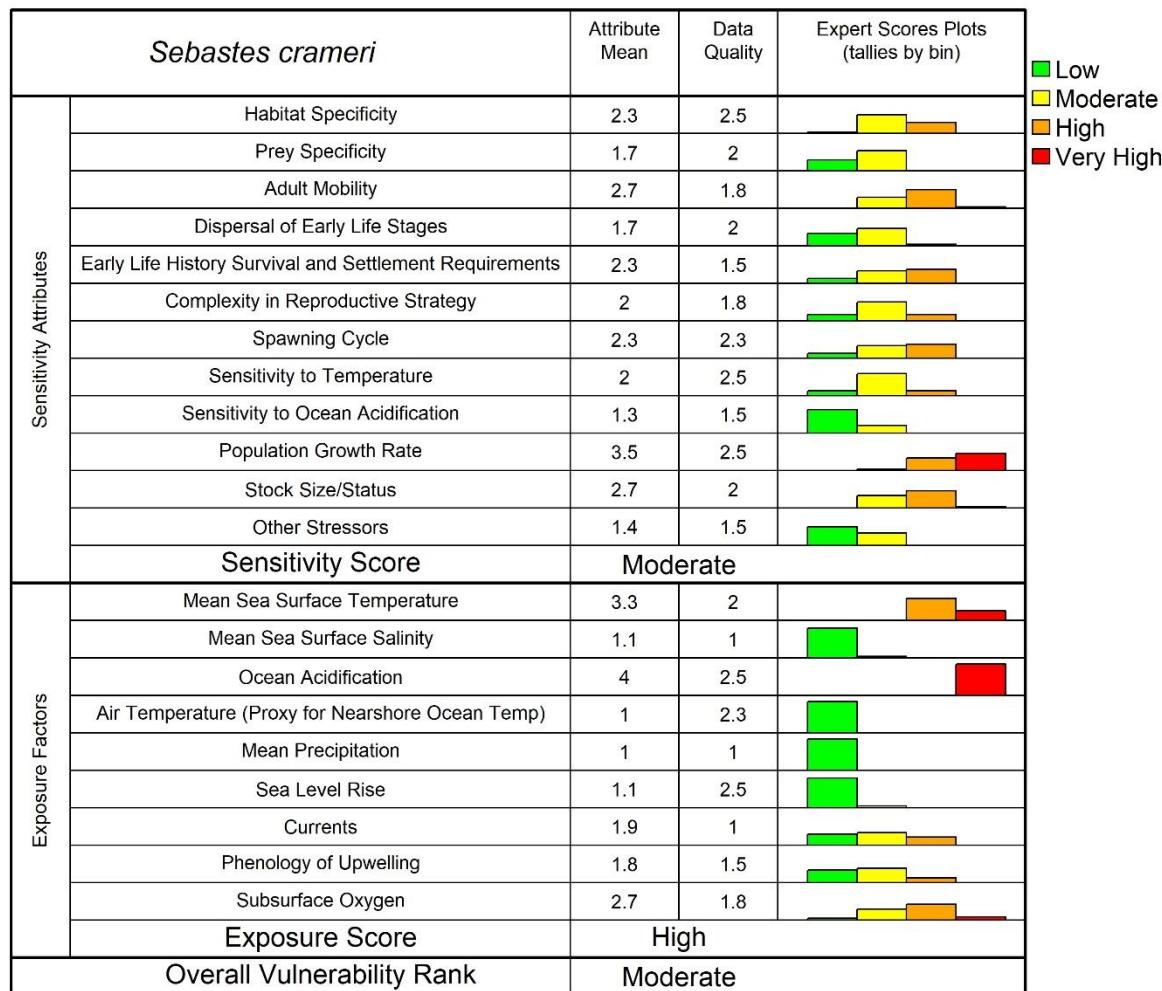
Darkblotched Rockfish (*Sebastodes crameri*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 52% of scores ≥ 2



Life History Synopsis

There are no clear stock delineations for darkblotched rockfish in U.S. waters, and no distinct breaks in fishery landings and catch distributions. Survey catches exhibit a continuous distribution of fish over most of the species range, with areas of higher abundance present in the Columbia, Eureka, and Monterey statistical areas designated by the International North Pacific Fisheries Commission.

Microsatellite analyses of spatial genetic structure in darkblotched rockfish conducted by Gomez-Uchida and Banks (2005) suggested a possibility of some genetic differentiation among stocks along the coast, but the level of differentiation was low, as indicated in only a few of the loci examined. No distinct breaks in the stock were identified. This was the most recent and perhaps the only population genetic study performed for this stock to date.

Darkblotched rockfish is among the longer living rockfishes; stock assessment data include individuals aged to 98 years (Wallace and Gertseva 2017). In the literature, maximum darkblotched rockfish age is 105 years (Love et al. 2002). As with many other *Sebastodes* species, darkblotched rockfish exhibit sexually-dimorphic growth; females reach larger sizes than males, while males attain maximum length earlier than females (Love et al. 2002; Nichol 1990).

Darkblotched rockfish mate from August to December, eggs are fertilized from October through March, and larvae are released from November through April (Love et al. 2002). Fecundity increases with fish size, and all larvae are released in one batch. Pelagic juveniles settle at 4-6 cm in length at depths of about 55-200 m (Love et al. 2002). As in many other *Sebastodes* species, darkblotched rockfish exhibits ontogenetic movement, with fish migrating to deeper waters as they mature and increase in size and age (Lenarz 1993; Nichol 1990).

Climate Effects on Abundance and Distribution

Darkblotched rockfish is found in the Northeast Pacific Ocean from the southeastern Bering Sea and Aleutian Islands to near Santa Catalina Island in southern California. This species is most abundant from off British Columbia to Central California. Darkblotched rockfish occur at depths of 25-900 m (Love et al. 2002), with the majority of fish inhabiting depths between 100 and 600 m. Commercially important concentrations are found from the Canadian border through Northern California, on or near the bottom, at depths of 183-366 m. Specific temperatures preferences are not reported for darkblotched (Wallace and Gertseva 2017).

Darkblotched rockfish larvae and early juveniles are pelagic. There is little research on the influence of environmental factors on initiation of settlement. Off California, rockfish settlement might be associated with regional upwelling events and onshore transport during intermittent periods of reduced winds. Nothing is reported for darkblotched rockfish specifically; however, global climate change affecting the timing, frequency, and strength of upwelling would in turn affect darkblotched settlement.

Climate Vulnerability Rankings

Overall climate vulnerability was ***moderate*** with 98% certainty from bootstrap

analysis. Climate exposure was ranked **high**, and attributes influencing this rank included high *mean sea surface temperature* (3.3) and very high *ocean acidification* (4.0). Scoring for *subsurface oxygen* was particularly uncertain, with scores distributed from low to very high. Biological sensitivity was ranked **moderate**. Contributing attribute scores included high *population growth rate* (3.5), low sensitivity to *ocean acidification* (1.3), and low sensitivity to *other stressors* (1.4).

Distributional vulnerability and directional effect

Inverse scores of two attributes indicated **moderate** vulnerability to distributional shift as a response to climate change. These were the high scores for *dispersal of early life stages* (3.3) and moderate score for *habitat specificity* (2.7). Directional effect of climate change on darkblotched rockfish was **negative** (-0.38).

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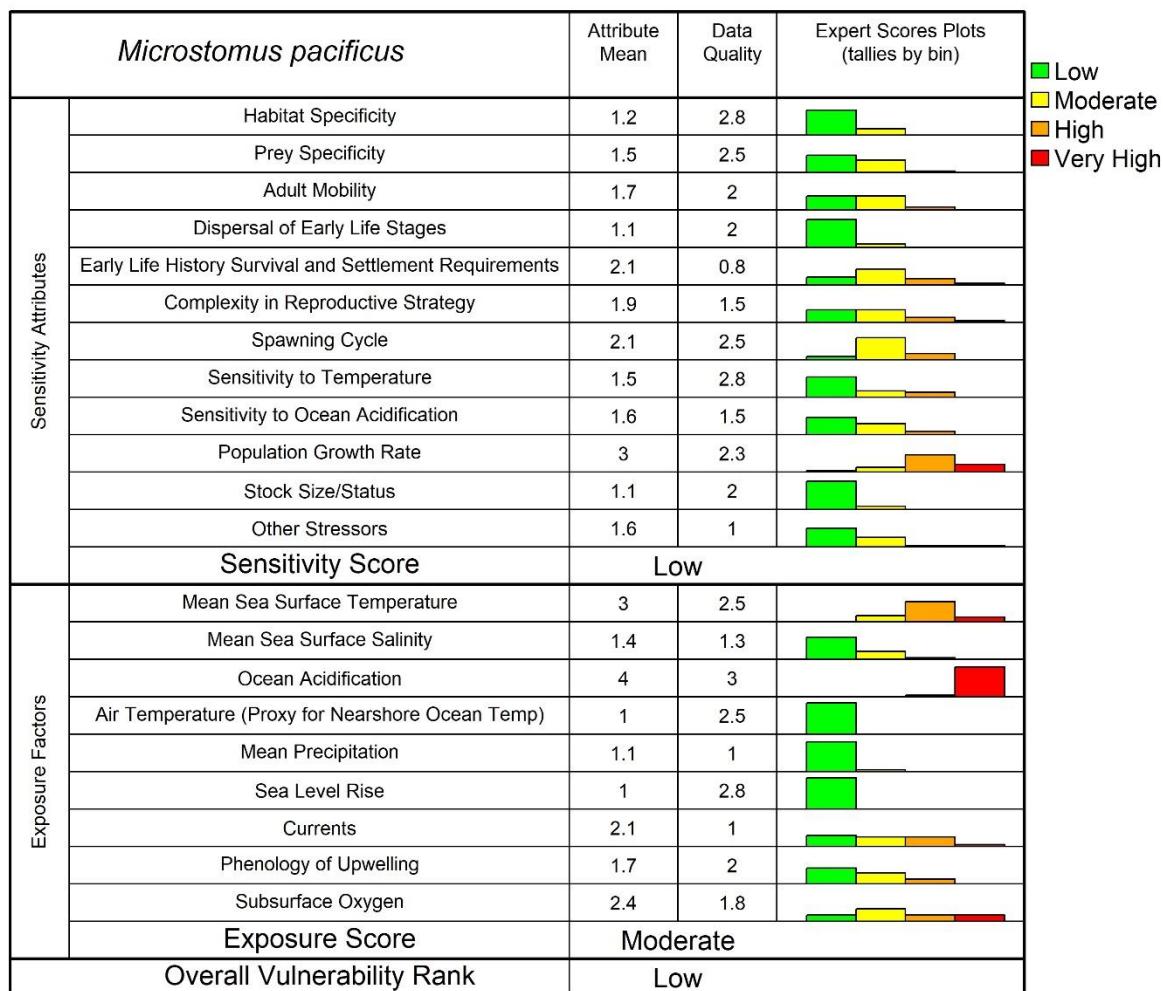
Dover Sole (*Microstomus pacificus*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = Moderate 

Data Quality = 62% of scores ≥ 2



Life History Synopsis

Dover sole is a batch spawner, with females releasing batches of about 1,000-15,000 eggs in about nine batches per year. Spawning occurs November to April or May, with heavy spawning during December to February (Hagerman 1952; Yoklavich and Pikitch 1989; Hunter et al. 1992; Brodziak and Mikus 2000; Love 2011). In the Gulf of Alaska, Abookirea and Bailey (2007) observed that eggs spawned in deep waters were

found in surface waters near spawning areas.

Dover sole larvae did not appear to have an organized migration from offshore spawning grounds toward coastal nursery areas, and data indicated facultative settling to their juvenile habitat in winter. Pelagic larvae hatch at about 6 mm standard length (SL), but with delayed metamorphosis. The species has a protracted planktonic stage that may span from 9 months to 2 years (until close to 100 mm SL). Larvae are collected off the coast of California year-round, but are most numerous off northern and central California in April through June (Matarese et al. 1989; Charter and Moser 1996).

Juvenile Dover sole settle on the outer continental shelf and slope, then move inshore to nursery areas greater than 150 m in depth, and after growing to about 20 cm, begin to move into progressively deeper water. They inhabit mud and mud-sand seafloor (Pearcy and Hancock 1978; Toole et al. 1997; Toole et al. 2011; Love 2011). A large percentage of the spawning biomass of Dover sole lives on the upper continental slope characterized by low oxygen concentrations ($0.2\text{--}0.5 \text{ mL L}^{-1}$). At these concentrations, Dover sole are living close to their lower lethal limit for dissolved oxygen (Hunter et al. 1990; Jacobson and Hunter 1993; Vetter et al. 1994).

Geographic range of Dover sole extends from the northwestern Bering Sea and Aleutian Islands to Punta San Juanico, southern Baja California. Dover sole is a dominant flatfish on the continental shelf and slope within the California Current, inhabiting mud or mud-sand seafloor over a broad depth range from the nearshore to 1,372 m. Observational studies show Dover sole occur on patches of unconsolidated seafloor within mixed habitats that include rock outcrops, boulders, and cobbles (Pearcy and Hancock 1978; Hunter et al. 1990; Nasby-Lucas et al. 2002; Love et al. 2005; Love 2011; Getsiv-Clemons et al. 2012). Dover sole is carnivorous, foraging on polychaetes, mollusks, crustaceans, and echinoderms, with polychaetes forming a larger proportion of the juvenile diet compared to adults (Allen 1982).

Results from tagging studies during 1948–1979 indicate seasonal movement of Dover sole onto the shelf in summer and off the shelf in winter, with little evidence of north-south movement or mixing between Pacific Marine Fisheries Commission statistical areas (Westrheim et al. 1992). Few tagged fish moved long distances.

Climate Effects on Abundance and Distribution

Dover sole is widely distributed along the West Coast, occurring from Baja California to the Bering Sea (Love et al. 2012). Given the wide range of environmental conditions under which Dover sole is present, the high availability of preferred substrate, and the ability to switch between prey types, concern for the population under climate change is relatively low. Juveniles and adults have a broad diet of epibenthic and infaunal invertebrate prey that includes mollusks and echinoderms (e.g., brittlestars), which may be vulnerable to climate change impacts on ocean chemistry. More broadly, behavioral effects of ocean acidification may affect olfaction, predator-prey interactions,

locomotory function, and habitat choice (Somero et al. 2016).

There is no direct evidence of vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items of Dover sole include crustaceous zooplankton that could be impacted by ocean acidification, but the direction and impact of this effect remains highly uncertain.

Climate Vulnerability Rankings

Overall climate vulnerability was *low* with 98% certainty from bootstrap analysis. Overall climate exposure was ranked *moderate*, given the distribution of Dover sole and the magnitude of projected changes in climate and ecosystem properties. This rating was primarily due to very high exposure to *ocean acidification* (4.0) and high exposure to *mean sea surface temperature* (3.0), attributes that show significant change throughout the northeastern Pacific.

Dover sole had *low* biological sensitivity, given its broad diet and range of habitats including mud, sand, and gravel (Pearcy and Hancock 1978; Hunter et al. 1990; Nasby-Lucas et al. 2002; Love et al. 2005; Love 2011; Getsiv-Clemons et al. 2012). Among the sensitivity attributes considered, only *population growth rate* was in the moderate range (3.0). This species is relatively long-lived (up to 60 years) with a low natural mortality rate (~0.1 yr⁻¹; Hicks and Wetzel 2011).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was considered *high* for Dover sole in part due to a high inverse score for *adult mobility* (3.4) and a very high score for *habitat specificity* (3.8). As broadcast spawners with planktonic durations on the order of several months (Butler et al. 1996; Abookirea and Bailey 2007; Love 2011), the inverse score for *dispersal of early life stages* was also very high (3.9). Directional effect of climate change on Dover sole was *neutral* (-0.06).

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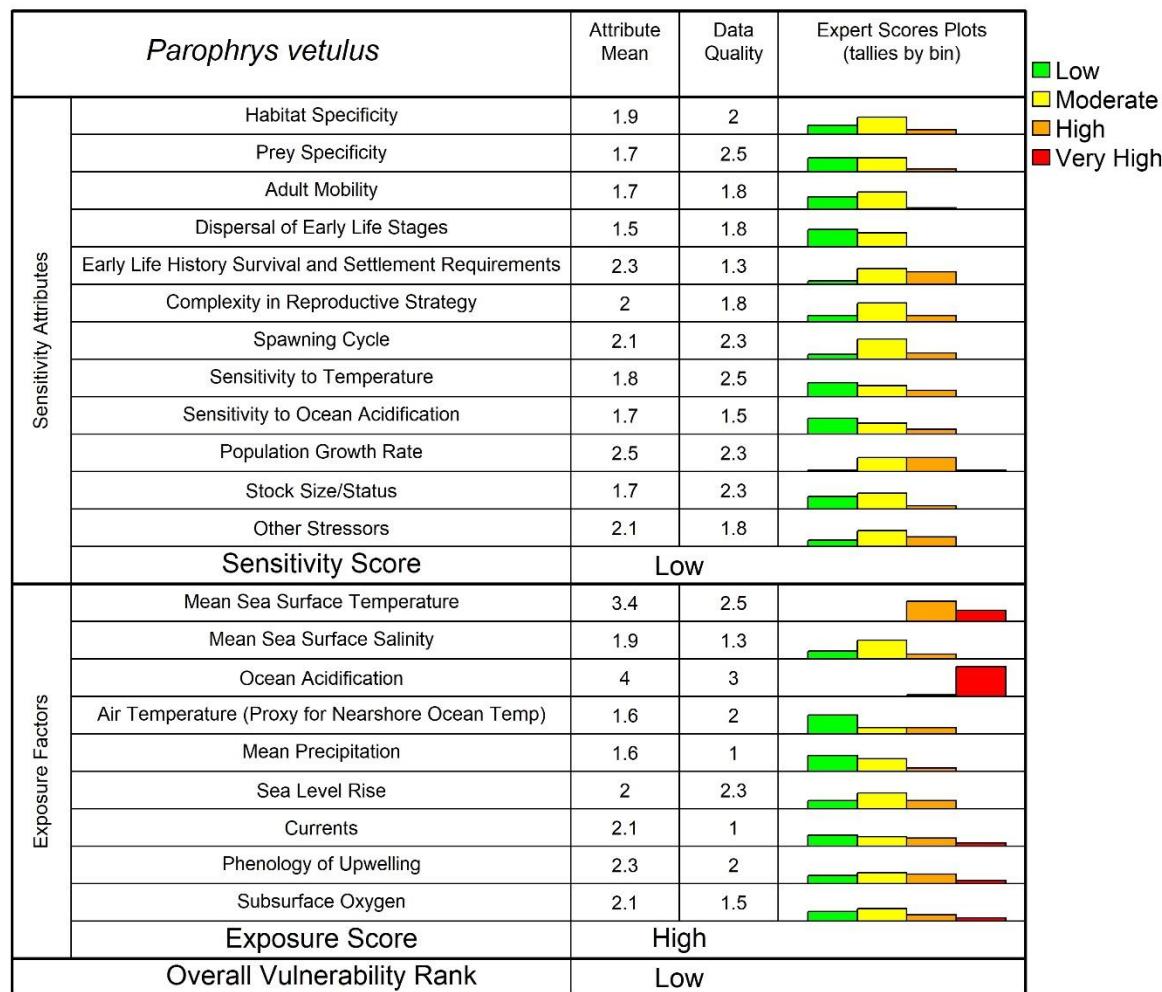
English Sole (*Parophrys vetulus*)

Overall Vulnerability Rank = Low

Habitat Sensitivity = Low

Climate Exposure = High

Data Quality = 52% of scores ≥ 2



Life History Synopsis

In the California Current, English sole spawn from at least September to April with a possible peak in January and February. In Alaska, spawning occurs in late spring and summer. Females produce 150,000 to 2,100,000 eggs. A summary of spawning times in the eastern North Pacific notes that timing varies with geographic area: October-May in the CalCOFI area; January-April in Puget Sound, Washington; and late

spring-summer in Alaskan waters (Matarese et al. 2003). The pelagic larvae settle nearshore and in estuaries with an ontogenetic shift to deeper waters as size increases. In estuaries, juvenile English sole inhabit muddy and sandy seafloor habitats and eelgrass beds. Young-of-the year migrate from estuaries to the open coast by 150 mm standard length (SL).

Fifty percent maturity is 4-7 years for females and 2-3 years for males. From the most recent stock assessment, length at 50% maturity is 23.3 cm fork length (FL). These findings differ substantially from the observations of Harry (1959), who found that 50% of female English sole matured at 31 cm FL. This dramatic change in length at maturity between the 1950s and 1990s indicates that much smaller fish are contributing to the present spawning biomass (Stewart 2005, 2007).

The geographic range for English sole extends from the Bering Sea and Aleutian Islands to Baja San Cristobal in central Baja California. English sole inhabit depths from the intertidal zone as juveniles to about 550 m as adults, but are most common at depths less than 200 m. English sole make limited migrations. Rooper (as cited in Love 2011) commented that adults make along-shelf migrations during winter to suitable spawning habitats on mud and sandy seafloor. English sole off Washington show a northward post-spawning migration in spring to summer feeding grounds, and a southward movement in fall (Garrison and Miller 1982). Ketchen observed a general movement to deeper waters as fish grow.

Gadomski and Boehlert (1984) observed that the diet of English sole larvae off Oregon was very specific; appendicularians (*Oikopleura* spp.) comprised 97% of the total number of food items consumed. Both English sole larvae and appendicularians are most abundant during fall and winter, when zooplankton concentrations off Oregon are low.

Climate Effects on Abundance and Distribution

Juvenile and adult English sole have a broad diet of epibenthic and infaunal invertebrate prey that includes mollusks and echinoderms (e.g., brittlestars), which may be vulnerable to global change impacts on ocean chemistry. More broadly, behavioral effects of ocean acidification may affect olfaction, predator-prey interactions, locomotory function, and habitat choice (Somero et al. 2016). However, the broad opportunistic nature of the English sole diet may buffer potential loss of certain prey types.

Alderdice and Forrester (1968) reported optimum conditions for larval survival at salinities of 25-28 ppt and temperatures of 8-9°C. Temperatures around 18°C appear to be the upper thermal tolerance for juvenile English sole, with higher temperatures leading to reduced daily ration and growth (Yoklavich 1982). The upper lethal limit for English sole is 26.1°C (Ames et al. 1978). Production of recruits and population distribution is limited at the extreme southern end of the range because of increased water temperatures, especially in estuaries. An increase in temperatures could result in a northward shift to

more ideal temperature ranges.

West Coast estuaries, bays, and inland seas, such as Puget Sound, are critical nurseries for English sole. Therefore, the species is more vulnerable to anthropogenic impacts to these habitats associated with development and land use activities. The combination of anthropogenic and climate change impacts (e.g. sea level rise) may render many of these nearshore habitats unsuitable for English sole.

Climate Vulnerability Rankings

Overall climate vulnerability for English sole was ***low*** with 94% certainty from bootstrap analysis, although overall climate exposure was ranked ***high***. Two attributes led to the high exposure ranking for English sole: *mean sea surface temperature* (3.4) and *ocean acidification* (4.0). Overall biological sensitivity was ranked ***low***, with only *population growth rate* (2.5) ranking in the moderate category. *Early life history survival and settlement requirements* (2.3) also bordered between low and moderate.

Distributional vulnerability and directional effect

Vulnerability to distributional shift was ranked ***high*** for English sole. Adults migrate between spawning and feeding grounds; thus, the inverse score for *adult mobility* ranked high (3.3). Inverse scores for *dispersal of early life stages* ranked very high (3.5), as larvae are pelagic and disperse to estuaries along the coast. Inverse scores for *habitat specificity* ranked high (3.1), as English sole are both pelagic and benthic, utilizing estuaries for rearing and the nearshore shelf for migrations. Directional effect of climate change on English sole was ***neutral*** (-0.19).

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Gopher Rockfish (*Sebastodes carnatus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 48% of scores ≥ 2

<i>Sebastodes carnatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.8	2.8	 
	Prey Specificity	1.6	2.8	 
	Adult Mobility	2.8	2.5	 
	Dispersal of Early Life Stages	1.7	1.8	 
	Early Life History Survival and Settlement Requirements	2.7	1.3	 
	Complexity in Reproductive Strategy	2.2	1.3	 
	Spawning Cycle	2.6	2.5	 
	Sensitivity to Temperature	2.3	2.5	 
	Sensitivity to Ocean Acidification	1.3	1.5	 
	Population Growth Rate	3.3	2.3	  
	Stock Size/Status	1.7	1.5	 
	Other Stressors	1.8	1.3	 
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.3	2	 
	Mean Sea Surface Salinity	1.1	1	
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.3	2.3	 
	Mean Precipitation	1.1	1	 
	Sea Level Rise	1.2	2.5	 
	Currents	1.9	1	   
	Phenology of Upwelling	1.7	1.5	 
	Subsurface Oxygen	2.5	1.8	 
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Gopher rockfish is common in central California and ranges from Baja California (Mexico) to southern Oregon. Parturition occurs from March to May (Wyllie Echeverria 1987), followed by a 1- to 2-month pelagic juvenile stage. Juveniles settle primarily into nearshore kelp canopies. Adults associate with rocky reef habitat in waters 12-80 m deep (Love et al. 2002).

Like other rockfish species, gopher rockfish is long-lived (30+ years), slow growing, and a highly fecund live-bearer. Gopher rockfish are territorial with small home ranges of 10-12 m², although movement of greater distances have been observed. Primary prey items include copepods and krill during the pelagic juvenile stage, with a shift to benthic crabs and shrimp in adults (Love et al. 2002). Genetic analyses suggest that gopher rockfish is closely related to black-and-yellow rockfish (*S. chrysomelas*), with low levels of genomic divergence (Love et al. 2002; Buonaccorsi et al. 2011).

Climate Effects on Abundance and Distribution

Gopher rockfish is strongly associated with shallow, nearshore, rocky reef habitats. These constitute approximately 15-20% of nearshore habitats off Central and Northern California (Eschmeyer and Herald 1983; Love 1996; R. Miller, NMFS SWFSC, pers. comm.). Effects of temperature change on the distribution of kelp and associated species (e.g. prey items) may affect the distribution and/or survival of newly settled and adult gopher rockfish.

Climate Vulnerability Rankings

Overall climate vulnerability of gopher rockfish was ***moderate*** with 90% certainty and ***high*** with 10% certainty from bootstrap analysis, with climate exposure ranking ***high***. Three attributes contribute to the high exposure score: *high ocean surface temperature* (3.3), *very high ocean acidification* (4.0), and to a lesser degree, *subsurface oxygen* (2.5). *Mean sea surface salinity*, *air temperature*, *mean precipitation*, and *sea level rise* scored low to moderate.

Overall biological sensitivity of gopher rockfish was ranked ***moderate***. One sensitivity attribute was ranked high: *population growth rate* (3.3). Sensitivity attributes scored as moderate included *adult mobility* (2.8), *early life history survival and settlement requirements* (2.7), *habitat specificity* (2.8), *spawning cycle* (2.6), *prey specificity* (1.6), *dispersal of early life stages* (1.7), *complexity in reproductive strategy* (2.2) and *sensitivity to temperature* (2.3). All other sensitivity attributes were scored as moderate, with most having some scores in either the low or high categories. Only three sensitivity attributes received a very high score.

Distributional vulnerability and directional effect

The potential for distributional shift of gopher rockfish in response to climate change was ***low***. Inverse scores of all attributes ranked in the low category with the exception of *dispersal of early life stages* (3.3). The directional effect of climate change on gopher rockfish was ***negative*** on average (-0.38), with 0 positive, 10 neutral, and 6 negative scores.

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Honeycomb Rockfish (*Sebastes umbrosus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 29% of scores ≥ 2

<i>Sebastes umbrosus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.5	1.8	 
	Prey Specificity	1.7	1	 
	Adult Mobility	2.6	1.3	 
	Dispersal of Early Life Stages	1.6	1.3	 
	Early Life History Survival and Settlement Requirements	2.8	1.3	 
	Complexity in Reproductive Strategy	2.2	0.8	  
	Spawning Cycle	2.7	1.8	  
	Sensitivity to Temperature	2.3	2.5	 
	Sensitivity to Ocean Acidification	1.3	1	 
	Population Growth Rate	3.5	2	  
	Stock Size/Status	1.6	0.5	 
	Other Stressors	1.5	1.5	 
	Sensitivity Score	Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.7	2	 
	Mean Sea Surface Salinity	1.1	1	 
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.3	2.3	  
	Mean Precipitation	1	1	 
	Sea Level Rise	1.1	2.5	 
	Currents	1.8	1	  
	Phenology of Upwelling	1.8	1.5	  
	Subsurface Oxygen	2.3	1.8	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Honeycomb rockfish is a solitary species found in relatively shallow waters of 30-270 m over rocky substrate (Love et al. 2002). Honeycomb ranges primarily between 27 and 34°N, from Baja California to Point Conception but can also be found in Central California (Love et al. 2002). Little is known about the species life history. Honeycomb rockfish reach maturity at 5-8 years (Love et al. 2002). Spawning occurs during

March-July, with a peak in April (Love 1996; Chen 1971), and temperature may affect spawning time. Parturition occurs later in the year at higher latitudes for similar species.

Larval duration is not known, but is likely similar to that of other rockfishes (1 month-1 year). Juveniles recruit to shallow (<70 m) habitats with structure (Love et al. 1991). Adults are also primarily benthic and not highly mobile, but can be found 3-4 m off the seafloor (Love et al. 1991; Love et al. 2002). Neither the juvenile or adult diet are known, though diets for both stages are assumed to be composed of euphausiids and other planktonic crustaceans (Love 1996; Love et al. 2002). Maximum age is at least 31 years (Love et al. 2002). Honeycomb rockfish is caught by recreational fishers but is typically discarded because of its small size. However, there has been a rise in recreational catches of honeycomb as larger species become depleted (Love et al. 1998).

Climate Effects on Abundance and Distribution

No studies have examined climate change effects on honeycomb rockfish abundance or distribution. However, Jarvis et al. (2004) found that from 1980 to 2000, recreational landings of honeycomb rockfish were negatively correlated with offshore temperature; as offshore temperature increased, honeycomb rockfish catch rates decreased. Honeycomb rockfish may also be exposed to hypoxic waters that could potentially extend to the continental shelf with climate change.

Climate Vulnerability Rankings

Overall climate vulnerability of honeycomb rockfish was ***moderate*** with 97% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***, with two exposure attributes contributing to this score: *mean sea surface temperature* (3.7) and *ocean acidification* (4.0). Exposure to increasing sea surface temperatures in Southern California and Baja California was expected to be very high.

Overall biological sensitivity was ranked ***moderate***, with four attributes contributing to this score: *adult mobility* (2.6), *early life history survival and settlement requirements* (2.8), *spawning cycle* (2.7), and *population growth rate* (3.5). High variability in honeycomb rockfish recruitment suggests that early life history survival is affected by environmental conditions.

Distributional vulnerability and directional effect

Inverse scores from two attributes indicated ***moderate*** vulnerability to distributional shift in response to climate change: high *dispersal of early life stages* (3.4) and moderate *habitat specificity* (2.5). Directional effect of climate change on honeycomb rockfish was ***neutral*** (-0.13).

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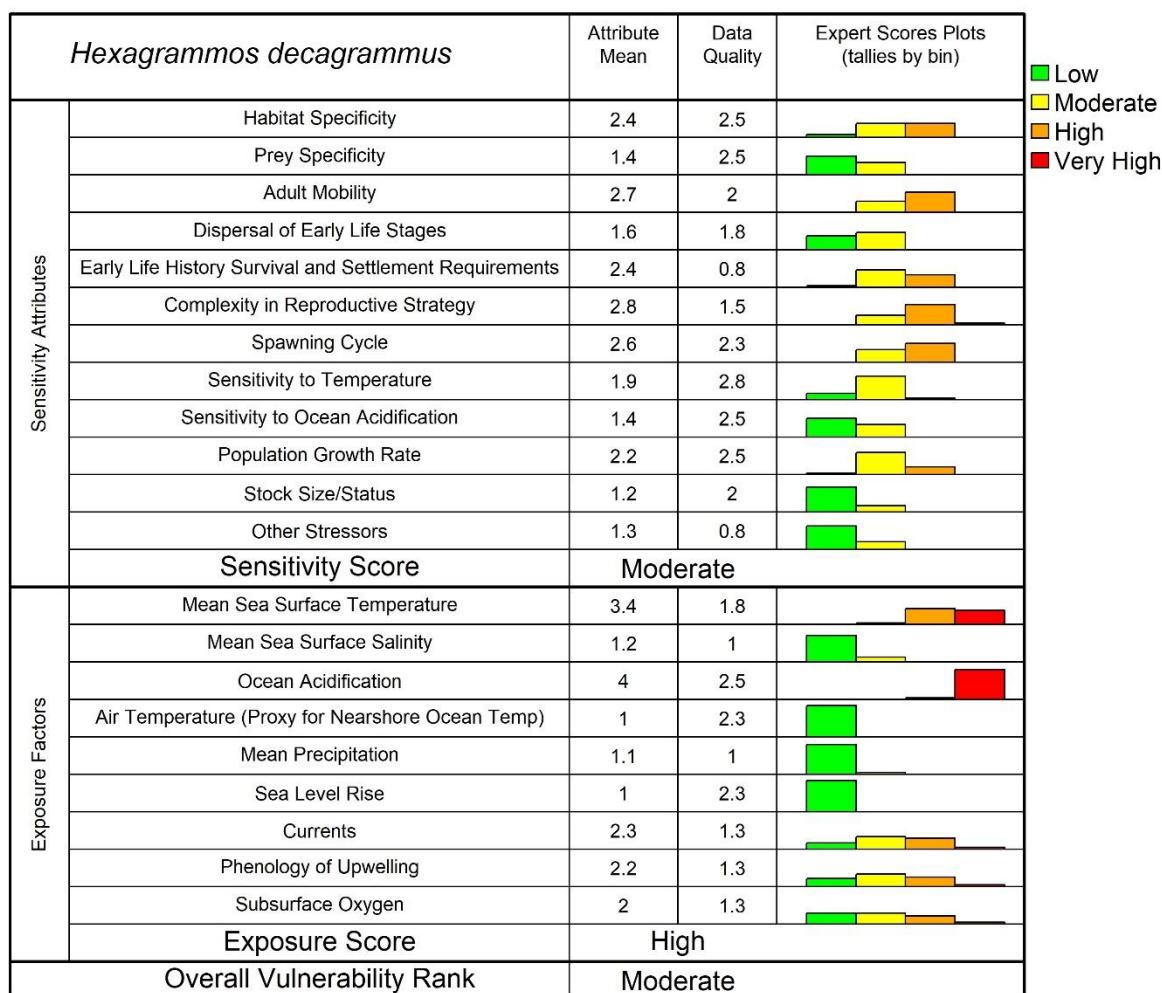
Kelp Greenling (*Hexagrammos decagrammus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 52% of scores ≥ 2



Life History Synopsis

Kelp greenling is a nearshore species that occurs from the Aleutian Islands and Gulf of Alaska, south to La Jolla, Southern California; however, it is found primarily from the Aleutians to Point Conception (Love 2011). Juveniles and adults are solitary and demersal, inhabiting rocky reefs from shallow subtidal areas to depths of 130 m, although much of the species range is restricted to depths less than 20 m (Love 2011;

Freiwald 2012; Easton et al. 2015). Kelp greenling is a moderately long-lived (20-25 years) and fast-growing species, with a maximum length of 62.9 cm (Berger et al. 2015).

Kelp greenling is both gonochoristic and sexually dimorphic (size and coloration), and most individuals are sexually mature by age 2. Spawning occurs between July and January. Females are highly fecund, producing 28,500-125,000 eggs per year. Several clutches are attached to rocky substrate and other structures. Males guard multiple egg clutches until they hatch. Egg duration is about 30 d at 10°C (DeMartini 1986), and young spend several months as epipelagic larvae and juveniles that settle to shallow rocky reefs after attaining 5-9 cm in length (Burge and Schultz 1973; Love 2011; Marliave 1975; Matarese et al. 1989; ODFW 2002; Berger et al. 2015). Both juveniles and adults exhibit movements of less than 0.5 km, especially on isolated rocky reefs (Freiwald 2009; 2014).

Larval diets are unknown, though the vast majority of larval fishes feed on crustacean zooplankton, with juveniles and adults feeding on small benthic crustaceans (e.g., amphipods), polychaete worms, brittle stars, echinoderms, mollusks, fish eggs (including kelp greenling), and small fishes (Bryant 1978; Love 2011; Moulton 1977).

Climate Effects on Abundance and Distribution

No studies have examined the effect of climate factors on the population productivity, abundance, or distribution of kelp greenling. Larval, juvenile, and adult stages of this shallow-dwelling nearshore species are exposed to projected increases in mean sea surface temperature and ocean acidification. These changes will likely impact distribution and prey availability.

Climate Vulnerability Rankings

For kelp greenling, overall climate vulnerability was ***moderate*** with 99% certainty from bootstrap analysis. Overall climate exposure was ranked ***high***. Primary drivers of this rank included a high exposure score for *mean sea surface temperature* (3.4) and a very high exposure score for *ocean acidification* (4.0). Increasing exposure to these attributes was expected during the larval, juvenile, and adult stages of this shallow-dwelling nearshore species. Overall biological sensitivity of kelp greenling was ranked ***moderate***. Primary drivers of sensitivity included *adult mobility* (2.7), *complexity in reproductive strategy* (2.8) and *spawning cycle* (2.6).

Distributional vulnerability and directional effect

A ***moderate*** likelihood of distributional shift for kelp greenling reflected the high inverse score for *dispersal of early life stages* (3.4) and moderate inverse scores for habitat specificity (2.6) and adult mobility (2.3), with a low inverse score for *sensitivity to temperature* (1.9). Directional effect of climate change for kelp greenling on the U.S. West Coast shelf was ***neutral*** (-0.33), reflecting capacity for this species to redistribute to preferred environmental conditions. However, there was much variation in this score

among experts.

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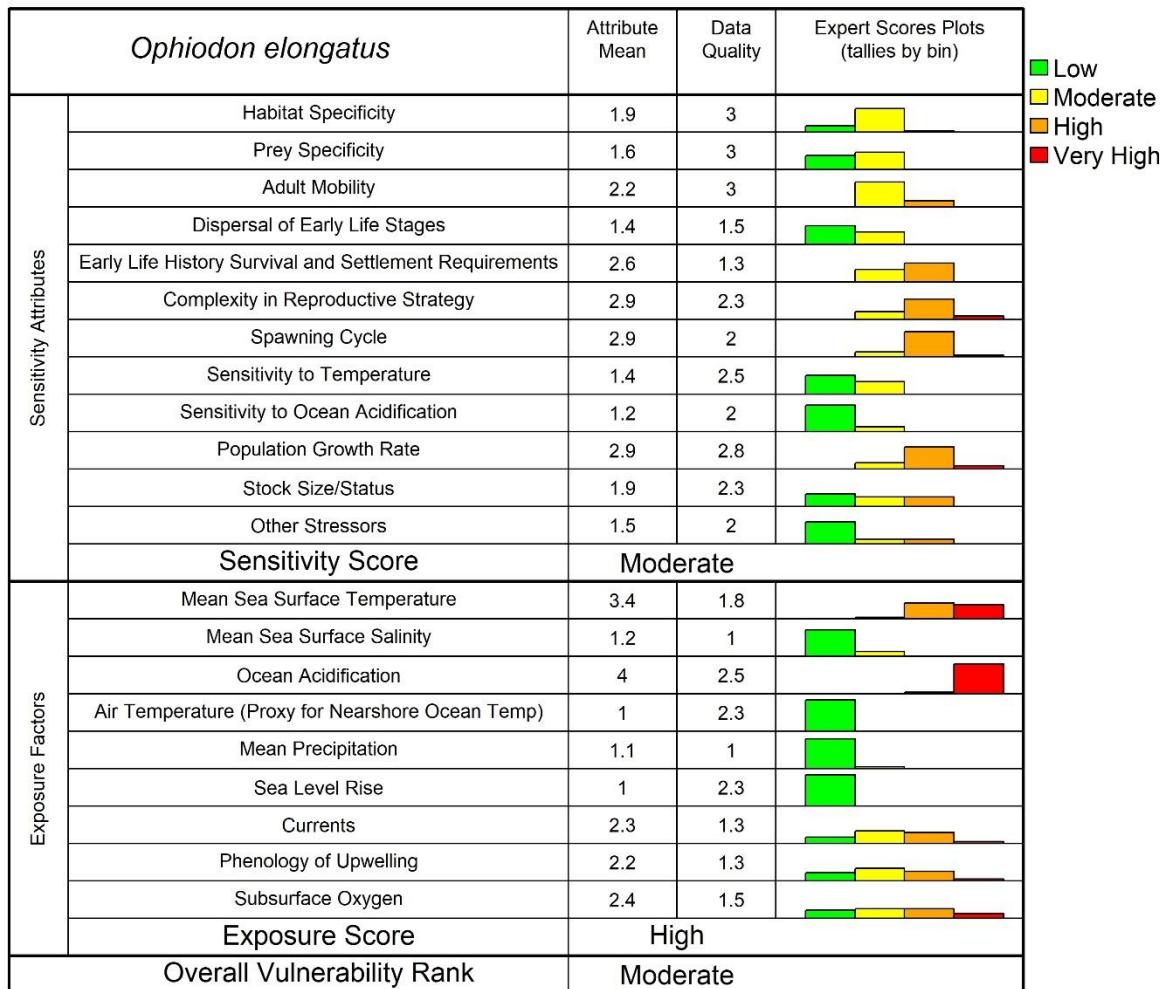
Lingcod (*Ophiodon elongatus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 62% of scores ≥ 2



Life History Synopsis

Lingcod occur along the coast of the northeast Pacific Ocean from the Aleutian Islands to Baja California, with the center of abundance off British Columbia and Washington State (Hart 1973). Juveniles and adults are solitary and demersal. At about 3 months of age, juveniles settle on sandy bottom areas near eelgrass or kelp beds. By age-1 or -2, lingcod move into rocky habitats, similar to those occupied as adults but

shallower. Adults are demersal, display a patchy distribution, and are most abundant in areas of hard bottom with rocky relief at depths less than 183 m, although they are occasionally found at depths exceeding 366 m (Miller and Geibel 1973; Smith and Forrester 1973; Phillips and Barraclough 1977; Buckley et al. 1984; Love 2011). Lingcod is a long-lived, fast-growing species, reaching ages of at least 25 years and maximum lengths of 152 cm.

Female lingcod are fecund, depositing 97,000-490,000 eggs per year. Several clutches attach to the rocky substrate and other structures, and males guard multiple egg clutches until they hatch. Nest deposition typically occurs in rock crevices, on rock ledges, or under boulders in areas of swift current. Ambient oxygen levels are critical to egg survival (Georgi 1981), with salinity and temperature affecting egg survival as well (Cook et al. 2005). Spawning locations range from the intertidal zone to a depth of 126 m (Georgi 1981; LaRiviere et al. 1981; O'Connell 1993). Egg duration ranges 24-72 d and is temperature-dependent.

Lingcod young spend 3 months as pelagic larvae and juveniles before settling to sandy-bottom areas of the seafloor (Phillips and Barraclough 1977). Epipelagic larvae are found near the surface during the day and deeper at night. Juveniles eventually associate with rocky habitat, and adults associate with higher rocky relief reefs.

Estimates of adult movement based on numerous tagging and telemetry studies suggest a wide range of movement, with distances of 0-47 km, although many studies indicate more limited movement. These results suggest that some individuals move much more than others (Cass et al. 1990; Matthews 1992; Starr et al. 2004, 2005; Greenley 2009; Tolimieri et al. 2009; Reynolds et al. 2010; Beaudreau and Essington 2011; Freiwald 2012). Females migrate from deep to shallow reefs annually to reproduce with resident adult males (Miller and Geibel 1973; Greenley 2009).

Epipelagic larvae feed on small copepods and copepod eggs, shifting to larger copepods and fish larvae as they grow (Phillips and Barraclough 1977; Cass et al. 1990). Juvenile lingcod feed on small fishes including herring, Pacific sand lance, flatfish, shiner perch, and walleye pollock, as well as an assortment of invertebrates including shrimp and prawns. Adult lingcod are generally considered top predators, eating multiple types of fish, crustaceans, octopus, squid, and other prey (Cass et al. 1990), including coastal pelagic fish and rockfishes (Beaudreau and Essington 2007, 2009; Tinus 2012).

Climate Effects on Abundance and Distribution

No studies examine the effect of climate factors on the population productivity, abundance, or distribution of lingcod. However, because lingcod inhabits nearshore waters, exposure to increasing sea surface temperature can potentially result in a distributional shift. Lingcod spawning is restricted to winter seasons (Wilby 1937; LaRiviere et al. 1981). There is also the possibility of a shift in diet composition as ocean

acidification increases.

Climate Vulnerability Rankings

Overall climate vulnerability was **moderate** with 90% certainty and **high** with 10% certainty from bootstrap analysis. Overall climate exposure was ranked **high**. Primary drivers of exposure included *mean sea surface temperature* (3.4) and *ocean acidification* (4.0). Lingcod exposure to change in these two attributes is high during larval, juvenile, and adult stages of this shallow-dwelling, nearshore species. Overall biological sensitivity was ranked **moderate**. Primary drivers of sensitivity included *complexity in reproductive strategy* (2.9), *population growth rate* (2.9), *spawning cycle* (2.9), and *early life history survival and settlement requirements* (2.6).

Distributional vulnerability and directional effect

A **high** likelihood of distributional shift in response to climate change was reflected by a moderate inverse score for *adult mobility* (2.8), a high inverse score for *habitat specificity* (3.1), and a very high inverse score for *dispersal of early life stages* (3.6). Directional effect of climate change on lingcod of the U.S. West Coast shelf was **neutral** (-0.31).

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Pacific Cod (*Gadus macrocephalus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = Moderate 

Data Quality = 48% of scores ≥ 2

<i>Gadus macrocephalus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.3	2.8	 
	Prey Specificity	1.4	3	 
	Adult Mobility	1.4	3	 
	Dispersal of Early Life Stages	1.4	1.5	 
	Early Life History Survival and Settlement Requirements	2.5	1	 
	Complexity in Reproductive Strategy	2.4	2.5	 
	Spawning Cycle	3.1	1	 
	Sensitivity to Temperature	1.3	2.8	 
	Sensitivity to Ocean Acidification	1.1	3	 
	Population Growth Rate	2.5	1.8	 
	Stock Size/Status	2.3	1.5	  
	Other Stressors	1.6	1.3	 
	Sensitivity Score	Moderate		
Exposure Factors	Mean Sea Surface Temperature	2.9	2.3	  
	Mean Sea Surface Salinity	1.3	1.5	 
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	 
	Mean Precipitation	1	1	 
	Sea Level Rise	1	2.8	 
	Currents	2.3	1.3	 
	Phenology of Upwelling	2.1	1.3	  
	Subsurface Oxygen	2.4	1.8	  
	Exposure Score	Moderate		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Pacific cod occur along the northeast and northwest coasts of the Pacific Ocean from Japan (northern Yellow Sea), through the Bering Sea, Gulf of Alaska and south to southern California. Juveniles and adults are demersal and highly mobile (Shimada and Kimura 1994). They occur on the continental shelf from near-surface areas to depths of 875 m, although most occur at the 50- to 200-m depth. Pacific cod is a fast-growing

species, reaching a maximum length of 120 cm; individuals live at least 17 years.

Females mature at around 4 to 6 years and are highly fecund, producing 225,000 to 6.4 million eggs in only one batch per year (Love 2011). Demersal or semi-demersal eggs are spawned over coarse sand and gravel seafloors on the continental shelf or shallow slope. Survival, development, and hatching of eggs are temperature dependent (Bian et al. 2014).

Spawning of Pacific cod off the U.S. West Coast is not documented, although a small inshore stock regularly spawns off Port Townsend, Washington. In northern Puget Sound, spawning occurs from February to March at Amphirite Bank west of Vancouver Island. Tagging studies indicate the existence of migratory exchange between stocks in U.S. waters and those off the west coast of Vancouver Island in Canada, where other spawning occurs (Low et al. 1993).

However, recent analyses of elemental and isotopic otolith composition suggest that in the Pacific Northwest, inshore and offshore populations of Pacific cod are separate (Gao et al. 2005). Moreover, recent studies of spatial genetic structure in Pacific cod indicate not only population differences inshore and offshore, but also among coastal fjords, with larval dispersal estimates of only 30 km (Cunningham et al. 2009).

Epipelagic larvae are found near the surface.

Data for juvenile Pacific cod off the U.S. West Coast are largely unavailable, but juveniles are believed to be habitat generalists, inhabiting sheltered embayments in some areas and eelgrass beds in others (Laurel et al. 2007). In the Bering Sea, residency occurs along a gradient from coastal-demersal to shelf-pelagic (Hurst et al. 2012; 2015; Parker-Stetter et al. 2013). Adults exhibit extensive onshore/offshore migrations, although the extent of movement alongshore is less clear (Shimada and Kimura 1994).

Data from the Gulf of Alaska and Bering Sea suggest that young Pacific cod feed on amphipods and copepods, switching to age-0 walleye pollock during warm years (Abookire et al. 2007; Farley et al. in press). Adult Pacific cod are omnivores with a diet that consists largely of small fish—principally sand lance and herring—as well as a wide variety of invertebrates, including euphausiids, shrimps, crabs, and squid (Albers and Anderson 1985).

Climate Effects on Abundance and Distribution

Laboratory studies suggest two potential climate change vulnerabilities. First, temperature fluctuations in the North Pacific have direct potential to impact the size, growth, and endogenous reserves of Pacific cod larvae, which in turn will likely influence survival through interaction within the prey and predator field (Laurel et al. 2008). Second, under warmer water conditions, mismatches in prey can significantly impact growth and survival. However, both yolk reserves and compensatory growth mechanisms can reduce the severity of mismatches during the first 3 weeks of

development.

Laboratory experiments also detect a direct effect of temperature on larval behavior; larvae exhibit a weaker surface orientation at warmer water temperatures (Hurst et al. 2009). Pelagic larval duration is unknown, but juveniles settle to shallow nearshore intertidal and sand habitats.

No studies examine the effect of climate factors on the distribution and population productivity of Pacific cod. Adults are demersal and at depth, however juveniles occur in shallow nearshore ecosystems, including estuaries, which are likely to experience marked changes in temperature, salinity, and acidification; these changes may alter productivity of nursery habitats. Because larvae occur in the upper water column, they are susceptible to increased water temperature and the ensuing higher metabolic rate and greater demand on food availability in a stratified water column. However, these effects may be ameliorated by the broader distribution of juveniles outside embayments.

Changes in water temperature and productivity may lead to mismatches between larvae and prey because of a restricted spawning period that may be timed with periods of productivity for larvae. Populations are likely to shift with changes in ocean temperature because both adults and larvae are highly mobile.

Climate Vulnerability Rankings

Overall climate vulnerability of Pacific cod was ***moderate*** with 86% certainty from bootstrap analysis. Overall climate exposure was also ranked ***moderate***. Primary drivers of exposure include *mean sea surface temperature* (2.9) and *ocean acidification* (4.0). Pacific cod are exposed to projected increases in these attributes at the larval, juvenile and adult stages. Overall biological sensitivity was ranked ***moderate*** for Pacific cod. Primary drivers of this rank were the sensitivity attribute scores for *spawning cycle* (3.1), *early life history and settlement requirements* (2.5), and *population growth rate* (2.5). Juveniles inhabit estuarine environments.

Distributional vulnerability and directional effect

Three attributes indicated a very ***high*** likelihood of distributional shift for Pacific cod in response to climate change: very high inverse scores for *dispersal of early life stages* (3.6), *habitat specificity* (3.7), and *adult mobility* (3.6). However, with growing evidence of separate inshore and offshore stocks, these mobility estimates may be overestimated for inshore stocks. Otherwise, because both adults and larvae of offshore stocks are highly mobile, populations are likely to shift with changes in ocean temperature. Moreover, inshore populations may shift to deeper offshore water. The directional effect on Pacific cod was considered likely to be ***negative*** (-0.56).

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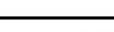
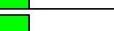
Pacific Grenadier (*Coryphaenoides acrolepis*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = Moderate 

Data Quality = 52% of scores ≥ 2

<i>Coryphaenoides acrolepis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.1	2.5	 
	Prey Specificity	1.5	2.8	 
	Adult Mobility	2.1	1.5	  
	Dispersal of Early Life Stages	1.4	1	 
	Early Life History Survival and Settlement Requirements	2.2	0	  
	Complexity in Reproductive Strategy	1.2	2.3	 
	Spawning Cycle	1.2	2.3	 
	Sensitivity to Temperature	1.1	2.5	 
	Sensitivity to Ocean Acidification	1.2	2	 
	Population Growth Rate	3.7	2.5	 
	Stock Size/Status	1.9	0	  
	Other Stressors	1.4	0	  
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	2.8	2.3	  
	Mean Sea Surface Salinity	1.2	1.5	 
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.8	
	Currents	2.3	1.3	  
	Phenology of Upwelling	2.1	1.3	  
	Subsurface Oxygen	2	1.8	  
	Exposure Score	Moderate		
Overall Vulnerability Rank		Low		

Life History Synopsis

Pacific grenadier is one of the most abundant fish on continental slopes worldwide, occurring from the Sea of Okhotsk and the Pacific Ocean off Japan, across the Bering Sea and Aleutian Islands to central Baja California (Matsui et al. 1990). Off California, adults are found in deep water of 1,000-2,500 m (Love 2011). Little is known about the habitat requirements of juveniles, which are reported to settle on soft substrate in the shallower part of the adult range (Love 2011). Juveniles have been observed at

40 m off the seafloor, and diel migration to deeper water may occur during daylight hours.

Age is difficult to determine due to sagittal otolith shape (Burton 1999), maximum age range is estimated from 56-73 years (Matsui et al. 1990, Andrews et al. 1999) to as high as 80 years (Love 2011). Age at maturity is estimated at 20-40 years (Love 2011). Grenadier is relatively slow growing, with the Von Bertalanffy growth rate estimated at approximately 0.04. Other productivity-related life history parameters are not available for Pacific grenadier.

Pacific grenadier is oviparous, with planktonic larvae (Ambrose 1996). Spawning occurs year-round, with a peak in early spring (Love 2011). Ripe females are present off Oregon in spring and fall, and high variability in spawning condition is observed among individuals captured in the same longline sets. Therefore, it is likely that, like many other deep-sea fish, Pacific grenadier has a protracted spawning season. Eggs are broadcast at depth and develop in the water column (Ambrose 1996).

Pacific grenadier off the U.S. West Coast is largely a benthic feeder, with a broad trophic profile (Percy and Ambler 1974; Okamura 1970). Smaller fish mostly feed on polychaetes, amphipods, cumaceans, and mysid shrimps (Love 2011). Some have found that this species can also feed on pelagic items, including nekton and macroplankton (Savvatimskii 1969).

Climate Effects on Abundance and Distribution

No studies examine climate change effects on Pacific grenadier abundance or distribution. Pacific grenadier has dispersive early life stages and a broad distribution (Matsui et al. 1990). The broad geographic range suggests that this species can change distribution in response to climate change. Ocean acidification has negative effects on fertilization success and on egg and larval viability in most invertebrate species (Byrne 2011; Whitely 2011), but mixed effects are reported for early life history stages of many marine fish species (Munday et al. 2009; Pankhurst and Munday 2011).

Climate Vulnerability Rankings

Overall climate vulnerability for Pacific grenadier was ***low*** with 95% certainty from bootstrap analysis. Overall climate exposure was ranked ***moderate***. Attributes contributing most to this rank were low scores for *mean sea surface salinity* (1.2), *air temperature* (1.0) *mean precipitation* (1.0), and *sea level rise* (1.0). Exposure attributes scoring moderate were *mean sea surface temperature* (2.8), *currents* (2.3), *phenology of upwelling* (2.1), and *subsurface oxygen* (2.0). The one high exposure score was *ocean acidification* (4.0).

Overall biological sensitivity was ranked ***low*** for Pacific grenadier, with most attributes scoring low to moderate: *habitat specificity* (1.1) and *prey specificity* (1.5) were low; *early life history survival and settlement requirements* (2.2) and *adult mobility*

(2.1) were moderate. *Population growth rate* was scored high (3.7), but there is no direct information on most of the critical life history parameters of Pacific grenadier, and the closest estimate of intrinsic rate of increase was a proxy from another grenadier species (giant grenadier) that differs substantially in habitat, size and growth.

Distributional vulnerability and directional effect

A **high** likelihood of distributional shift in response to climate change was reflected by scores for lack of *habitat specificity* (3.9) and *dispersal of early life stages* (3.6). Directional effect of climate change on the Pacific grenadier of the U.S. West Coast shelf was **neutral** (-0.25).

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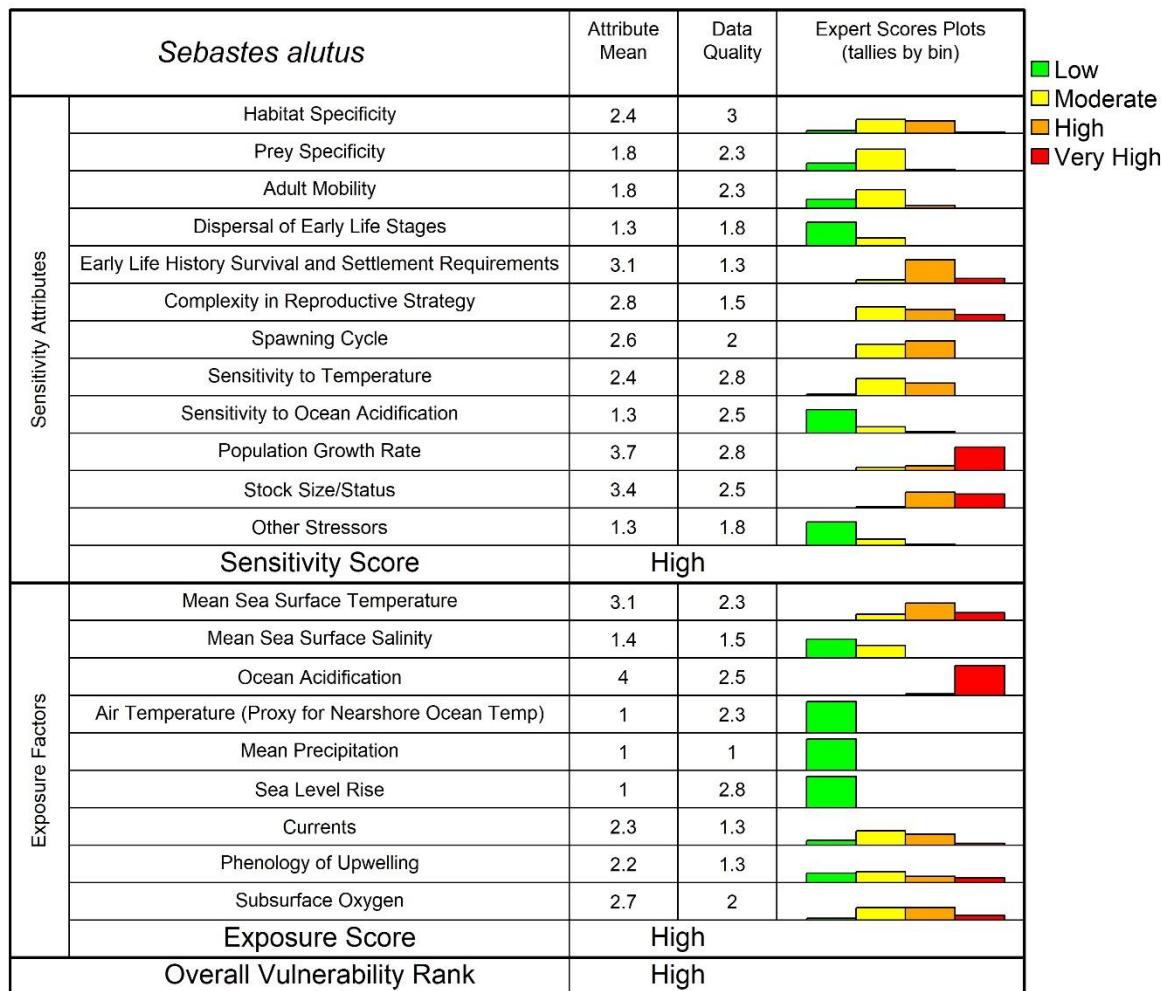
Pacific Ocean Perch (*Sebastodes alutus*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 62% of scores ≥ 2



Life History Synopsis

Pacific ocean perch occur along the northeast and northwest coast of the Pacific Ocean from Japan (Sea of Okhotsk), through the Bering Sea, Gulf of Alaska and south to central Baja California, Mexico. Pacific ocean perch is found off Oregon and Washington, sparsely off northern California, and rarely off central and southern California. Pacific ocean perch tend to be found at temperatures in the 4-7°C range.

Adults are mostly demersal, associated with flat, pebbled substrate along the continental shelf at depths of 150-350 m during summer, and at potentially deeper depths in fall and winter (Hoff 2013; von Szalay et al. 2011; Love et al. 2002; Gunderson 1971). Schools of juveniles and adults occur along the bottom, but rise high into the water column. Individuals can live at least 104 years and reach a maximum length of 53 cm (Love et al. 2002).

Females mature around 4-10 years and are highly fecund, depositing 2,000-505,000 eggs (Love 2011). Pacific ocean perch parturition occurs primarily in late winter to early spring (February-May), though in highly variable oceanic conditions. Variation in timing between food availability and parturition likely accounts for some of the variability in early survival and recruitment success (Love et al. 2002; TenBrink and Spencer 2013). During summer and fall, males and females co-occur and mate in relatively shallow waters. Females migrate deeper onto the continental slope to give birth then return to join males at shallower depths.

Pacific ocean perch has a complex reproduction strategy involving courtship, mating, and internal fertilization and embryonic development (Love et al. 2002). Fecundity is a function of food availability, which is partially dependent on temperature via oceanographic conditions, and temperature-dependent metabolic rates. These factors affect the rate of embryonic development and date of parturition.

Juvenile Pacific ocean perch reside in a pelagic phase for an unknown period after metamorphosis from the larval stage, although spatial analyses of genetic stock structure indicate that Pacific ocean perch disperse on a scale of 70-400 km. Genetic analysis, in contrast, suggests three stocks off British Columbia (Wither et al. 2001; Palof et al. 2011). Juveniles age 1-3 probably live in rocky inshore areas associated with boulders, sponges, and upright coral (Carlson and Haight 1976; Rooper and Bolt 2005; Rooper et al. 2007; NPFMC 2010).

Pacific ocean perch is primarily planktivorous. Small juveniles eat mostly calanoid copepods, and larger juveniles eat mostly euphausiids (Yang 2003). Adults consume mostly euphausiids, with fish (primarily myctophids) and calanoid copepods also contributing to the diet (Yang 2003).

Climate Effects on Abundance and Distribution

The West Coast stock of Pacific ocean perch occupies the southern end of the species range, primarily off Oregon and Washington, but extends north into the Bering Sea and west to the Sea of Okhotsk. High adult mobility, very high dispersal of early life stages, and moderate habitat specificity all suggest a high likelihood of distributional shift in response to changing environmental conditions. Juveniles are associated with physical habitat structure in inshore waters.

Larvae occur high in the water column and therefore are exposed and sensitive to the effects of changing sea surface temperature, thermal stratification, and ocean acidification. A change in distribution toward the preferred temperature range (4-7°C) could lead to a range shift northward. Pacific ocean perch is a long-lived species with low population growth rates (Love et al. 2002; Love 2011), status of the stock was uncertain. All life stages were likely to exhibit marked distributional shifts. A shift away from the southern end of the present range would likely result in decreased abundance off the West Coast.

Climate Vulnerability Rankings

Overall climate vulnerability for Pacific ocean perch was **high** with 68% certainty and **moderate** with 32% certainty from bootstrap analysis. Overall climate exposure was ranked *high*, with two attributes contributing to this score: *ocean surface temperature* (3.1) and *ocean acidification* (4.0). Biological sensitivity was ranked **high**, with three attributes scored at or above 3.0: *early life history survival and settlement requirements* (3.1), *population growth rate* (3.7) and *stock size/status* (3.4).

Distributional vulnerability and directional effect

Inverse scores from three attributes indicate **high** likelihood of distributional shift as a response to climate change for Pacific ocean perch: high *adult mobility* (3.2), very high *dispersal of early life stages* (3.7), and moderate *habitat specificity* (2.6). The overall directional effect of climate change on Pacific ocean perch off of the U.S. West Coast was **negative** (-0.56).

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Pacific Sanddab (*Citharichthys sordidus*)

Overall Vulnerability Rank = Low

Habitat Sensitivity = Low

Climate Exposure = High

Data Quality = 67% of scores ≥ 2

<i>Citharichthys sordidus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	2	
	Prey Specificity	1.3	2.8	
	Adult Mobility	1.7	2	
	Dispersal of Early Life Stages	1.1	2	
	Early Life History Survival and Settlement Requirements	2	1.5	
	Complexity in Reproductive Strategy	1.5	1.8	
	Spawning Cycle	1.8	2.5	
	Sensitivity to Temperature	1.9	2.5	
	Sensitivity to Ocean Acidification	1.6	2	
	Population Growth Rate	1.8	2.8	
	Stock Size/Status	1.4	2	
	Other Stressors	1.3	1	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.1	2.3	
	Mean Sea Surface Salinity	1.4	1.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.3	2.3	
	Mean Precipitation	1.3	1	
	Sea Level Rise	1.2	2.5	
	Currents	2.1	1	
	Phenology of Upwelling	2.1	2	
	Subsurface Oxygen	2.4	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Pacific sanddab lives up to 13 years, but few individuals are older than 11 years (Arora 1951; He et al. 2013). Off central California, 50% of females are mature at 119 mm (total length) and nearly all are mature by 149 mm. The corresponding (unreported) age at 50% maturity is 1.13 years; however, caution should be used in interpreting age at maturity due to a large number of false marks observed in otoliths during the first years

of life (He et al. 2013; Lefebvre et al. 2016).

Female Pacific sanddab are oviparous broadcast spawners, and whether they aggregate to spawn is unknown. Chamberlain (1979) suggested they do not undergo extensive migrations. Additionally, sex ratios, size range, and frequency of occurrence does not differ between spawning and inter-spawning seasons in the same location off central California, suggesting they do not form large spawning aggregations (Moser and Sumida 1996; Lefebvre et al. 2015).

Females can spawn daily during the reproductive season, with larger females spawning more frequently than smaller females (Lefebvre et al. 2016). A protracted spawning season and frequent spawning events buffer against potential mismatch between larvae, their prey, and favorable environmental conditions. The spawning season varies with latitude and occurs during at least July–October off southern California, May–January in central California, in spring and summer in Oregon, and February–May in Puget Sound. Only Pacific sanddab from central California are well studied, and spawning in other regions may occur over a broader time range than reported here (Chamberlain 1979; Ureña 1989; Lefebvre et al. 2016).

Pelagic larval duration is up to 271 days. By 150 days fish attain the initial stages of metamorphosis, wherein the right eye is moving, but still located on the right side of head. Fish at this stage are most abundant offshore in the transition zone between oceanic and nearshore water at depths of 0–30 m. Fish at later stages of eye migration (both eyes on the left side) span pelagic depths to 110 m and are typically found nearshore in coastal upwelling zones. Post-metamorphosis juveniles (ages 0 and 1) are encountered in the same habitats as adults over sandy substrate at depths of 18–275 m (Sakuma and Larson 1995; Donohoe 2000).

Abundance of post-settlement juveniles on the upper continental slope and outer shelf off central Oregon are positively correlated with mean onshore Ekman transport. Peak settlement in this same area occurs in late fall to winter, outside the time period associated with increased seasonal upwelling (Donohoe 2000).

Larval and post-larval Pacific sanddab are planktivorous; however, prey preference is unknown at present (Rackowski and Pikitch 1989). Adults are generalists and primarily feed on pelagic prey, including northern anchovies, euphausiids, shrimps, amphipods, and crustaceans. Adults feed less often on benthic taxa, including cephalopods, gelatinous zooplankton, and other fish species (Kravitz et al. 1977; Pearcy and Hancock 1978; Wakefield 1984).

There is no quantitative estimate of Pacific sanddab stock status; however, the 2013 stock assessment implied that the stock is unlikely overfished or experiencing overfishing (He et al. 2013).

Climate Effects on Abundance and Distribution

Few studies examine the effects of climate change on the abundance and distribution of Pacific sanddab. The species ranges from Baja Mexico to the eastern Bering Sea, Alaska with a center of abundance in north to central California from San Francisco to Eureka (Arora 1951; He et al. 2013; Rackowski and Pikitch 1989). Adults are most commonly found in waters of the continental shelf over sandy habitats at depths of 35-95 m but can occur from 18-275 m (Sakuma and Larson 1995; Donohoe 2000).

Temperature tolerance for Pacific sanddab is unknown; however speckled sanddab, which inhabits shallower waters in the same region, show preference for temperatures of 10-20°C. Anecdotal evidence from a laboratory study of adults collected in central California suggests that spawning activity in females ceases when water temperatures drops below 10°C or rises above 13°C (Lefebvre unpublished data).

Climate Vulnerability Rankings

Overall climate vulnerability for Pacific sanddab was **low** with 100% certainty from bootstrap analysis, although overall climate exposure was ranked **high**. Two exposure attributes contributed to this score: *ocean acidification* (4.0) and *mean sea surface temperature* (3.1). Highly uncertain attributes included *currents*, *phenology of upwelling* and *subsurface oxygen*, with scores ranging from low to very high. All life stages of Pacific sanddab use marine habitats.

Overall biological sensitivity was ranked **low**, with attributes generally in the low to moderate range. The highest scoring sensitivity attribute was *early life history survival and settlement requirements* (2.0). Pacific sanddab is relatively fast growing and matures quickly, with an estimated age at 50% maturity of 1.13 years. The species is relatively short-lived with a maximum age of 13 years, but few fish are older than 11. Pacific sanddab has high reproductive output with females capable of spawning daily throughout the spawning season (Lefebvre et al. 2016).

Distributional vulnerability and directional effect

Pacific sanddab was ranked **high** in vulnerability to distributional shift in response to climate change. Inverse scores from three attributes contributed to this high rank: *adult mobility* (3.3), *habitat specificity* (3.2) and *dispersal of early life stages* (3.9). Pacific sanddab is mobile and lives over sandy substrate that is widely available. The species has broad dispersal during early life stages. Thus, the directional effect of climate change on Pacific sanddab was **neutral** (-0.13). This is likely due to low biological sensitivity to climate change, including an abundance of available habitat, wide species range, dispersal of larvae, a generalist feeding strategy, and high reproductive output.

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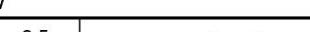
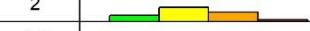
Pacific Hake (*Merluccius productus*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2

<i>Merluccius productus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	2.8	 (Legend: Low = green, Moderate = yellow, High = orange, Very High = red)
	Prey Specificity	1.5	3	
	Adult Mobility	1.1	3	
	Dispersal of Early Life Stages	1.9	2.5	
	Early Life History Survival and Settlement Requirements	2.3	2	
	Complexity in Reproductive Strategy	2	2	
	Spawning Cycle	2.4	2.3	
	Sensitivity to Temperature	1.6	2.5	
	Sensitivity to Ocean Acidification	1.7	1.8	
	Population Growth Rate	2.2	2.8	
	Stock Size/Status	1.4	3	
	Other Stressors	1.8	1.5	
	Sensitivity Score	Low		
Exposure Factors	Mean Sea Surface Temperature	3.3	2.5	
	Mean Sea Surface Salinity	1.3	1.5	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.5	
	Currents	2.2	1	
	Phenology of Upwelling	2.2	2	
	Subsurface Oxygen	2.3	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Pacific hake is a prominent species within the California Current Large Marine Ecosystem (CCLME). It is important ecologically both as predator and prey (Hamel et al. 2015; Love 2011; Field and Francis 2006), and economically as the largest west coast fishery by volume (Hamel et al. 2015). Managed jointly by the U.S. and Canada, Pacific hake include three stocks: a large coastal stock whose range extends from Baja to

Southeast Alaska, and smaller regional stocks found in Puget Sound and the Strait of Georgia (Iwamoto et al. 2004). Pacific hake can live to 20+ years, although it is uncommon for individuals to exceed 15 years of age (Hamel et al. 2015). Hamel et al. (2015) noted that 50% reach maturity by 4 years of age.

The Pacific hake coastal stock appears to form spawning aggregations in winter off southern California, although data are limited and spawning schools are difficult to locate due to varying location and depth (Saunders and McFarlane 1997; Bailey et al. 1982). The coastal stock spawns from January to March, forming dense spawning aggregations at depths varying depths offshore of southern California (Alverson and Larkins 1969).

However, since spawning aggregations data are limited, most of what is known about spawning is inferred from CalCOFI egg and larval data (Hollowed 1992; Saunders and McFarlane 1997). Pacific hake appears to occasionally spawn in alternate areas (Ressler et al. 2007). Spawning cues are unknown (Saunders and McFarlane 1997). The embryonic period is 5-9 d, while the larval stage lasts about 20 d after fertilization (Bailey et al. 1982).

Survival of larval and young Pacific hake in the first few months is influenced by ocean conditions such as favorable upwelling, advection, and water temperature (Hamel et al. 2015; Hollowed and Bailey 1989). Pre-recruit survival appears critical for the strength of a year class; the present model is that larval survival is favored by periods of weak offshore transport in January-February and stronger upwelling in March. More recruits appear to survive in warm years, presumably because they are not advected away from shelf nursery areas; however, a warm-water year does not guarantee high recruitment (Hollowed and Bailey 1989).

Recruitment is typified by episodic strong year classes, which appear largely independent of spawning stock size (Hamel et al. 2015). Hamel et al. (2015) also concluded that a strong year class may achieve abundances far greater than weaker year classes, even by 1-2 orders of magnitude, and that variation in mortality in the pre-recruit period "is a common explanation for similar recruitment dynamics in other species."

Later in spring, juveniles forage in the upwelling-driven production at the shelf break and shelf. Juveniles tend to be found in bays and estuaries, as well as shallower shelf locations than mature fish, although some juveniles can be found as far offshore as adult fish. Juveniles do not migrate as far north as older fish, though in some years juveniles have been found north of California in shelf regions off Oregon, Washington, and even British Columbia (Hamel et al. 2015; Love 2011; Ressler et al. 2007). Smaller juveniles feed on copepod eggs, copepods, and juvenile euphausiids. Large juveniles eat primarily euphausiids and calanoid copepods (Grover et al. 2002; Livingston and Bailey 1985; Bailey et al. 1982).

Adult Pacific hake in the coastal stock are widely distributed. As a fish ages and grows, it undertakes a summer feeding migration north along the shelf and shelf-break through California, Oregon, Washington, British Columbia, and as far north as southeast Alaska. Younger fish do not migrate as far north as older fish (Hollowed 1992). Adult hake distribution is most likely correlated with ontogenetics (Hamel et al. 2015; Dorn 1995), ocean temperatures, upwelling, currents (Hamel et al. 2015; Ressler et al. 2007; Agostini et al. 2006), and prey availability (Swartzman 2001; Buckley and Livingston 1997). Pacific hake exhibit diel vertical migration, presumably to feed. During the day, Pacific hake are generally found at the 50-500 m depth (Alverson and Larkins 1969).

Pacific hake is an opportunistic predator, especially on schooling or aggregating prey. Adults prey on euphausiids and sergestid and pandalid shrimps and a wide range of fishes, such as herring, Pacific sand lance, and eulachon (Livingston and Bailey 1985; Bailey et al. 1982). Cannibalism is common, especially during years with low prey availability (Buckley and Livingston 1997). Overall, there appear to be seasonal and interannual changes in the assortment of prey items consumed. Additionally, Pacific hake is an important prey item for various marine mammals, large fish, and Humboldt squid, supplying an important trophic link in the CCLME (Field et al. 2013; Love 2011; Bailey et al. 1982).

Climate Effects on Abundance and Distribution

It is important to consider the effect of environmental conditions on Pacific hake distribution across life history stages (Malick et al. 2020). Adult hake feeding, growth, and migration will likely change in response to varying environmental factors (Ressler et al. 2007; Field and Francis 2006); in general, this species appears to migrate further north in warm summers (Edwards et al. 2018; Hamel et al. 2015; Ressler et al. 2007; Ware and McFarlane 1995). Specifically, Malick et al. (2020) found warmer than average subsurface temperatures appear related to higher biomass of mature hake (age 3+) north of Vancouver Island but lower biomass offshore southern Vancouver Island and Washington, while immature hake (age 2) appear to exhibit higher biomass coast wide during cooler than average temperatures. Larval and young Pacific hake are vulnerable to variability in springtime ocean conditions, which may reduce or impede access to nursery habitats near or on the shelf (Hollowed and Bailey 1989). The rise and distribution of strong Pacific hake year classes impacts the abundance of other species in the CCLME through predation (Field and Francis 2006).

Adult Pacific hake are very mobile, and can swim approximately 5-12 km per d (Francis 1983). This high mobility will allow Pacific hake to shift its latitudinal distribution in relation to ocean conditions, possibly shifting a portion of the coastal population north out of U.S. waters. The summer feeding migration in coastal waters ranges north from California to southeast Alaska. This northward migration is influenced by ocean conditions and upwelling-driven productivity near the shelf break, and possibly

by variations in flow within the California Current and Undercurrent near the shelf break (Hamel et al. 2015; Ressler et al. 2007; Agostini et al. 2006; Swartzman 2001). In comparison, the reverse autumnal migration to the spawning grounds is less well understood. Dispersal of early life stages and the distance traveled by Pacific hake eggs and larvae is unknown; eggs and larvae are found far from traditional spawning grounds. Ressler et al. (2007) details evidence that Pacific hake spawning grounds may already be shifting north in response to overall warming.

Climate Vulnerability Rankings

Overall climate vulnerability for Pacific hake was ranked ***low*** with 96% certainty from bootstrap analysis. Climate exposure was ranked ***high***, with two attributes driving this rank: *ocean acidification* (4.0) and *mean sea surface temperature* (3.3). All life stages of Pacific hake use marine habitats, and its reproductive success, growth, and migration are strongly influenced by coastal environmental conditions. Biological sensitivity was ranked ***low***, with all sensitivity attributes scoring 2.4 or less, and with only three scoring higher than 2.0: *spawning cycle* (2.4), *early life history and settlement requirements* (2.3), and *population growth rate* (2.2).

Distributional vulnerability and directional effect

Inverse scores from three attributes drove a ***high*** expected vulnerability to distributional shift in response to climate change for Pacific hake: *adult mobility* (3.9), *habitat specificity* (3.6), and *dispersal of early life stages* (3.1). Climate change was predicted to have a ***negative*** directional effect on Pacific hake (-0.44).

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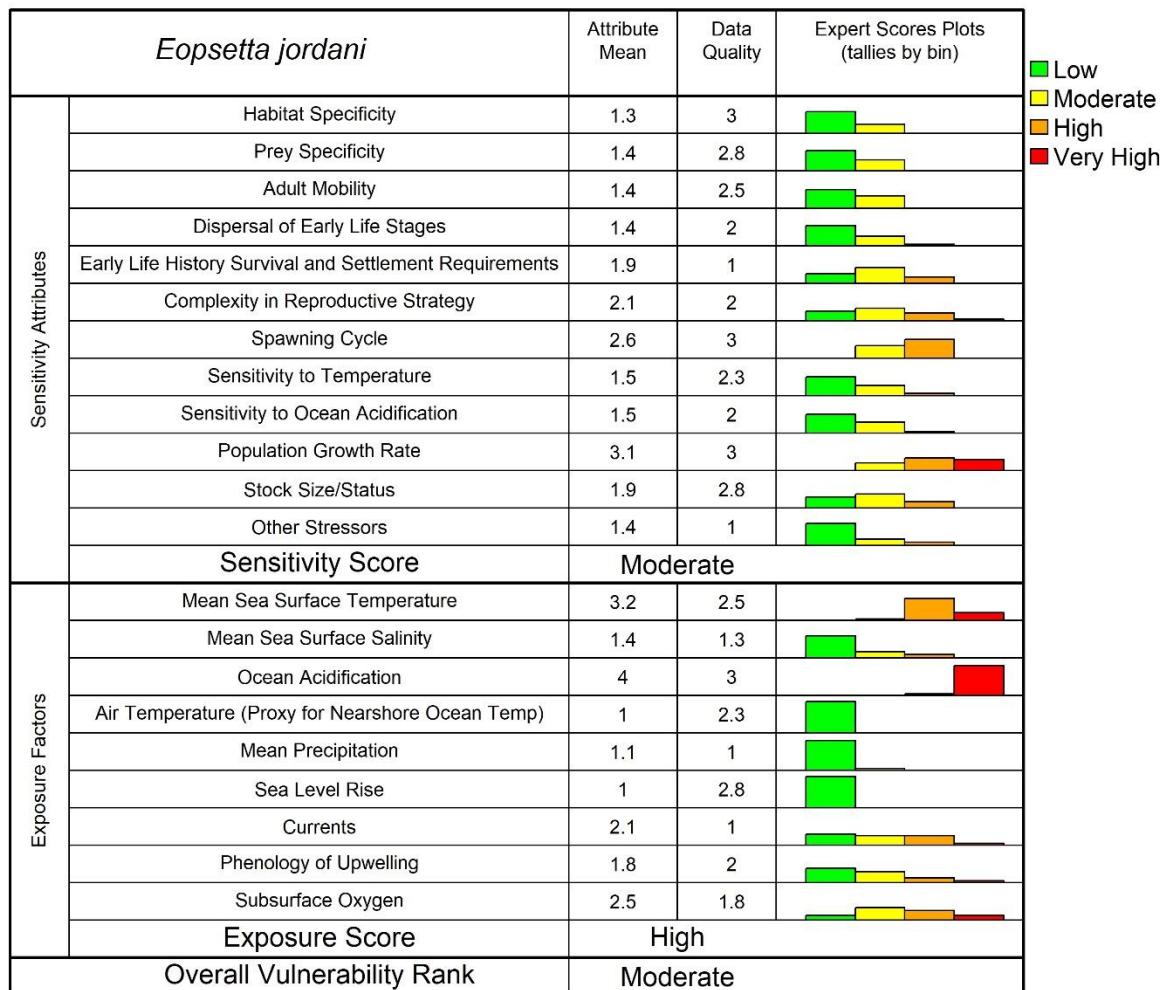
Petrale Sole (*Eopsetta jordani*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2



Life History Synopsis

Female petrale sole spawn annually during winter, and fecundity varies with fish size: one large female can lay as many as 1.5 million planktonic eggs (Porter 1964). The spawning season is approximately November–February. Research suggests that horizontal advection affects density-independent survival during early life stages, specifically that offshore transport of eggs and larvae results in poor recruitment

(Castillo et al. 1994, Castillo 1995, Haltuch et al. 2020).

Eggs rise to the surface between November and April, remaining in surface waters for 6 to 14 days (Alderdice & Forrester 1971, Hart 1973, Love 1996, Casillas et al. 1998). Eggs then sink to a depth of approximately 400 m before hatching as yolk-sac larvae (Mason et al. 1983, Kendall & Matarese 1987, Hunter et al. 1989, Moser et al. 1994). After hatching, larvae rise to the upper 50 m of the water column and remain there for approximately 5 months, through the feeding larval stage (Alderdice & Forrester 1971, Hart 1973, Pearcy et al. 1977, Love 2011, Casillas et al. 1998).

Planktonic petrale sole larvae range in size from approximately 3 to 20 mm, and are found up to 150 km offshore foraging upon copepod eggs and nauplii (Hart 1973, MBC Applied Environmental Sciences 1987, Moser 1996, Casillas et al. 1998). While there is limited information regarding vertical migration of larval petrale sole, species in the Pleuronectidae family exhibit diel vertical migration, generally within the upper 50 m of the water column, as well as horizontal swim speeds that increase with larval growth.

At about 2.2 cm in length, petrale sole larvae settle to the benthos as age-0 recruits on the inner continental shelf (Pearcy et al. 1977). Benthic juveniles inhabit sandy or sand-mud bottoms (Eschmeyer et al. 1983, MBC Applied Environmental Sciences 1987), ranging in size from approximately 2.2 cm to size at maturity. While specific nursery areas are unknown beyond soft substrate areas on the continental shelf, these nursery areas are spatially distinct from the deep-water spawning areas. Fifty percent of the population is mature at approximately 38 cm for males and 41 cm for females (Casillas et al. 1998).

Adults move inshore to feeding grounds during spring and summer and offshore to discrete deep-water spawning grounds in fall and winter. Tagging studies show along-shelf movements that in a few cases range from northern California to British Columbia. Generally, adult petrale sole can be highly migratory, moving up to 350-390 miles, with possible homing ability.

Climate Effects on Abundance and Distribution

Petrale sole ranges from the western Gulf of Alaska to the Coronado Islands, northern Baja California, and prefers soft substrates at depths up to 550 m (Love 2011, Haltuch et al. 2013). Petrale sole spawn in relatively deep waters on the continental shelf, where climate effects may be more limited than in nearshore waters. Adults tolerate a wide range of bottom temperatures (Perry et al., 1994) from Baja California to British Columbia. However, as a species with low habitat specificity, it is likely to shift distribution in response to changing ocean conditions.

Petrale sole consume a wide range of prey items, some of which have calcium carbonate exoskeletons or shells. Although it is not clear exactly how ocean acidification

will affect petrale sole, some of its prey species will likely decline. Petrale sole juveniles are carnivorous, foraging on annelid worms, clams, brittle star, mysids, sculpin, amphipods, and other juvenile flatfish (Ford 1965; Casillas et al. 1998; Pearsall and Fargo 2007.)

As an ambushing flatfish, petrale sole has a diverse diet that becomes more piscivorous at larger sizes. Adult petrale sole forages for a variety of invertebrates including, crab, octopi, squid, euphausiids, and shrimp, as well as anchovies, hake, herring, sand lance, and other smaller rockfish and flatfish. In Canadian waters, evidence suggests that petrale sole tends to prefer herring.

Climate Vulnerability Rankings

Overall climate vulnerability of petrale sole was ***moderate*** with 80% certainty and ***low*** with 20% certainty from bootstrap analysis. Climate exposure was ranked high, with two exposure attributes contributing to this ranking: high *mean sea surface temperature* (3.2) and very high *ocean acidification* (4.0). Biological sensitivity was ranked ***moderate***, with two sensitivity attributes contributing to this score: high *population growth rate* (3.1) and moderate *spawning cycle* (2.6).

Distributional vulnerability and directional effect

For petrale sole, vulnerability to distributional shift as a response to climate change was ranked ***very high***. Very high inverse scores from three attributes contributed to this rank: *adult mobility* (3.7), *dispersal of early life stages* (3.6), and *habitat specificity* (3.7). The directional effect of climate change on petrale sole was ***neutral*** (-0.06).

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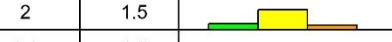
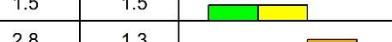
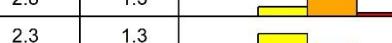
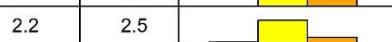
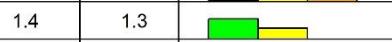
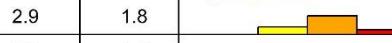
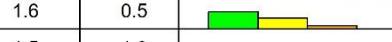
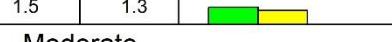
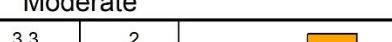
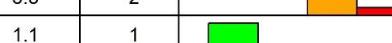
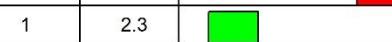
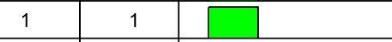
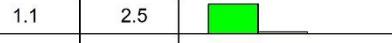
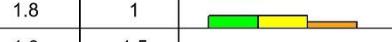
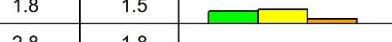
Pygmy Rockfish (*Sebastodes wilsoni*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 29% of scores ≥ 2

<i>Sebastodes wilsoni</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	2.3	
	Prey Specificity	2	1.5	
	Adult Mobility	2.2	1.5	
	Dispersal of Early Life Stages	1.5	1.5	
	Early Life History Survival and Settlement Requirements	2.8	1.3	
	Complexity in Reproductive Strategy	2.3	1.3	
	Spawning Cycle	2.7	1.3	
	Sensitivity to Temperature	2.2	2.5	
	Sensitivity to Ocean Acidification	1.4	1.3	
	Population Growth Rate	2.9	1.8	
	Stock Size/Status	1.6	0.5	
	Other Stressors	1.5	1.3	
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.3	2	
	Mean Sea Surface Salinity	1.1	1	
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1.1	2.5	
	Currents	1.8	1	
	Phenology of Upwelling	1.8	1.5	
	Subsurface Oxygen	2.8	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Pygmy rockfish is a small species with a maximum length of 23 cm. It is a demersal species found primarily over rock substrate in offshore waters at depths of 60-150 m (Stein et al. 1992, Love et al. 2002, Yoklavich et al. 2002, Anderson and Yoklavich 2007; Laidig et al. 2009; Love et al. 2009). Pygmy rockfish range from Southern California to the Gulf of Alaska, preferring temperatures of 4.5-12.1°C; abundance is highest off Southern California (Love et al. 2002, Love 2011).

Timing of parturition for pygmy rockfish varies with latitude, occurring in June off British Columbia and in January–February off Central California (Wyllie Echeverria 1987, Laidig et al. 2004). Pygmy rockfish form large schools over sand and mud near rocks, which may indicate spawning aggregations (Love et al. 2002). Larval duration is approximately 80 d and the combined larval and juvenile phase lasts 4–5 months (Love et al. 2002, Laidig et al. 2004).

Juveniles first recruit to shallow habitats of less than 70 m in depth and with unspecified structure. Upon reaching 5 cm total length, they move to deeper boulder and cobble areas where adults are found (Love et al. 2002, Laidig et al. 2009, Love 2011). Exact age at maturity is unknown, but it is younger than many other rockfish species. Maximum age is at least 26 years (Love et al. 2002). Both juveniles and adults specialize on small prey items, primarily feeding on euphausiids but also copepods and snail-like gastropods (York 2005). Pygmy rockfish is not targeted by fishers, but is used as baitfish.

Climate Effects on Abundance and Distribution

No studies examine climate change effects on pygmy rockfish abundance or distribution. Pygmy rockfish recruitment is variable, and larval prey are present for a limited time, depending on physical conditions. These characteristics indicate that early life history survival and growth is affected by environmental conditions. Additionally, pygmy rockfish may form spawning aggregations, and spawn timing could be altered due to changes in environmental cues.

Climate Vulnerability Rankings

Overall climate vulnerability for pygmy rockfish was ***moderate*** with 97% certainty from bootstrap analysis. Climate exposure was ranked ***high***, with two attributes contributing to this score: *mean sea surface temperature* (3.3) and *ocean acidification* (4.0), pygmy rockfish uses marine habitat at all life stages. Biological sensitivity was ranked ***moderate***, and three sensitivity attributes contributed to this score: *early life history survival and settlement requirements* (2.8), *spawning cycle* (2.7), and *population growth rate* (2.9).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***moderate*** for pygmy rockfish. Inverse scores from three attributes contributed to this ranking: moderate *adult mobility* (2.8), very high *dispersal of early life stages* (3.5) and moderate *habitat specificity* (2.7). Directional effect of climate change on pygmy rockfish was ***neutral*** (-0.19).

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Rosethorn Rockfish (*Sebastodes helvomaculatus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 29% of scores ≥ 2

<i>Sebastodes helvomaculatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	1.5	
	Prey Specificity	1.8	1.8	
	Adult Mobility	2.5	1.3	
	Dispersal of Early Life Stages	1.6	1.3	
	Early Life History Survival and Settlement Requirements	2.8	0.8	
	Complexity in Reproductive Strategy	2.3	1.3	
	Spawning Cycle	2.6	2	
	Sensitivity to Temperature	2.3	2.5	
	Sensitivity to Ocean Acidification	1.3	1.5	
	Population Growth Rate	3.8	1.5	
	Stock Size/Status	1.6	0.5	
	Other Stressors	1.5	1.3	
	Sensitivity Score	Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.4	2	
	Mean Sea Surface Salinity	1.1	1	
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1.1	2.5	
	Currents	1.9	1	
	Phenology of Upwelling	1.7	1.5	
	Subsurface Oxygen	2.8	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Rosethorn rockfish is a small benthic species with a maximum length of less than 30 cm. The species is found most commonly at depths of 100-350 m, although it occasionally occurs at shallower depths. Rosethorn rockfish range from 27 to 60°N, and individuals are most commonly found approximately north of Point Conception (34°N), and "often rest on mud sheltered against boulders and cobble" (Love et al. 2002).

Rosethorn rockfish spawn between May and June off Central and Northern California (Love 1996), although Love et al. (2002) suggests that females release larvae from February to September, with a peak from April to June. Females produce one brood per year, and parturition appears to occur later in the northern range of this species, off Oregon to British Columbia (June), and earlier off Central and Northern California (May-June). These trends indicate potential temperature-dependent effects on reproduction (Kendall and Lenarz 1986, Richardson and Laroche 1979).

Duration of the pelagic stage is unknown, but available evidence points to an extended midwater early life history phase, with high potential for dispersal. Larval duration in most rockfishes is 1-2 months, and the pelagic juvenile stage can last 1 month to 1 year (Rocha-Olivares and Vedder 1999, Love et al. 2002). In rosethorn rockfish populations, 50% are mature at 10-14 years, and nearly 100% are mature at 20 years of age. Maximum age is at least 87 years (Love et al. 2002).

Rosethorn rockfish eat krill, gammarid amphipods, and fish off the coasts of Oregon and Washington (Love et al. 2002). Similarly, off Central California, rosethorn rockfish eat mostly euphausiids and other crustaceans (McCain et al. 2005). Euphausiids make up the majority prey item by weight for this species (82%; Shaw 1999). No distinction between juveniles and adults was made in these diet studies. No information is available about the stock status of rosethorn rockfish, though MacCall (2002) suggested that changes to the competitive environment may improve the recent success of this species.

Climate Effects on Abundance and Distribution

No studies examine the effect of climate factors on the abundance or distribution of rosethorn rockfish. Rosethorn rockfish will likely be exposed to rising temperatures and ocean acidification, which may affect its distribution, as well as its diet composition. Exposure to these two factors occurs during all life stages, as rosethorn rockfish uses coastal and nearshore benthic habitats, usually at depths of 100-350 m, and has a pelagic larval stage.

Climate Vulnerability Rankings

Overall climate vulnerability was ***moderate*** with 97% certainty from bootstrap analysis. Climate exposure was ranked ***high***, with two attributes contributing to this score: *ocean acidification* (4.0) and *mean sea surface temperature* (3.4). Biological sensitivity was ranked ***moderate***, with six attributes contributing to this score: *habitat specificity* (2.3), *adult mobility* (2.5), *early life history requirements* (2.8), *complexity in reproductive strategy* (2.3), *spawning cycle* (2.6), and *sensitivity to temperature* (2.3). Rosethorn rockfish is a long-lived fish with a relatively low natural mortality rate (Love et al. 2002, Shaw and Gunderson 2008).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **moderate** for rosethorn rockfish. One attribute made the primary contribution to this ranking: **adult mobility** (2.5). Adult rosethorn rockfish have small home ranges and the little movement they exhibit is generally limited to a local scale (McCain et al. 2005). Overall directional effect of climate change on rosethorn rockfish along the U.S. West Coast was **neutral** (effect score -0.25).

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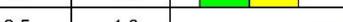
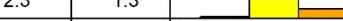
Rougheye Rockfish (*Sebastes aleutianus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 29% of scores ≥ 2

<i>Sebastes aleutianus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.4	2	
	Prey Specificity	1.6	1.3	
	Adult Mobility	2.3	1.5	
	Dispersal of Early Life Stages	1.4	1.5	
	Early Life History Survival and Settlement Requirements	2.5	1.3	
	Complexity in Reproductive Strategy	2.3	1.3	
	Spawning Cycle	2.6	1.8	
	Sensitivity to Temperature	2.2	2.5	
	Sensitivity to Ocean Acidification	1.3	1.5	
	Population Growth Rate	3.9	1.8	
	Stock Size/Status	1.9	1.8	
	Other Stressors	1.5	1.3	
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.4	2	
	Mean Sea Surface Salinity	1.1	1	
	Ocean Acidification	4	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1.1	2.5	
	Currents	1.8	1	
	Phenology of Upwelling	1.7	1.5	
	Subsurface Oxygen	2.8	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Relatively little is known about rougheye rockfish aside from its potentially long lifespan. Natural mortality for rougheye rockfish is thought to be low ($<0.05 \text{ yr}^{-1}$), and maximum age of the species has been reported at over 200 years, with maturity not reached before age 5 (Hicks et al. 2013; Munk 2001). Species range extends from the Pacific Coast of Japan to Southern California, although it is more common north of 42°N.

Rougheye is found at depths of less than 100 m to at least 489 m, and it prefers the rocky, boulder, or steep substrate habitats typical of many rockfish species.

Adults may form large aggregations in autumn and winter. Large catches of rougheye rockfish occasionally occur in the Pacific hake midwater fishery, also suggesting aggregations. The stock makes diurnal migrations and forms dense aggregations to feed on the deep scattering layer (Love et al. 2002; Hicks et al. 2013). Adults feed on a wide range of prey items with crangid and pandalid shrimp making up the majority of diets. They also feed on amphipods, mysids, crabs, polychaetes, and octopuses (Love et al. 2002; Love et al. 2011).

Spawning occurs seasonally and is likely dependent on seasonal aggregations of individuals, with birth of live young occurring between February and June (Love et al. 2002). Larvae are zooplanktivores and capable swimmers that can feed immediately after birth, although whether larvae prey on a specific food item is not known (Wourms 1991; Love et al. 2002). However, the larval stage can last up to 5 months. Smaller fish tend to occur inshore, and a trawl survey observed smaller fish off Southern California, with individuals moving progressively northward as they aged (Hicks et al. 2013). Adults are capable of moving, but whether they actually do is not known.

Climate Effects on Abundance and Distribution

Little is known about the influence of climate variability or climate change on rougheye rockfish. However, given the distribution of rougheye rockfish, it is expected to experience higher levels of exposure to altered climate and ecosystem properties such as sea surface temperature and low oxygen concentrations.

There is no direct evidence of vulnerability to ocean acidification. However, acidification has been shown to impact survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Prey items of rougheye rockfish include crustaceous zooplankton, which could be impacted by ocean acidification. Ocean acidification and sea surface temperature are expected to change significantly throughout the northeastern Pacific. However, the direction and impact of such changes on rougheye rockfish remain highly uncertain.

Climate Vulnerability Rankings

Overall climate vulnerability was ***moderate*** with 94% certainty from bootstrap analysis, although overall climate exposure was ranked ***high***. Exposure attributes contributing to this ranking included *ocean acidification* (4.0) and *mean sea surface temperature* (3.4). Also of concern for rougheye was exposure to low levels of *subsurface oxygen* (2.8). Rougheye rockfish was ranked ***moderate*** in biological sensitivity. Attributes contributing to this rank were a very low *population growth rate* (3.9) and a complicated *spawning cycle* (2.6).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ranked **moderate** for rougheye rockfish, with high inverse scores for *dispersal of early life stages* (3.6) and moderate inverse scores for *adult mobility* (2.7), and *habitat specificity* (2.6). Overall directional effect of climate change on rougheye rockfish was predicted to be **neutral** (-0.31)

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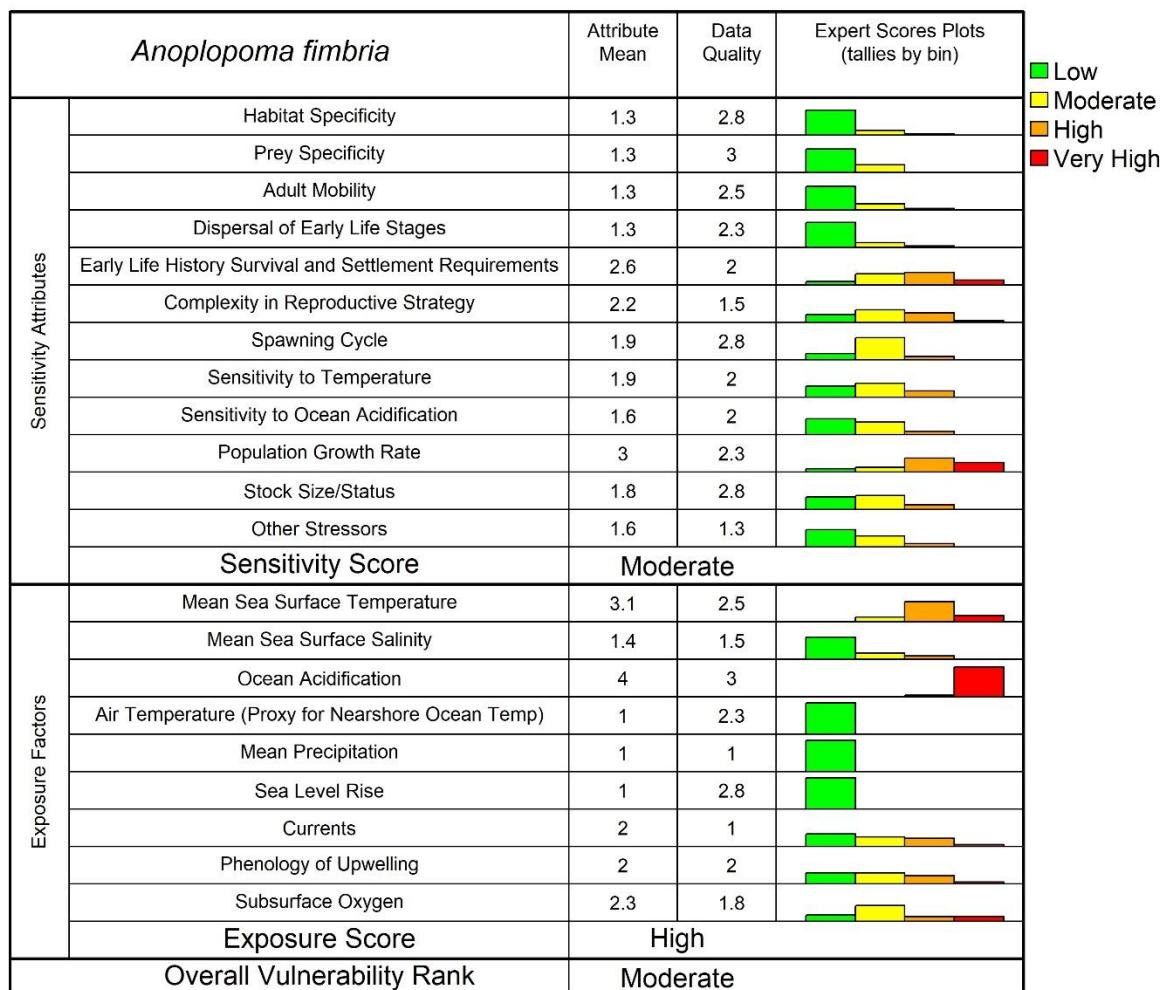
Sablefish (*Anoplopoma fimbria*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2



Life History Synopsis

Sablefish is iteroparous and oviparous, spawning from October to July (Love 2011). Eggs are buoyant and subject to passive transport by currents in the surface layer, including advection offshore (Haltuch et al. 2019). Post-larval juveniles eventually migrate inshore to settle. Actual dispersal distances are unknown, but given the pelagic duration and offshore distribution of larvae, dispersal on the order of thousands of

kilometers is possible.

Adult sablefish are found primarily on the continental shelf and shelf break, but are highly mobile (Shaw and Parks 1997; Maloney and Heifetz 1997; Kimura et al. 1998; Maloney 2004; Love 2011; Johnson et al. 2015), sometimes moving between coastal areas and offshore seamounts. Observed movement distances are variable, from 15 to over 1,000 nautical miles, although the vast majority move less than 500 miles, with larger movements observed in other regions. There is some evidence of marginal stock structure at the regional scale (Kimura et al. 1998; Haltuch et al. 2019), but movement rates have not been quantified well enough to clearly define stock structure, and the present understanding of stock structure may be incorrect.

Sablefish is a generalist in terms of both habitat (Love 2011; Johnson et al. 2015) and prey (Low et al. 1976), yet larvae and young juveniles may be highly dependent on copepods and copepod nauplii (Grover and Olla 1987; Love 2011; Coutre et al. 2015). Species dispersal is thought to be broad based on adult mobility and long pelagic egg and larval duration (40-80 days; Sogard 2011), with its broad offshore distribution (reviewed in Haltuch et al. 2019).

Adult sablefish consume a variety of prey at moderate-to-high trophic levels, including fish, cephalopods, crustaceans (Low et al. 1976). Similarly, post-settlement juveniles predate and occasionally scavenge many fishes, benthic invertebrates, and plankton. Some cannibalism has been documented (Haltuch et al. 2019). Diets of larvae and young juveniles are likely more specialized, and dominated by copepods and copepod nauplii (Grover and Olla 1987; Love 2011; Coutre et al. 2015).

Individual growth is fast, with a high von Bertalanffy growth coefficient, k (Haltuch et al. 2019). Sablefish reaches maturity between ages 1-7 (Saunders et al. 1997; Love 2011; Haltuch et al. 2019) and can live up to 113 years (Love 2011). Although sablefish population growth rate is unknown, it may be limited due to the species' long lifespan. Sablefish is a primary target of the commercial groundfish fishery, yet is estimated to have a biomass greater than the stock size that would produce maximum sustainable yield. However, spawning stock biomass has declined until recently (Haltuch et al. 2019).

Climate Effects on Abundance and Distribution

Specific climate effects on sablefish are not well known, but will likely fluctuate with changes in ocean circulation, temperature, and ocean productivity. Lower ocean productivity may result in particularly negative effects, as inferred from laboratory studies on growth and condition (Sogard and Spencer 2004). Survival, transport and settlement of fishes with long pelagic early-life phases generally are influenced by the timing of parturition and of local oceanographic conditions such as upwelling and alongshore and onshore transport, as well as broad-scale oceanic changes, such as sea surface temperature.

Sablefish abundance and distribution may respond to that of the zooplankton prey they rely on in early life, whereas adult stages are not as likely to be directly affected because they consume a diversity of prey types (Grover and Olla 1987; Love 2011; Coutre et al. 2015). The consequences of indirect effects of climate on sablefish through changes in the abundance or distribution of their predators are unknown. However, there is speculation that the recent rebuilding of predators such as lingcod may be reducing juvenile survival, thus contributing directly to declines in recruitment and indirectly to declines in spawning stock size (Johnson et al. 2015).

Sablefish larvae may be particularly sensitive to changes in oceanographic conditions, as a suite of oceanographic conditions at specific times and locations explain some variation in recruitment (Schirripa and Colbert 2006; Schirripa et al. 2009, Tolimieri et al. 2018). Furthermore, temporal overlap between hatching of eggs and abundance of small zooplankton may influence variability in early life survival (McFarlane and Beamish 1992; Schirripa and Colbert 2006). Early life survival may also be influenced by the effects of temperature on lipid storage and somatic growth (Sogard and Spencer 2004).

A recent reanalysis of recruitment-environment relationships for sablefish found that recruitment was positively correlated with (1) colder conditions during the spawner preconditioning period, (2) warmer water temperatures during the egg stage, (3) stronger cross-shelf transport to nearshore nursery habitats during the egg stage, (4) stronger along-shore transport to the north during early development, and (5) cold surface-water temperatures during the larval stage (Tolimieri et al. 2018).

Climate Vulnerability Rankings

Overall climate vulnerability of sablefish was ***moderate*** with 76% certainty and ***low*** with 23% certainty from bootstrap analysis. Climate exposure was ranked ***high***, and three exposure attributes were primary contributors to this score: *sea surface temperature* (3.1), *ocean acidification* (4.0), and *subsurface oxygen* (2.3). Adults were primarily demersal, but larvae are pelagic, and juveniles were found throughout the water column, meaning there was exposure to a variety of environments early in the life cycle (Kulikov 1965; Love 2011).

Biological sensitivity was ***moderate***, with both low and high attribute scores contributing to this rank: *population growth rate* (3.0), *early life history survival and settlement requirements* (2.6) and *complexity in reproductive strategy* (2.2) scored highest, while *habitat specificity*, *prey specificity*, *adult mobility*, and *dispersal of early life stages* scored lowest (all 1.3).

Distributional vulnerability and directional effect

Vulnerability to change in sablefish distribution was *very high* as determined by very high inverse scores for *adult mobility* (3.7), *dispersal of early life stages* (3.7), and *habitat specificity* (3.7). The directional effect of climate change on sablefish was predicted to be *neutral* (-0.19).

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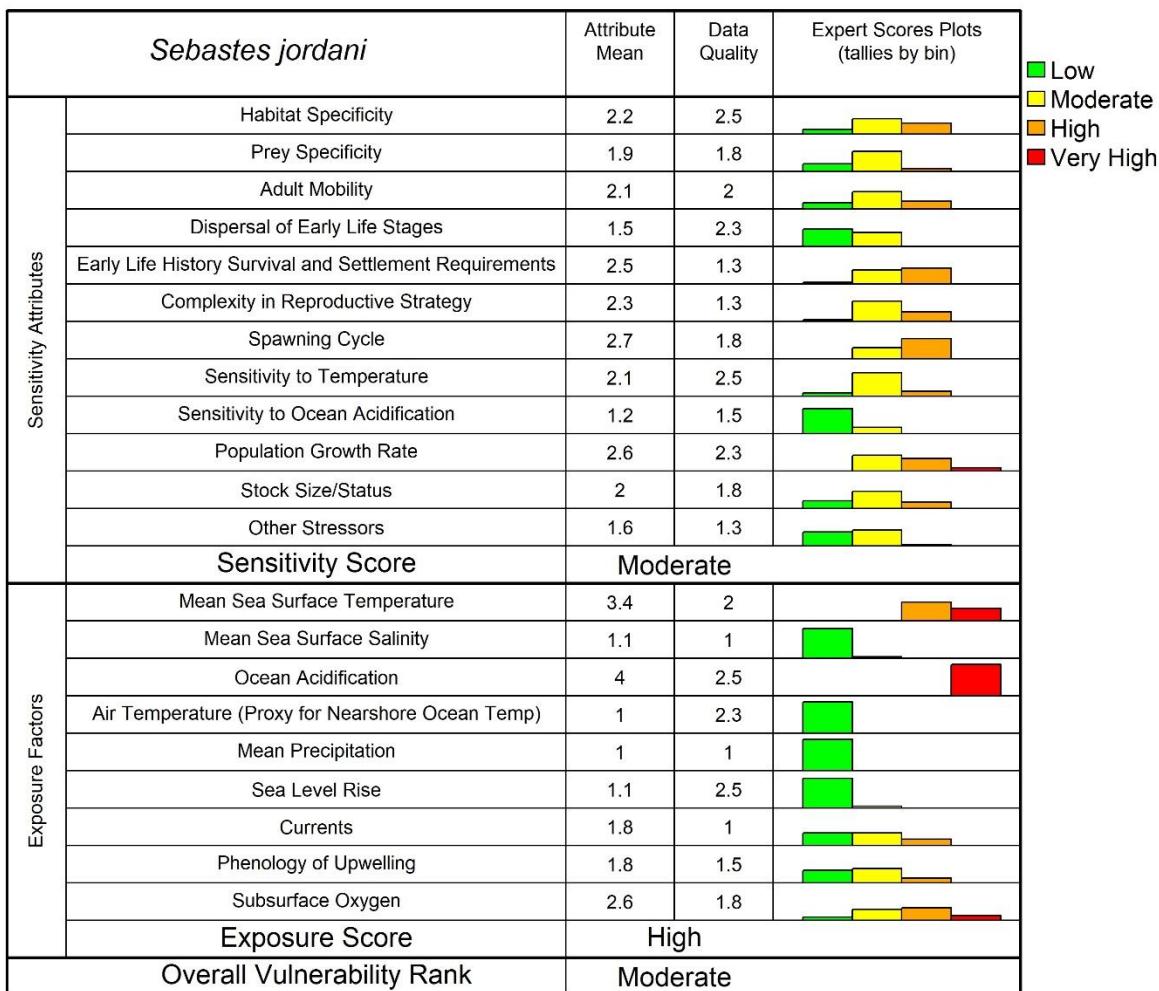
Shortbelly Rockfish (*Sebastes jordani*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 43% of scores ≥ 2



Life History Synopsis

Like other rockfishes, shortbelly rockfish is iteroparous and viviparous. Mating occurs during November-January, with parturition typically from January to March (Moser and Boehlert 1991; Ralston 2003). Pelagic young-of-the-year are widely dispersed from the surface to a depth of 100-m until 4-5 months of age, after which they move to midwater habitats on the continental shelf. Adults then move toward the

continental shelf break (Chess et al. 1988; Ralston and Howard 1995; Moser et al. 2000; Love et al. 2002; Ralston et al. 2003; Ross and Larson 2003). Individuals form large aggregations (Lenarz 1980; Chess et al. 1988).

Shortbelly rockfish mature early, by age 2, but can live up to 30 years, although very few individuals live beyond 20 years (Pearson et al. 1991; Field et al. 2007). Among rockfishes, they are likely one of the fastest-growing species (their von Bertalanffy growth coefficient, k , is estimated at 0.2 to 0.25; Pearson et al. 1991; Field et al. 2007). The small size, fast growth, and high abundance of shortbelly makes it an important forage species for many fishes, seabirds, and marine mammals (Chess et al. 1988; Sydeman et al. 2001). Therefore, changes in productivity or distribution of this species would likely have a large indirect effect on the climate sensitivity of predators in the California Current.

The most recent evaluation of stock status estimated relative abundance at below, but fairly close to, long-term equilibrium of unfished levels. However, biomass varies greatly over time, likely due to environmental factors (Field et al. 2007). Despite occasional interest in potential commercial exploitation, there has never been a substantive fishery on this stock. The population growth rate of shortbelly rockfish is unknown, but the species is likely quite productive, particularly compared to other rockfishes (Field et al. 2007).

Climate Effects on Abundance and Distribution

Climate effects on shortbelly rockfish are unknown, but will likely fluctuate with changes in ocean circulation and productivity. As a midwater species, it is subject to changes in environmental conditions throughout the coastal marine water column (Chess et al. 1988). Survival, transport, and settlement of young are generally influenced by timing of parturition and localized oceanographic features such as upwelling and alongshore and onshore transport, as well as characteristics such as temperature change. These conditions seem particularly influential on shortbelly rockfish (Ralston and Howard 1995; Ralston et al. 2003, 2013).

Shortbelly rockfish is a semipelagic species occurring from Punta Baja in Baja California to La Perouse Bank off British Columbia, but by far the greatest abundance is off central and southern California (Moser et al. 2000; Love et al. 2002). This distribution, combined with its relatively high mobility (Lenarz 1980) and low habitat specificity, indicates that the center of shortbelly rockfish distribution could shift north with increased climate-driven warming of ocean temperatures. The species is likely sensitive in early life stages due to its long pelagic larval and juvenile stages (~150 d; Laidig 1991; Woodbury and Ralston 1991).

Shortbelly rockfish abundance will likely be influenced by changes in the abundance and distribution of their prey and predators. Recent increases in the abundance of bird and mammal predators, along with a range expansion of Humboldt

squid, may be causing increased predation mortality (Ainley et al. 1993; Lowry and Carretta 1999; Field et al. 2007; Field et al. 2013). Although ocean acidification was ranked as the lowest risk factor, it should be noted that some shortbelly prey such as krill, copepods, and other zooplankton (Chess et al. 1988), are likely sensitive to ocean acidification (e.g., Haigh et al. 2015 and references therein).

Climate Vulnerability Rankings

Overall climate vulnerability for shortbelly rockfish was **moderate** with 87% certainty and **low** with 13% certainty from bootstrap analysis. Climate exposure was ranked **high**, with three attributes contributing to this rank: *sea surface temperature* (3.4), *ocean acidification* (4.0), and *subsurface oxygen* (2.6). Biological sensitivity was ranked **moderate**, with the lowest score for *ocean acidification* (1.2) and the highest scores for *population growth rate* (2.6), *spawning cycle* (2.7), and *early life history survival and settlement requirements* (2.5).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ranked **moderate** for shortbelly rockfish, as determined by moderately low inverse scores for *habitat specificity* (2.8), *adult mobility* (2.9), and *sensitivity to temperature* (2.1). The directional effect of climate change for this species was expected to be **neutral** (-0.19).

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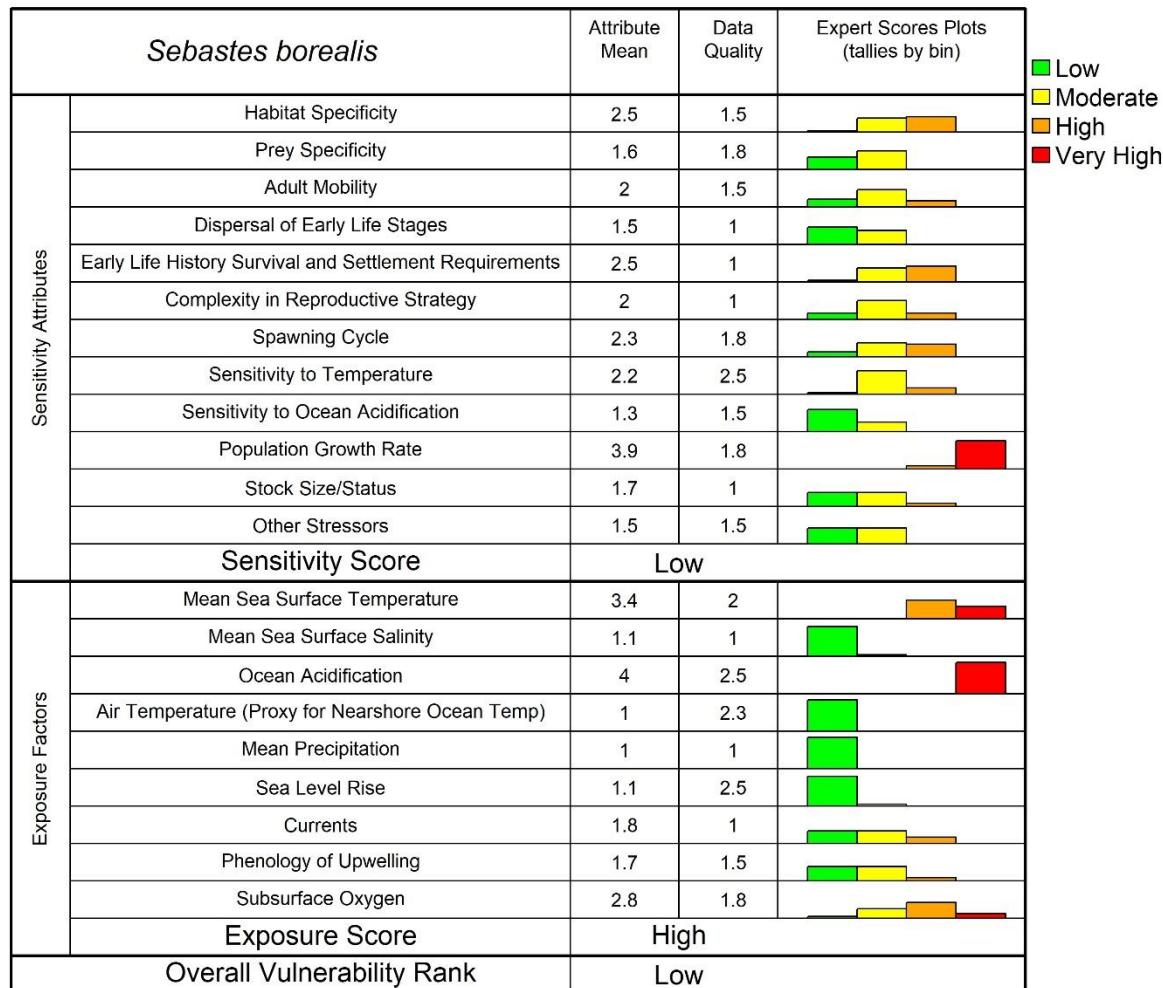
Shortraker Rockfish (*Sebastodes borealis*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 24% of scores ≥ 2



Life History Synopsis

Shortraker rockfish is a long-lived species, with an estimated maximum age exceeding 150 years. The species is viviparous with a protracted reproductive period, spawning throughout spring and summer in Alaskan waters (Westerheim 1975; McDermott 2004). Little is known of shortraker rockfish early life history and dietary habits, as immature fish are rarely observed. However, some evidence suggests that juveniles born off the West Coast are transported northward to the Aleutian Islands by

currents (Orlov 2001). Juvenile settlement occurs at a length of ~10 cm, and reverse migrations to reproductive areas peak at lengths over 35 cm (Orlov 2001).

Adult shortraker rockfish are relatively evenly distributed along steep areas of the continental slope and do not tend to aggregate (Spies et al. 2014). Observations from a manned submersible indicated that adults prefer steep slopes with frequent boulders (Clausen and Echave 2011) and may be more abundant in boulder patches associated *Primnoa* coral (Krieger and Ito 1999; Krieger and Wing 2002). Adults are near-bottom feeders with prey including of myctophids, shrimp, and squid (Yang et al. 2006).

Shortraker rockfish has low population growth rates (Spies et al. 2014). At present, the population is experiencing low exploitation in Alaskan waters (Spies et al. 2014). Status of the stock off the West Coast is unknown; these fish are caught only incidentally in the bottom-trawl fishery off the Washington coast (NMFS 2015).

Climate Effects on Abundance and Distribution

Little research examines potential impacts of climate factors on shortraker rockfish. Juveniles complete lengthy migrations, and the species ranges from Hokkaido Island, Japan through the Aleutian Islands, the Gulf of Alaska, and southward off the West Coast. Pelagic larvae and juveniles move northward from the coasts of British Columbia, Washington, and Oregon and are transported by currents to the Aleutian Islands (Clausen and Echave 2011; Orlov 2001). The center of abundance appears to be in the Gulf of Alaska (Clausen and Echave 2011; Cope et al. 2011; Spies et al. 2014), where adults are particularly concentrated in a narrow band along the 300-500 m depth interval of the continental slope (Clausen and Echave 2011; Cope et al. 2011).

Climate Vulnerability Rankings

Overall climate vulnerability was ranked ***low*** with 32% certainty and ***moderate*** with 68% certainty from bootstrap analysis. Climate exposure was ***high***, with two attributes contributing to this rank: *ocean surface temperature* (3.4) and *ocean acidification* (4.0). Larval stages occur in the upper portion of the water column where they are exposed to these two factors (Love et al. 2002). Biological sensitivity was ***low***, with three attributes contributing to this rank: *early life history survival and settlement requirements* (2.5), *population growth rate* (3.9), and *stock size/status* (1.7).

Distributional vulnerability and directional effect

For shortraker rockfish, vulnerability to distributional shift as a response to climate change ranked ***low***, with inverse scores of three attributes contributing to this rank: *adult mobility* (3.0), *early life stage dispersal* (3.5), and *habitat specificity* (2.5). The directional effect of climate change on shortraker rockfish was expected to be ***negative*** (-0.25).

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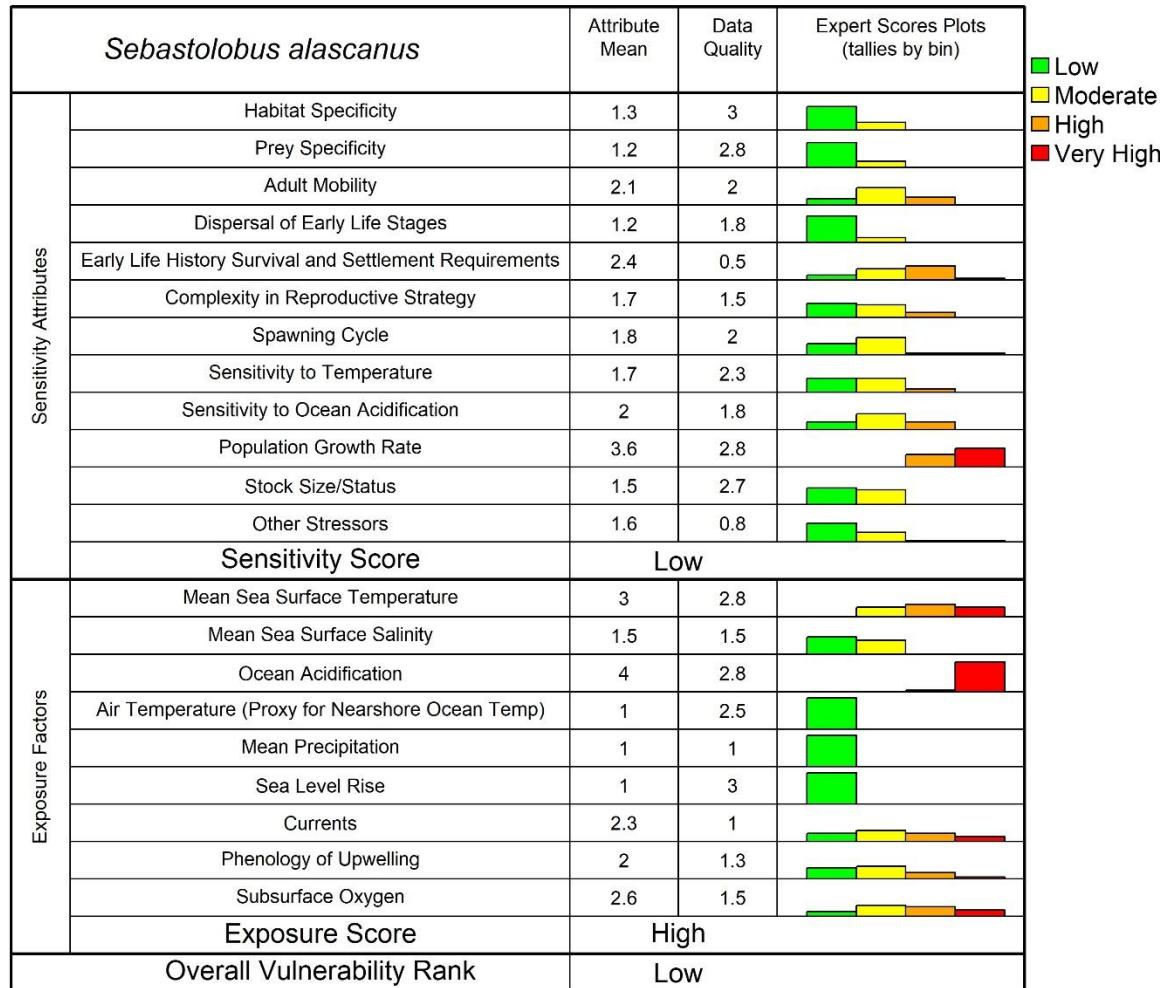
Shortspine Thornyhead (*Sebastolobus alascanus*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 52% of scores ≥ 2



Life History Synopsis

Shortspine thornyhead is found in waters off the West Coast from northern Baja California to the Bering Sea at depths of 20 to over 1,500 m. Adults are most abundant in the oxygen minimum zone, at 600-1,400 m (Jacobson and Vetter 1996). Thornyhead is oviparous, spawning in spring and producing gelatinous egg masses between December and May (Wakefield 1990; Erickson and Pikitch 1993; Pearson and Gunderson 2003).

Egg masses float to the surface where final development and hatching occur.

Juveniles are pelagic, settling at around 1 year of age (22-27 mm in length), likely at depths of 100-200 m (Vetter and Lynn 1997) and migrating into deeper waters as they grow. Shortspine thornyhead grow slowly, but individuals may continue growing throughout life, reaching maximum lengths of over 70 cm. Shortspine thornyhead is difficult to age, but research suggests that the species can live 80-100 years. Females reach larger sizes than males.

Maturity occurs near 18 cm, at 8-10 years of age in females (Pearson and Gunderson 2003). Adult shortspine thornyhead prey on a variety of fish and invertebrates, including shrimp and amphipods (Butler and Love 2011). Estimates of natural mortality range 0.013-0.07 (Butler et al. 1995; Kline 1996; Pearson and Gunderson 2003). Butler et al. (1995) suggested that natural mortality is lower for older, larger adults residing in the oxygen minimum zone due to lack of predators.

Climate Effects on Abundance and Distribution

No studies examine climate change effects on shortspine thornyhead abundance or distribution. Shortspine thornyhead has a broad latitudinal distribution and is found in waters off the West Coast from northern Baja California to the Bering Sea, at 20 to over 1,500 m depths (Taylor and Stephens 2014). The species also has a dispersive early life stage. Both of these characteristics suggest that this species can change distribution in response to climate change.

Juvenile shortspine thornyhead are pelagic, while adult fish are benthic; thus, exposure to ocean acidification, rising sea surface temperature, and low dissolved oxygen occurs during all life stages. This species utilizes marine habitats at all ages, and potential impacts include altered food availability and metabolic rates.

Climate Vulnerability Rankings

Overall climate vulnerability was ***low*** with 68% certainty and ***moderate*** with 32% certainty from bootstrap analysis. Climate exposure was ***high***, with three attributes contributing to this rank: *ocean acidification* (4.0), *mean sea surface temperature* (3), and *subsurface oxygen* (2.6). Biological sensitivity was ***low***, with only one attribute scored above 2.5: *population growth rate* (3.6). Shortspine thornyhead was a low-productivity and slow-growing species (Taylor and Stephens 2014).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***high*** for shortspine thornyhead. Inverse scores from two attributes contributed to this rank: *dispersal of early life stages* (3.8) and *habitat specificity* (3.7). The directional effect of climate change on shortspine thornyhead was ***neutral*** (-0.19).

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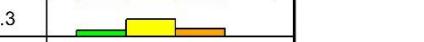
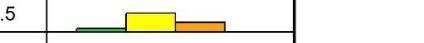
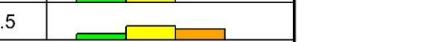
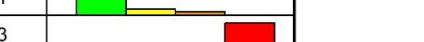
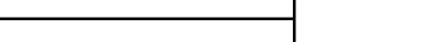
Southern Rock Sole (*Lepidopsetta bilineata*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 67% of scores ≥ 2

<i>Lepidopsetta bilineata</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	2.5	
	Prey Specificity	1.5	2.8	
	Adult Mobility	2.1	2	
	Dispersal of Early Life Stages	2.1	2.3	
	Early Life History Survival and Settlement Requirements	2.2	1.5	
	Complexity in Reproductive Strategy	2.1	2	
	Spawning Cycle	1.9	2.8	
	Sensitivity to Temperature	1.8	2.5	
	Sensitivity to Ocean Acidification	1.7	2	
	Population Growth Rate	2.8	2	
	Stock Size/Status	1.4	1.3	
	Other Stressors	2.2	1.5	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.2	2.3	
	Mean Sea Surface Salinity	1.4	1	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1.1	1	
	Sea Level Rise	1	2.5	
	Currents	2.2	1	
	Phenology of Upwelling	2.3	2	
	Subsurface Oxygen	2.4	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Southern rock sole is a broadly distributed flatfish in the Northeast Pacific, ranging from central California north to Alaska and south to the Korean Peninsula. Adults reach a length of up to 60 cm and a weight of up to 2.7 kg (Horton et al. 1989), and are taken in various shallow-water fisheries. Abundance along the West Coast has not been assessed, but the population in the Strait of Georgia appears to have increased

markedly in the latter half of the 20th century (Fargo and Richards 1998).

A recent stock assessment concluded that the population in the Gulf of Alaska is stable and above overfished and overfishing thresholds (A'mar and Palsson 2014). Southern rock sole is fairly slow-growing and long-lived, reaching 50% maturity by ages 3-5 (~29 cm in length) and maximum ages of over 20 years off British Columbia (Horton 1989; Fargo and Wilderbuer 2000; Munk 2001). The intrinsic rate of population increase is undocumented for southern rock sole.

Spawning takes place in late winter or spring in nearshore waters. Eggs are demersal and adhesive, affixing to substrates like sand, mud, or rock in subtidal and occasionally intertidal waters (Martin 2014). Larvae and early juveniles are pelagic, generally in waters within the 500-m bathymetric contour (Orr and Matarese 2000); the pelagic stage typically lasts 4-5 weeks, which is shorter than the pelagic stage of many other Northeast Pacific flatfishes (Fargo and Wilderbuer 2000).

Early juveniles settle at lengths ranging 1.3-3.4 cm (Orr and Matarese 2000). After settlement, juveniles and adults prefer sand, mud, or gravel habitats from subtidal waters to depths of about 75 m. During winter months, adults move into deeper waters up to ~300 m (Horton 1989; Kramer et al. 1995). Tag-recapture studies indicate that adults have small home ranges (Forrester and Thomson 1969), which may be indicative of discrete subpopulations (Forrester 1969). There was no evidence of latitudinal migrations—only seasonal changes in depth.

Southern rock sole has expressed some sensitivity to temperature at different life history stages. In waters off British Columbia, southern rock sole year class strength has a dome-shaped relationship with springtime sea surface temperature, with optimum year class strength occurring at 6.1-6.3°C (Forrester and Thompson 1969; Fargo and McKinnell 1989). Temperatures above 7.0°C or below 5.5°C exerted negative effects on year class strength (Fargo and McKinnell 1989), possibly due to density-dependent mortality among larvae or juveniles (Fargo and Wilderbuer 2000). Southern rock sole can tolerate water temperatures up to 24.9°C (Ames et al. 1978).

The diet of larvae is unknown. Juveniles (<29 cm) mainly feed on benthic invertebrates, including polychaetes, benthic crustaceans, clams, and ophiuroids (Horton et al. 1989). Adults (>29 cm) feed on such benthic invertebrates as crabs, shrimp, clams, scallops, and ophiuroids, as well as on other fishes, including sand lance and herring; the presence of fish in their stomachs is evidence that adults can expand their diets, despite a mouth morphology that is more adapted to preying on benthic invertebrates (Horton et al. 1989).

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on the abundance or distribution of southern rock sole. Eggs are adhesive and affixed to bottom substrates (Horton 1989;

Martin 2014), which could render them vulnerable to unfavorable conditions. Year class strength has a dome-shaped relationship with springtime sea surface temperature, with an optimum of about 6.1-6.3°C off British Columbia (Forrester and Thompson 1969; Fargo and McKinnell 1989). Temperature-mediated, density-dependent mortality may occur among larvae or juveniles (Fargo and Wilderbuer 2000). Juvenile and adult habitat may be limiting, given the relatively narrow depth range and high biomass concentrations in some areas (Horton 1989; Fargo and Wilderbuer 2000). Southern rock sole is mobile and expresses some flexibility in depth, diet, and spawning habitat. Its relatively brief pelagic larval phase may lessen exposure to climate-driven changes in water column properties. Winter and spring temperature increases could lower recruitment

Diets of southern rock sole (particularly post-settled juveniles) include benthic invertebrates that have calcium carbonate exoskeletons or shells and live in waters regularly exposed to ocean acidification; thus, portions of the diet may be vulnerable to ocean acidification (Feely et al. 2008). In addition, southern rock sole is a relatively shallow-dwelling fish. Spawning is subtidal or occasionally intertidal, and most age groups occur in waters less than 75 m deep. These habitats were regularly exposed to ocean acidification (Feely et al. 2008).

Climate Vulnerability Rankings

Overall climate vulnerability was *low* with 76% certainty and *moderate* with 24% certainty from bootstrap analysis. Climate exposure was *high*, with two attributes contributing to this rank: *ocean acidification* (4.0) and *ocean surface temperature* (3.2). Biological sensitivity for southern rock sole ranked *low*, with only *population growth rate* (2.8) scoring above 2.5.

Distributional vulnerability and directional effect

Southern rock sole vulnerability to distributional shift as a response to climate change was *moderate*. Inverse scores from three attributes contributed to this score: *adult mobility* (2.9), *dispersal of early life stages* (2.9), and *habitat specificity* (2.7). The directional effect of climate change on southern rock sole along the West Coast was *neutral* (-0.31).

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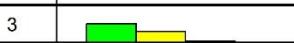
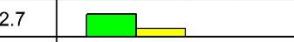
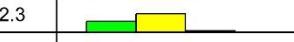
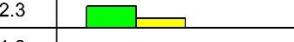
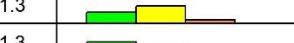
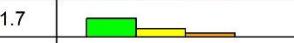
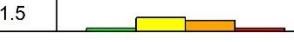
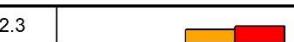
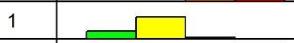
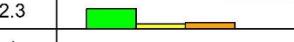
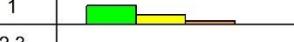
Starry Flounder (*Platichthys stellatus*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 52% of scores ≥ 2

<i>Platichthys stellatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.5	3	
	Prey Specificity	1.3	2.7	
	Adult Mobility	1.7	2.3	
	Dispersal of Early Life Stages	1.3	2.3	
	Early Life History Survival and Settlement Requirements	1.8	1.3	
	Complexity in Reproductive Strategy	1.5	1.3	
	Spawning Cycle	2.5	2	
	Sensitivity to Temperature	1.2	2.7	
	Sensitivity to Ocean Acidification	1.5	1.5	
	Population Growth Rate	2.1	2.3	
	Stock Size/Status	1.5	1.7	
	Other Stressors	2.5	1.5	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.6	2.3	
	Mean Sea Surface Salinity	1.8	1	
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.6	2.3	
	Mean Precipitation	1.5	1	
	Sea Level Rise	2.4	2.3	
	Currents	2.5	1	
	Phenology of Upwelling	2.3	1.3	
	Subsurface Oxygen	2.3	1.3	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Starry flounder spawns from November through February with a peak in December and January. Larvae are present year-round in San Francisco Bay, and spawning may be continuous in some regions (Orcutt 1950; Love 2011). Limited evidence suggests that some adults move inshore to spawn. These adults appear to use estuaries opportunistically, and spawning probably occurs in both the ocean and

estuaries. Historically, large spawning aggregations were recorded in Humboldt Bay (Love 2011), but none currently occurs.

Starry flounder larvae feed on microscopic plankton. Duration of the planktonic egg and larval life stage is about 3 months (Orcutt 1950); timing of metamorphosis to juveniles is probably related to size, although there is little information available (Orcutt 1950). Dispersal distances of larvae are probably limited.

Juvenile starry flounder are generally limited to nearshore waters at depths of less than 30 m, and most settle in fresh or brackish water of inshore bays and estuaries. These juveniles occur over all types of substrate except rocky areas. They are frequently found in estuaries and caught in areas with salinities less than 0.02 ppt. The ability to survive in freshwater makes them relatively unique among west coast flatfish (Orcutt 1950; Pearson 1989; Baxter 1999; Kimmerer 2002; Love 2011). Juveniles feed on a wide variety of benthic invertebrates.

Age at maturity is thought to be 3 years, although this is tentative and it may be as low as 2 years for males and as high as 4 years for females (Love 2011; Ralston 2006). Maximum recorded age in the California Current is 10 years, although this is also tentative, and longevity seems much greater in other regions, with evidence of ages up to 42 years for stocks in the Arctic (Love 2011; Ralston 2006). Adult starry flounder feed on a large variety of benthic invertebrates and small fish (Orcutt 1950).

Adults have been found as deep as 600 m; however, the majority inhabit depths less than 100 m and commonly occur in estuaries and coastal streams. Unpublished data based on otolith microchemistry suggest that adults move in and out of estuaries randomly (Orcutt 1950; Pearson 1989; Baxter 1999; Kimmerer 2002; Love 2011). Adults are not likely to be highly mobile, although a few tagged individuals have traveled as far as 200 km (Love 2011).

Climate Effects on Abundance and Distribution

No studies report on the effects of climate change on starry flounder, but its low overall climate vulnerability rank largely reflects the wide range of nearshore habitats and conditions apparently tolerated by this species. Larvae probably have a high tolerance to variable environmental conditions, inferred from their presence in both marine and estuarine environments and the wide geographic distribution of the species. Adults also use a wide range of thermal regimes, occurring in nearshore areas from southern California to the Bering Sea and then south to the Seas of Japan and Okhotsk. They can tolerate temperatures at least as low as -1.8°C (Orcutt 1950; Kimmerer 2002; Love 2011). Most feeding is on benthic invertebrates; however, some feeding on small fishes occurs higher in the water column, also suggesting thermal tolerance.

The principal risk from climate change is likely to be effects on estuaries from sea level rise and possibly streamflow. Some degradation of estuaries may occur in highly

urbanized inshore waters such as San Francisco Bay due to loss of habitat from filling, species invasions, and detrimental levels of pollution. Exposure to organic contaminants reduces egg viability in this area (Spies and Rice 1988). For other flatfish in the California Current, estuaries function as nursery habitat, producing adult recruits out of proportion to their small spatial extent (Brown 2006; Fodrie and Mendoza 2006). If this is also true of starry flounder, then estuaries may represent a key vulnerability to stock productivity.

Climate Vulnerability Rankings

Overall climate vulnerability for starry flounder was ***low*** with 71% certainty and ***moderate*** with 29% certainty from bootstrap analysis. Climate exposure was ***high***, with two attributes contributing to this rank: *mean sea surface temperature* (3.6) and *ocean acidification* (4.0). In addition, four exposures were particularly uncertain, with scores distributed from low to very high: *sea level rise*; *currents*; *phenology of upwelling*; and *subsurface oxygen*. Biological sensitivity ranked ***low***. In general, median scores for sensitivity attributes were low or moderate, with the exception of *other stressors* and *spawning cycle*, both of which scored high, at 2.5.

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***high*** for starry flounder. Inverse scores from three attributes contributed to this rank: very high *dispersal of early life stages* (3.7), high *adult mobility* (3.3), and very high *habitat specificity* (3.5). The directional effect of climate change on starry flounder was expected to be ***negative*** (-0.69).

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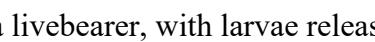
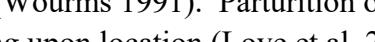
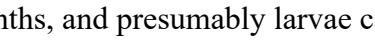
Widow Rockfish (*Sebastes entomelas*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 57% of scores ≥ 2

<i>Sebastes entomelas</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	3	
	Prey Specificity	1.5	2.5	
	Adult Mobility	1.9	2.1	
	Dispersal of Early Life Stages	1.6	1.8	
	Early Life History Survival and Settlement Requirements	2.9	1.3	
	Complexity in Reproductive Strategy	2.9	1.3	
	Spawning Cycle	2.8	2	
	Sensitivity to Temperature	2.3	2.5	
	Sensitivity to Ocean Acidification	1.9	2.3	
	Population Growth Rate	3.5	3	
	Stock Size/Status	1.9	2.3	
	Other Stressors	1.5	0.6	
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.3	2.8	
	Mean Sea Surface Salinity	1.5	1.5	
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.5	
	Mean Precipitation	1	1	
	Sea Level Rise	1	3	
	Currents	2.4	1	
	Phenology of Upwelling	2.2	1.3	
	Subsurface Oxygen	2.4	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Like other rockfishes, widow rockfish is a livebearer, with larvae released after completing development up to the feeding stage (Wourms 1991). Parturition occurs in winter months from December to April, depending upon location (Love et al. 2002). Pelagic larval and juvenile stages last up to 5 months, and presumably larvae can travel far, given the potential for offshore or alongshore advection.

Juvenile widow rockfish use inshore habitats, usually high-relief and cobblestone areas, and sometimes kelp beds. They are generalist consumers, primarily eating euphausiids, shrimp, and salps. Juveniles tend to occur off bottom and may school with squarespot, pygmy, and speckled rockfishes (Love et al. 2002).

Adults migrate to deeper habitats, and are often associated with rocky, high-relief areas. They are highest in density at depths of 140-210 m, but can be present at depths of over 500 m (Love et al. 2002). Adults tend to occur in the water column, often in large aggregations, and may school with other species, particularly yellowtail rockfish, and in more northern areas, with dusky rockfish. Like juveniles, adults feed on euphausiids, shrimp, and salps, but a large proportion of their diet includes fish (Adams 1987). Based on seasonal differences in diet, there may be an onshore and offshore movement of adults. Larger movement patterns have not been studied.

Like other rockfishes, widow is slow-growing and long-lived, with large, old females contributing disproportionately to reproduction (Stafford et al. 2014). Age at maturity is 3-8 years, and maximum age is 60 years (Love et al. 2002). Intrinsic rate of increase is likely low. Widow rockfish was declared overfished in 2001, but has shown sufficient increases in stock size since that time to be declared rebuilt in 2011 (He et al. 2011). There are regional differences in size at maturity and timing of parturition along the West Coast (Barss and Echeverria 1987).

Climate Effects on Abundance and Distribution

No studies report on the effects of climate change on widow rockfish. The stock ranges from northern Baja California to southeastern Alaska (Love et al. 2002), suggesting broad tolerance for temperature. As with most rockfishes, no studies show direct correlation between reproduction and temperature. Due to the high mobility of early life stages and moderate adult mobility, some shift in the distribution of widow rockfish is likely.

Climate Vulnerability Rankings

Overall climate vulnerability was ***moderate*** with 55% certainty and ***high*** with 45% certainty from bootstrap analysis. Climate exposure was ***high***, with two attributes contributing to this rank: high *mean sea surface temperature* (3.3) and very high *ocean acidification* (4.0). In addition, three exposure attributes were particularly uncertain, with scores distributed from low to very high. These were *currents*; *phenology of upwelling*; and *subsurface oxygen*. Biological sensitivity was ***moderate***, and the primary attribute contributing to this rank was very high *population growth rate* (3.5), with additional contributions from *early life history requirements* (2.9), *complexity in reproductive strategy* (2.9), and *spawning cycle* (2.8).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **high** for widow rockfish. Inverse scores from two attributes contributed to this rank: *dispersal of early life stages* (3.4) and *adult mobility* (3.1). Directional effect of climate change on widow rockfish along the West Coast was expected to be **neutral** (-0.19).

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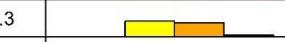
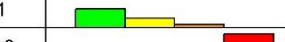
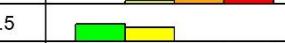
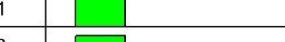
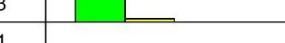
Yelloweye Rockfish (*Sebastes ruberrimus*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 43% of scores ≥ 2

<i>Sebastes ruberrimus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.5	3	
	Prey Specificity	1.6	1.9	
	Adult Mobility	2.7	1.8	
	Dispersal of Early Life Stages	1.8	1	
	Early Life History Survival and Settlement Requirements	2.9	1	
	Complexity in Reproductive Strategy	2.9	1.5	
	Spawning Cycle	2.6	2.3	
	Sensitivity to Temperature	2.1	2.5	
	Sensitivity to Ocean Acidification	1.5	1	
	Population Growth Rate	4	2.8	
	Stock Size/Status	3.5	2.5	
	Other Stressors	2	1.3	
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.3	2.5	
	Mean Sea Surface Salinity	1.5	1.5	
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.5	
	Mean Precipitation	1	1	
	Sea Level Rise	1.1	3	
	Currents	2.4	1	
	Phenology of Upwelling	2.2	1.3	
	Subsurface Oxygen	2.7	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Yelloweye is one of the largest rockfish species, with a maximum length of 91 cm. It is primarily found in deeper offshore waters of 91-180 m (Love et al. 2002). Adults generally move into deeper water as they increase in size and age, but as habitat specialists, they usually exhibit strong site-fidelity to rocky bottoms and outcrops (O'Connell & Carlisle 1993; Richards 1986; Stein et al. 1992; Yoklavich et al. 2000).

Yelloweye distribution ranges from the eastern Aleutian Islands to Ensenada, Mexico.

Timing of parturition for yelloweye rockfish varies with latitude, occurring from April to September off British Columbia and from March to July in off California (Love et al. 2002). Larvae remain planktonic for several months before settling to subtidal rocky habitats. Young-of-the-year recruit first to shallow, structured habitats of less than 30 m in depth; they then move to the deeper boulder and cobble areas where adults are found (Love et al. 2002).

Subadults and adults are generally solitary (Love et al. 2002), but aggregations have been observed on seamounts in British Columbia (L. Yamanaka, *pers. comm.*) and banks off the Oregon Coast (P. Rankin, *pers. comm.*). In waters off British Columbia, females reach sexual maturity at 17-20 years of age and at sizes of 42-49 cm (Kronlund and Yamanaka 2001) and maximum age is 147 years (Taylor and Wetzel 2011).

Juveniles consume a generalist diet of copepods and euphausiids of all life stages, while adults eat a variety of demersal invertebrates and small fishes, including other species of rockfishes associated with kelp beds, rocky reefs, pinnacles, and sharp drop-offs (Love et al. 2002). Yelloweye rockfish was overfished as of 1995 and has a rebuilding plan that suggests the population has a 50% probability of being rebuilt by 2067 (Taylor 2011).

Climate Effects on Abundance and Distribution

No studies examine climate change effects on yelloweye rockfish abundance or distribution. However, yelloweye rockfish is slow-growing with low productivity and a life history based on large yearly variation in reproductive success, with only an occasional year being productive. This contributed to a high overall climate vulnerability ranking. Yelloweye rockfish use marine habitats during all life stages. In addition, the species is overfished at present.

Climate Vulnerability Rankings

For yelloweye rockfish, overall climate vulnerability was ***high*** with 98% certainty from bootstrap analysis. Climate exposure was also ***high***, with three attributes contributing to this rank: *mean sea surface temperature* (3.3), *ocean acidification* (4.0), and *subsurface oxygen* (2.7). Biological sensitivity was ***high***, with four attributes contributing to this rank: *population growth rate* (4.0), *stock size/status* (3.5), *early life history survival and settlement requirements* (2.9), and *complexity in reproductive strategy* (2.9).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***moderate***. Inverse scores of two attributes contributed to this rank: high *dispersal of early life stages* (3.2) and moderate *habitat specificity* (2.5). Overall directional effect of climate

change on yelloweye rockfish was expected to be *neutral*.

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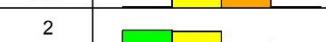
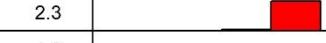
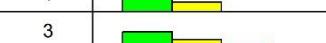
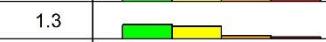
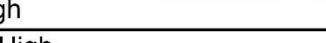
Yelloweye Rockfish (*Sebastes ruberrimus*) - Puget Sound Distinct Population Segment

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = Very High ■

Climate Exposure = High ■

Data Quality = 57% of scores ≥ 2

<i>Sebastes ruberrimus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.6	2.5	
	Prey Specificity	1.6	2	
	Adult Mobility	2.8	2	
	Dispersal of Early Life Stages	1.8	1.5	
	Early Life History Survival and Settlement Requirements	3	1.3	
	Complexity in Reproductive Strategy	3	1.8	
	Spawning Cycle	2.6	2	
	Sensitivity to Temperature	2.5	2.5	
	Sensitivity to Ocean Acidification	1.5	1.5	
	Population Growth Rate	4	2	
	Stock Size/Status	3.9	2	
	Other Stressors	3.6	2.3	
Sensitivity Score		Very High		
Exposure Factors	Mean Sea Surface Temperature	4	2.3	
	Mean Sea Surface Salinity	1.7	1.3	
	Ocean Acidification	4	2.8	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.3	2.3	
	Mean Precipitation	1.3	1	
	Sea Level Rise	1.6	3	
	Currents	2.2	1	
	Phenology of Upwelling	1.8	1.3	
	Subsurface Oxygen	3	1.3	
	Exposure Score	High		
Overall Vulnerability Rank		Very High		

Life History Synopsis

Yelloweye is one of the largest rockfish species, with a maximum length of 91 cm. It is primarily found in offshore waters at depths of 91-180 m (Love et al. 2002). Adults generally move to deeper water as they increase in size and age, but as habitat specialists, they usually exhibit strong site-fidelity to rocky bottoms and outcrops (Richards 1986; Stein et al. 1992; O'Connell & Carlisle 1993; Yoklavich et al. 2000;

Love et al. 2002). Yelloweye ranges from the eastern Aleutian Islands to Ensenada, Mexico.

Yelloweye rockfish of the Puget Sound and Georgia Basin Distinct Population Segment (DPS) is genetically differentiated from the coastal population (Andrews et al. 2018). However, the two populations share life-history characteristics. For example, both are strongly associated with cobble or rocky habitats, including pinnacles and “bathtub ring” outcroppings at depths of typically 60-150 m, but are also found in areas as shallow as 30 m. In the Puget Sound region, high-relief habitat is relatively abundant in the San Juan Islands and Strait of Georgia, but uncommon in Puget Sound proper. In Puget Sound proper, temperatures at the 100-m depth range 8 to 12.5°C between winter and summer, respectively. Hook-and-line sampling suggests size classes in Puget Sound range 28-78 cm (Andrews et al. 2018).

For the Puget Sound yelloweye rockfish DPS, parturition is thought to occur in spring to late summer (Washington et al. 1978), a period similar to the peak parturition during May and June observed in yelloweye off British Columbia (Love et al. 2002). Larvae remain planktonic for several months before settling to subtidal rocky habitats.

In Puget Sound, young-of-the-year are observed in areas of Hood Canal, such as Dabob Bay, near Hoodsport, Washington, as well as in high-relief rocky areas of the San Juan Islands (Washington Department of Fish & Wildlife, *unpubl data*). Juveniles first recruit to shallow, structured habitats at depths of less than 30 m, and then move to the deeper boulder and cobble areas where adults are found (Love et al. 2002).

In waters off British Columbia, females reach sexual maturity at 17-20 years of age and at sizes of 42-49 cm (Kronlund and Yamanaka 2001). Juveniles are opportunistic feeders, taking fish larvae, copepods, krill, and other prey (Love et al. 2002), while adults are capable of preying on smaller rockfishes, but typically prey on sand lance, gadids, flatfishes, shrimp, crabs, and gastropods (Love et al. 2002; Yamanaka et al. 2006). Yelloweye rockfish is not a targeted fishery in Puget Sound, but may be captured as bycatch in halibut, lingcod, and salmon fisheries. The coastal population has been identified as overfished

Climate Effects on Abundance and Distribution

No studies have examined climate-change effects on yelloweye rockfish abundance or distribution. However, yelloweye rockfish is a slow-growing species with low productivity, and its life history is based on large yearly variations in reproductive success, with only an occasional year being productive. Yelloweye rockfish in Puget Sound uses marine habitats at all life stages.

The Puget Sound yelloweye rockfish DPS has shown substantial decline in abundance and is listed as *threatened* under the U.S. Endangered Species Act. Analyses of data from recreational catch per unit effort, recreational scuba diver surveys, and trawl

surveys suggest annual declines of approximately 3.8% per year, or a total decrease in abundance of 77% since 1976. Although attributed largely to fishing, this low population size may increase the vulnerability of Puget Sound yelloweye rockfish to shifts in climate (Tolimieri, et al. 2017). Temperatures in the Puget Sound region have warmed substantially since 1980 and are expected to increase an additional 4.2°F over present temperatures by 2050 (Mauger et al. 2015).

Climate Vulnerability Rankings

For the Puget Sound yelloweye rockfish DPS, overall climate vulnerability was **very high** with 75% certainty and **high** with 25% certainty from bootstrap analysis. Climate exposure was **high**, with three attributes contributing to this rank: *mean sea surface temperature* (4.0), *ocean acidification* (4.0) and *subsurface oxygen* (3.0). Biological sensitivity was **very high**, with five sensitivity attributes contributing heavily to this rank: *population growth rate* (4.0), *stock size/status* (3.9), *other stressors* (3.6), *early life history survival and settlement requirements* (3.0) and *complexity in reproductive strategy* (3.0).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **low**. Inverse scores from four attributes contributed to this rank: *adult mobility* (2.4), *dispersal of early life stages* (3.2), *habitat specificity* (2.4) and *sensitivity to temperature* (2.5). The directional effect of climate change on yelloweye rockfish in Puget Sound was expected to be **negative** (-0.56).

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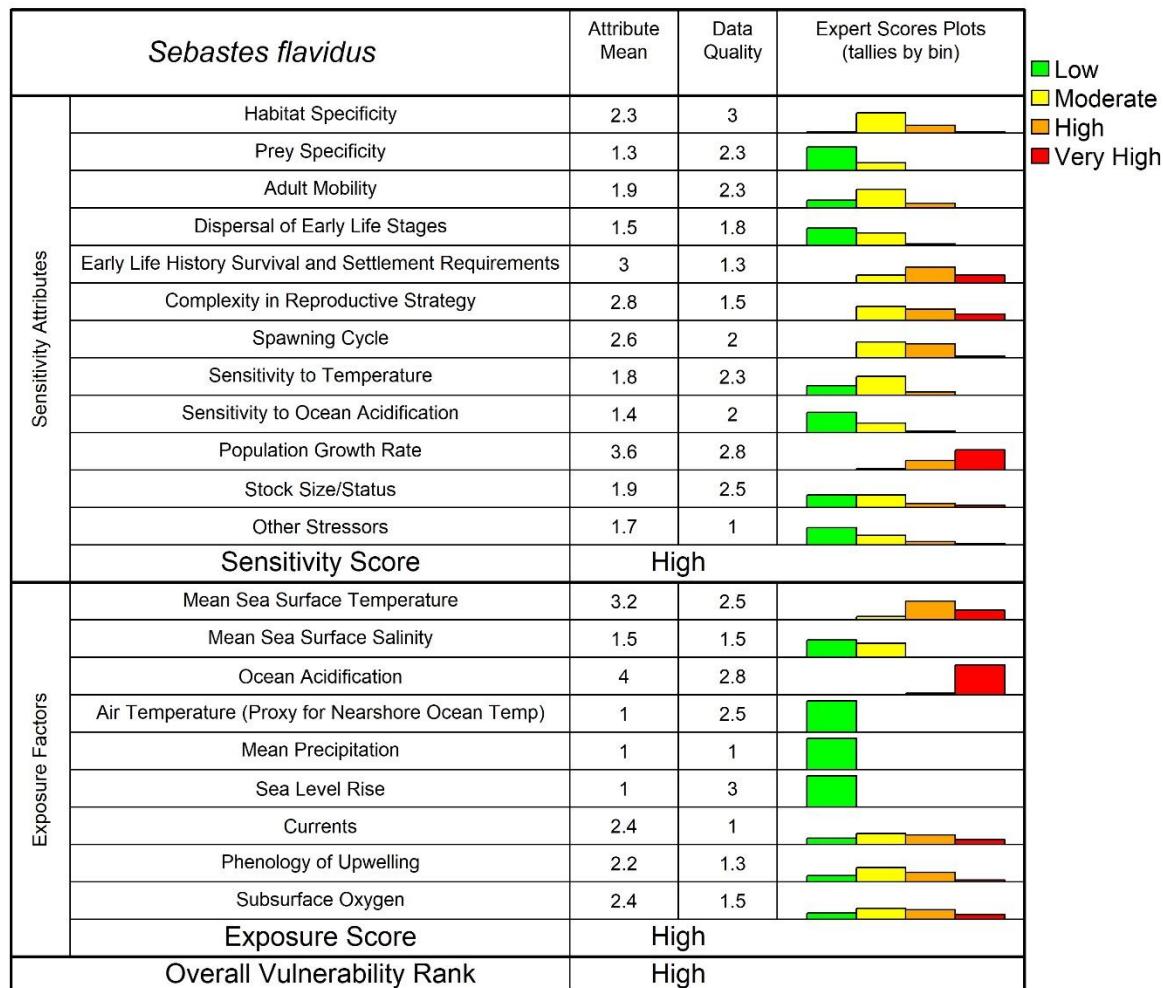
Yellowtail Rockfish (*Sebastodes flavidus*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 57% of scores ≥ 2



Life History Synopsis

Like other rockfishes, yellowtail hatches eggs internally and releases larvae. Adult females release larvae from January to April, depending upon location (Love et al. 2002). The planktonic larval stage lasts 3.5 months, and presumably, larvae can travel far given that they can be advected offshore and have been observed as far as 266 km from the coast.

Juvenile yellowtail rockfish use inshore habitats, sometimes characterized by bull kelp or other structures such as oil platforms. Presumably, changes in predators or the prey base of juveniles could affect persistence of the stock because juvenile survival has a high impact on spawning biomass per recruit (Thorson et al. 2015). Juvenile yellowtail rockfish are generalist planktivores, feeding on copepods and krill, but little else is known about feeding and predation at this stage, or about cues for settlement.

Adults migrate to deeper habitats, and are often associated with rocky, high-relief areas. Their highest densities are at depths of 90-180 m, but adult yellowtail can occur from intertidal areas to depths of 549 m. Depending upon the time of day, adults are associated with rock and crevice substrates, aggregates in the water column, or dispersals in the water column (Love et al. 2002). Adult mobility is mixed, with some tagged adults moving long distances and others showing strong site-fidelity and a tendency to return to an area if moved. Like juveniles, adults are generalist predators, feeding on both benthic and water-column prey, including lantern fishes (Love et al. 2002).

Like other rockfishes, yellowtail rockfish is slow-growing and long-lived, with larger, older females contributing disproportionately to reproduction. Age at maturity is 6-11 years (Wallace and Lai 2005), maximum age is 64 years (Love et al. 2002), and intrinsic rate of increase is likely low. At present, the stock is above its estimated maximum sustained yield.

Climate Effects on Abundance and Distribution

No studies report on the effects of climate change on yellowtail rockfish. The stock ranges from southern California at ~32°N to the inner Aleutian Islands at 55°N (Love et al. 2002), suggesting broad tolerance for temperature. However, recent genetic analyses show support for two distinct stocks, north and south of Cape Mendocino, respectively (Hess et al. 2011).

As with most rockfishes, no studies show direct correlation between reproduction and temperature, but size-dependent female fecundity varies both spatially and temporally, likely due to variability in habitat, temperature, and food resources (Eldridge and Jarvis 1995; Beyer et al. 2015). Barnett et al. (2015) found that recruitment of yellowtail rockfish in the California Current has a strong negative correlation with date of the spring transition to upwelling conditions. Their finding suggests that change in the phenology of upwelling could affect the long-term productivity of the stock.

Climate Vulnerability Rankings

Overall climate vulnerability of yellowtail rockfish was ***high*** with 60% certainty and ***moderate*** with 40% certainty from bootstrap analysis. Overall climate exposure was ***high***, with two attributes contributing to this rank: high *mean sea surface temperature*

(3.2) and very high *ocean acidification* (4.0). In addition, three exposure attributes were particularly uncertain with scores distributed from low to very high: *currents*; *phenology of upwelling*; and *subsurface oxygen*. Biological sensitivity was also **high**, with two attributes contributing to this rank: very high *population growth rate* (3.6) and high *early life history requirements* (3.0). *Complexity in reproductive strategy* was moderate overall, with some scores in the very high bin.

Distributional vulnerability and directional effect

For yellowtail rockfish, vulnerability to distributional shift as a response to climate change was **high**. Inverse scores of two attributes contributed to this rank: very high *dispersal of early life stages* (3.5) and high *adult mobility* (3.1). The directional effect of climate change on yellowtail rockfish was expected to be **neutral** (-0.19).

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Highly Migratory Species

Albacore (*Thunnus alalunga*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Thunnus alalunga</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.3	3	 
	Prey Specificity	1.4	3	 
	Adult Mobility	1.1	3	 
	Dispersal of Early Life Stages	1.1	2.3	 
	Early Life History Survival and Settlement Requirements	2.7	1.5	  
	Complexity in Reproductive Strategy	1.8	2.3	 
	Spawning Cycle	2.2	2.5	  
	Sensitivity to Temperature	1.2	2.8	 
	Sensitivity to Ocean Acidification	1.4	2.5	 
	Population Growth Rate	2.7	2.5	   
	Stock Size/Status	1.5	2.3	 
	Other Stressors	1.2	1	 
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.6	3	 
	Mean Sea Surface Salinity	1.7	2.3	  
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.5	
	Currents	2.3	1.3	  
	Phenology of Upwelling	1.5	1.5	 
	Subsurface Oxygen	1.9	2	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Albacore tuna is found throughout the North Pacific between about 5-10°N and 50-55°N. Surface water temperatures where this tuna is caught or tracked range 12-30°C (Foreman 1980; Otsu and Uchida 1963; Childers et al. 2011; Kohin et al. in prep).

Albacore vertical habitat ranges from the surface to depths exceeding 300 m, and this

spatial variation is likely dependent on prey availability and depths of the mixed layer and deep scattering layer. Albacore occupies the California Current seasonally, primarily to forage (Bograd et al. 2008; Block et al. 2011; Madigan et al. 2015). In the Northern California Current, albacore is predominately surface-dwelling, whereas off Southern California and Baja, it tends to swim into deeper waters during the day (Childers et al. 2011; Laurs and Lynn 1991; Foreman 1980; Xu et al. 2015a; Nieto et al. 2015; Zainuddin et al. 2006; Zainuddin et al. 2008).

Albacore spawns predominantly in the subtropical and tropical western and central Pacific between about 10 and 25°N. Spawning temperature in the North Pacific is likely 24°C or higher, as is found for albacore in the South Pacific and for other tunas in the Pacific. In some tunas, the spawning interval and absorption of post-ovulatory follicles is quicker at warmer temperatures. The same may be true of albacore, although no studies are available to support this possibility. Batch fecundity may also vary with temperature in tuna, but again, there are no studies showing this trend for albacore (South Pacific albacore, Farley et al. 2013; Schaefer 2001). For North Pacific albacore, the spawning area is a discrete but rather large region in the western and central Pacific subtropics and tropics.

Juveniles disperse from the spawning area shortly after birth but migrate back at maturity, having traveled thousands of miles annually throughout the temperate North Pacific as subadults. Whether the cue to move to the spawning area is environmentally or physiologically driven is not certain (Foreman 1980; Otsu and Uchida 1963).

Juveniles grow rapidly and migrate into temperate, highly productive waters shortly after birth. In the Eastern Pacific, age 2-4 juveniles are found seasonally off the coasts of California, Oregon, and Washington between June and November. For the rest of the year, juveniles migrate out into the central and western Pacific or to waters off Baja, California. The habitat in which juveniles reside is pelagic and temperate, and their movements may be linked to temperature and fronts, although the areas they inhabit cover a broad range of oceanographic conditions, and their distribution is vast.

Based on catch data and some tagging data, albacore apparently shifts from temperate waters to the subtropics near maturity at ~age 5. Adults are caught near the spawning area and around Hawaii during summer and farther from the spawning area in winter. However, adults are rarely if ever encountered in the California Current. The vertical habitat of adults differs from that of juveniles in that adults tend to spend less time in surface waters, with vertical excursions more typically ranging from the bottom of the mixed layer to depths exceeding 400 m. Adult albacore habitat is pelagic and subtropical, and adult movement, like that of juveniles, may be linked to temperature and fronts (Kimura et al. 1997; Laurs and Lynn 1991; Foreman 1980).

Albacore juveniles have a broad diet that includes small schooling fish such as

anchovy, sardine, saury, and hake, as well as squid and crustaceans. Juvenile diets in the California Current vary, depending upon prey availability, and juveniles appear to be opportunistic feeders (Madigan et al. 2015; Glaser et al. 2015; Pinkas et al. 1971; Snodgrass et al. in prep).

Little is known about the early life history of albacore in the Pacific, although it spawns in relatively oligotrophic areas, perhaps to avoid predation. There is evidence that albacore, southern bluefin, and skipjack tuna larvae in the southern Indian Ocean are food limited. If primary prey (copepods) for larvae were less abundant, then perhaps mortality would increase (Young and Davis 1990; Young, et al. 2015; ICCAT 2015).

Density-dependent growth is indicated in bluefin of the southern Indian Ocean, with slower growth at higher larval densities. For albacore in the Southern Pacific, there is also evidence of density-dependent growth, with smaller cohorts showing faster growth. Environmental conditions apparently have an effect on recruitment in North Atlantic albacore (Jenkins et al. 1991; Fournier et al. 1998; Arregui et al. 2006).

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on population abundance for albacore. However, changes in distribution predict a northward migration and increased availability of potential habitat within the North Pacific (Hazen et al. 2013). Exposure to ocean surface temperature and ocean acidification occurs during both juvenile and adult life stages. However, albacore larvae occur in tropical and subtropical waters, so exposures in the California Current represent only a part of the species range.

Albacore is a generalist predator, foraging on a suite of prey types (Young and Davis 1990). Adults may rely more heavily on species associated with the deep scattering layer, such as myctophids, crustaceans, and deep-water cephalopods. If the deep scattering layer becomes less accessible due to shoaling of the oxygen minimum zone, a portion of the forage base may be reduced (South Pacific albacore, Domokos et al. 2007 and Bertrand et al. 2002; Bograd et al. 2008; Prince et al. 2006; McClatchie et al. 2010). Although it has preferred temperature ranges, albacore is likely able to use a suite of habitats (Block et al. 2011).

Climate Vulnerability Rankings

Overall climate vulnerability for albacore was ***moderate*** with 74% certainty and ***low*** with 26% certainty from bootstrap analysis. Climate exposure was ***high***, with two attributes contributing to this rank: *ocean surface temperature* (3.6) and *ocean acidification* (4). Biological sensitivity was ranked ***moderate***, with two sensitivity attributes scoring above 2.5: *early life history survival and settlement requirements* (2.7) and *population growth rate* (2.7).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was *very high* for albacore. Very high inverse scores for all three distributional vulnerability attributes accounted for this rank: *adult mobility* (3.9), *dispersal of early life stages* (3.9), and *habitat specificity* (3.7). Directional effect of climate change on albacore was expected to be *negative* (-0.50).

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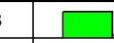
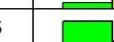
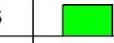
Blue Shark (*Prionace glauca*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Prionace glauca</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.2	2.8	 
	Prey Specificity	1.8	3	 
	Adult Mobility	1.1	3	 
	Dispersal of Early Life Stages	1.1	2.5	 
	Early Life History Survival and Settlement Requirements	1	2.8	 
	Complexity in Reproductive Strategy	1.7	1.3	 
	Spawning Cycle	2.1	2.8	  
	Sensitivity to Temperature	1.3	2.5	 
	Sensitivity to Ocean Acidification	1.5	2.5	 
	Population Growth Rate	2.6	2.3	  
	Stock Size/Status	1.6	2.8	 
	Other Stressors	1	1.5	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.6	3	 
	Mean Sea Surface Salinity	1.4	2.3	 
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.5	
	Currents	2.1	1.3	  
	Phenology of Upwelling	1.3	1.5	 
	Subsurface Oxygen	2.3	2	 
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Blue shark is a slow-growing, long-lived coastal and pelagic species that is broadly distributed across the North Pacific from approximately 10 to 50°N (Nakano 1994). Within this range, there is some apparent segregation by size and sex, with juveniles occurring at higher latitudes and larger sharks at lower latitudes (Nakano and Seki 2003). Blue shark is a highly migratory species, and its occurrence in the California

Current is seasonal, with more sharks present off the West Coast and Baja, Mexico, during summer and fewer as individuals disperse farther offshore in fall and winter (Urbisci et al. 2013; Nakano 1994). The mating area of blue shark is believed to be in the central Pacific at about 20-30°N, and females with bites, presumably from mating, are caught frequently in the California Current.

Blue shark in the California Current is thought to pup in spring and early summer in the Southern California Bight, based the occurrence of pups and the large relative abundance of young sharks from Point Conception to Sebastián Vizcaino Bay off Baja, California (Nakano 1994; Urbisci et al. 2013). Females mature slightly later (5-7 years) than males (4-6 years) and give birth to litters of 1-54 pups measuring 40-50 cm fork length (Cailliet et al. 1983; Nakano 1994; Smith et al. 2008).

Blue shark feeds on a broad range of fish and squid and appears to be an opportunistic feeder, although in comparison with other pelagic shark species, it seems to rely more on cephalopods and other prey in the deep scattering layer (Preti et al. 2012). Prey availability is likely the most important factor for juvenile blue sharks, and given their reliance on the deep scattering layer, changes in the oxygen minimum zone may result in either direct or indirect impacts on foraging (Bograd et al. 2008; Prince et al. 2006., McClatchie et al. 2010). Blue shark juveniles may not be able to penetrate as deep in the water column due to oxygen limitations, and shifts in the oxygen minimum zone may affect distribution of the deep scattering layer.

Based on a Pacific-wide stock assessment, blue shark is not overfished, and overfishing is not occurring (ISC 2014). Blue shark is taken primarily as bycatch in a range of fisheries targeting other highly migratory species such as tuna, swordfish, and sharks (Nakano 1994). Blue shark shares life history traits common to many sharks, such as its late age at maturity and low rebound potential. Thus, population growth rates were assessed as increasing climate vulnerability.

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on population abundance for blue shark. Projected changes in temperature and chlorophyll (Hazen et al. 2012) include a reduction of approximately ~25% in available habitat in the North Pacific, which would also result in changes to food webs. Some studies suggest an increase in temperature and reduction in pH will cause a shift to smaller, less energy-dense phytoplankton that would likely have negative effects on coastal and pelagic food webs (Hoegh-Guldberg and Bruno 2010; Guinder and Molinero 2014).

Habitat loss and altered food webs may be compounded by potential reductions in productivity of coastal and pelagic habitats (Polovina et al. 2008; Ainsworth et al. 2011; Donly et al. 2012; Guinder and Molinero 2014; Hoegh-Guldberg and Bruno 2010). For blue shark, shoaling of the oxygen minimum zone may also affect the ability to forage on

organisms associated with the deep-scattering layer (Preti et al. 2012; Bograd et al. 2008; Prince et al. 2006; McClatchie et al. 2010). There is no direct evidence of vulnerability to ocean acidification; however, acidification affects odor tracking and foraging behavior of some sharks (Dixon et al. 2015; Rosa et al. 2014). Although there is some separation of habitat among sex and age, exposure to both temperature and ocean acidification occurs across all life history stages of blue shark (Nakano and Seki 2003).

Blue shark is highly migratory with a broad latitudinal distribution: it is able to utilize a suite of habitats in coastal and offshore waters (Nakano 1994; Nakano and Seki 2003) and thus may be vulnerable to distributional shift. Finally, basic life history characteristics such as age at maturity (4-7 years) and natural mortality (mean 0.244 year⁻¹) increase the climate sensitivity risk associated with population growth for blue shark (ISC 2014; Cailliet et al. 1983; Smith et al. 2008).

Climate Vulnerability Rankings

Overall climate vulnerability of blue shark was ***low*** with 99% certainty from bootstrap analysis. Climate exposure was ***high***, with two exposure attributes contributing most to this rank: *ocean surface temperature* (3.6) and *ocean acidification* (4.0). Biological sensitivity was ***low***, with *population growth rate* (2.6) as the only sensitivity attribute scoring above 2.5.

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ranked ***very high*** for blue shark. Inverse scores of three attributes contributed to this rank: *adult mobility* (3.9), *dispersal of early life stages* (3.9), and *habitat specificity* (3.8). Only *sensitivity to temperature* attribute had a low score (1.3). The directional effect of climate change on blue shark in the Northeast Pacific was ***neutral*** (-0.19).

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Common Thresher Shark (*Alopias vulpinus*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Alopias vulpinus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	3	   
	Prey Specificity	2.5	3	  
	Adult Mobility	1.1	3	  
	Dispersal of Early Life Stages	1.1	2.5	  
	Early Life History Survival and Settlement Requirements	1	2.8	 
	Complexity in Reproductive Strategy	1.6	1.8	  
	Spawning Cycle	2.6	2	   
	Sensitivity to Temperature	1.2	2.8	  
	Sensitivity to Ocean Acidification	1.3	2.5	  
	Population Growth Rate	3.1	2.3	  
	Stock Size/Status	1.1	2.8	  
	Other Stressors	1	1.5	 
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.5	3	  
	Mean Sea Surface Salinity	1.4	2.3	  
	Ocean Acidification	4	3	 
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	 
	Mean Precipitation	1	1	 
	Sea Level Rise	1	2.5	 
	Currents	2	1.3	  
	Phenology of Upwelling	1.4	1.5	  
	Subsurface Oxygen	2.2	2	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Common thresher shark typically ranges over coastal and oceanic waters within 200 nautical miles off the U.S. West Coast and northern Mexico. Adults are present in these areas throughout the year, with juveniles common in the Southern California Bight (Cartamil et al. 2011; Hanan et al. 1993). Common thresher shark in the Northeast Pacific Ocean ranges from the surface to a depth of about 300 m and occasionally deeper,

encountering water temperatures as cold as 6°C during its vertical excursions (Cartamil et al. 2010a, 2011; Sepulveda et al. 2015; Baquero 2006). North and south movement along the coast appears to be driven at least in part by season, and adults are found farther north and farther offshore than juveniles (Cartamil et al. 2011; Hanan et al. 1993).

Thresher shark is a highly migratory species and habitat generalist, so habitat specificity is of little concern. There are no known specific adult mating aggregation sites; however, the Southern California Bight is thought to be a nursery area, and adult females may move into the bight to drop pups (Cartamil et al. 2010a, Cartamil et al. 2010b, Cartamil et al. 2011). Parturition is thought to occur most often in spring, with a peak in May, and litter sizes are typically small, with 3-6 pups born at about 110-155 cm total length (Bedford and Haugen 1992).

For thresher shark, reported maximum growth rate was 1.125, von Bertalanffy growth factor was k (0.129), age at maturity was over 4.8 years, and maximum age was 25 years (Smith et al. 1998, Smith et al. 2008; Cailliet and Bedford 1983; Gervelis and Natanson 2013).

Common thresher shark is an economically important species taken in recreational fisheries and as a secondary target in the California drift gillnet fishery for swordfish (Hanan et al. 1993). Thresher shark in the Eastern Pacific Ocean feeds opportunistically on a variety of fish and cephalopods, predominantly small schooling prey such as anchovy, sardine, Pacific hake, and market squid (Preti et al. 2001; Preti et al. 2012). Thresher uses its tail to stun prey, and this unique foraging strategy results in a much narrower diet than that of other pelagic sharks in the California Current.

The most recent thresher shark stock assessment indicates that threshers are likely not overfished (Teo et al. 2016), and overfishing is not occurring at present. Populations have recovered from a previously overfished state.

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on population abundance of common thresher shark. Given the apparent dispersal patterns in El Niño years to date, thermal habitat of both juveniles and adults will likely spread northward. The most profound climate effects will likely be those linked to shifts in food web composition across time and space.

Some studies suggest an increase in temperature and reduction in pH will cause a shift to smaller, less energy-dense phytoplankton. Such a shift would likely have negative effects on coastal and pelagic food webs (Hoegh-Guldberg and Bruno 2010; Guinder and Molinero 2014). This potential reduction in productivity in the California Current and in pelagic habitats would have an overall negative effect on the population. (Polovina et al. 2008; Ainsworth et al. 2011; Donly et al. 2012; Guinder and Molinero

2014; Hoegh-Guldberg and Bruno 2010)

Although there is some separation of habitat among life history stages, with larger individuals tending to extend farther north, exposure to both temperature and ocean acidification occurs across habitats occupied by all life history stages of common thresher shark (Cartamil et al. 2010a, Cartamil et al. 2010b, Cartamil et al. 2011). There is no direct evidence of thresher shark vulnerability to ocean acidification. However, in some sharks, ocean acidification affects odor tracking and foraging behavior, as well as survivorship at early life history stages (Dixon et al. 2015; Rosa et al. 2014).

Concerns about spawning cycle were linked to conditions during the relatively narrow period of pupping (Bedford and Haugen 1992; Cartamil et al. 2010a, Cartamil et al. 2010b, Cartamil et al. 2011). Thresher shark is highly migratory with a broad latitudinal distribution; however, juveniles tend to occupy nearshore waters over the continental shelf and therefore have higher vulnerability in terms of habitat specificity than adults (Cartamil et al. 2011; Hanan et al. 1993; Cartamil 2010a, 2010b).

Like many energetic and large pelagic fish, the thresher may be constrained to waters above the oxygen minimum zone. Shoaling of the oxygen minimum zone will not likely have severe impacts on common thresher shark, but it could reduce the amount of available foraging habitat and may affect nursery habitat in the Southern California Bight (Bograd et al. 2008; Prince et al. 2006; McClatchie et al. 2010). Nevertheless, a reduction in subsurface oxygen was thought less likely to impact common thresher shark than blue shark, as thresher diet was dominated by epipelagic prey and not dependent on species associated with the deep scattering layer (Preti et al. 2001; Preti et al. 2012).

Climate Vulnerability Rankings

Overall climate vulnerability for common thresher shark was ***moderate*** with 82% certainty and ***low*** with 16% certainty from bootstrap analysis. Climate exposure was ***high***, with two attributes contributing to this rank: *ocean surface temperature* (3.5), and *ocean acidification* (4.0). Biological sensitivity of thresher shark was ***moderate***, with three attribute scores contributing to this rank: *prey specificity* (2.5), *spawning cycle*, (2.6) and *population growth rate* (3.1). Like other sharks, thresher population growth rate scored high among sensitivity attributes. Consequently, most factors used to characterize population growth rates were more conservative than those of other species. Two other sensitivity attributes, *prey specificity* (2.5) and *spawning cycle* (2.6) were of elevated importance.

Distributional vulnerability and directional effect

For common thresher shark, vulnerability to distributional shift as a response to climate change was ***very high***. Inverse scores from three attributes contributed to this rank: *adult mobility* (3.9), *dispersal of early life stages* (3.9), and *habitat specificity* (3.6).

The directional effect of climate change on common thresher shark in the Northeast Pacific was expected to be ***negative*** (-0.50).

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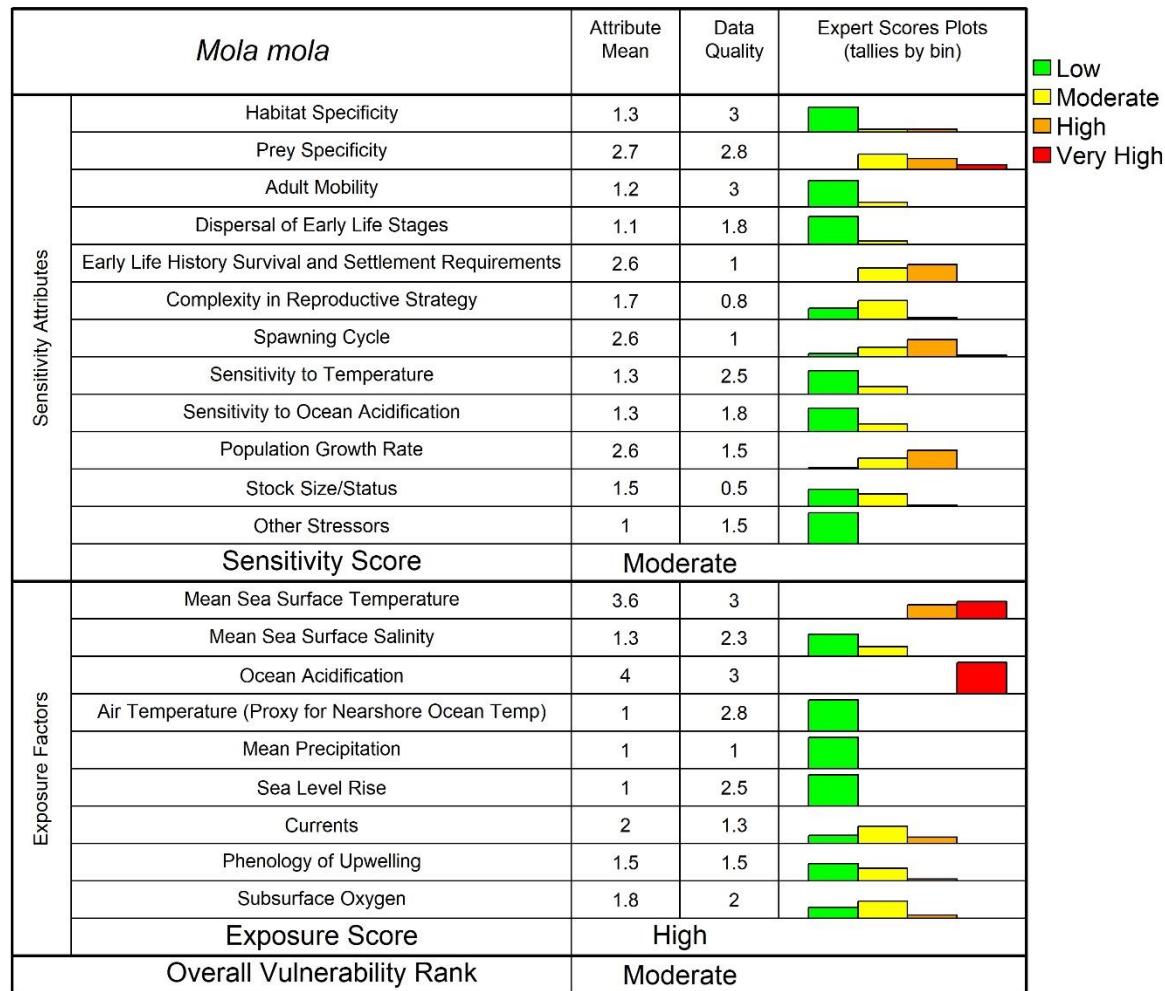
Mola (*Mola mola*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 48% of scores ≥ 2



Life History Synopsis

Mola, or ocean sunfish, is common in the California Current, although its range extends as far north as Alaska. Spawning is thought to occur in tropical and subtropical waters in all ocean basins. As juveniles, Mola likely moves into subtropical and temperate waters in coastal regions. While large Mola does occur offshore, the species is most common in coastal waters. There is overlap in adult and juvenile distribution in the California Current ecosystem, with seasonal north-to-south movements likely linked to

temperature.

Data from some telemetry studies and the reliance of mola on weakly swimming prey suggest the importance of frontal zone habitats. Habitat does not appear to be rare or disturbed. Both juveniles and adults are caught in the fishery. Prior to a large closed area limiting catches in 2001, the majority of catch took place at temperatures of 14-19°C (Pope et al. 2009; NOAA observer data, Thys, oceansunfish.org, unpublished data).

While it is generally accepted that both large juveniles and adults consume gelatinous zooplankton, other items are also found in mola stomachs, indicating a broader, more opportunistic diet (Pope et al. 2009; Nakamura and Sato 2014). These other items included small crustaceans, fish, and squid.

Results from a number of studies suggest that individual mola smaller than 50 cm feed on benthic crustaceans, but those larger than 200 cm feed on jellyfish (Pope et al. 2009; Nakatsubo et al. 2007; Bass et al. 2005; Thys et al. 2013; NOAA unpublished data, Nakamuro and Sato 2014, Thys et al. 2015). Mola makes regular vertical excursions to waters below the thermocline, where it likely targets prey in the deep scattering layer. Depths vary depending on location, but depths exceeding 500 m have been documented in the California Current (Dewar et al. 2010; Cartamil and Lowe 2004; Thys et al. 2015).

Some additional insight into spawning comes from studies in Japan. Around Japan, spawning occurs in the tropics, although the exact location is unknown. Average temperature during the purported spawning period south of Japan is 25.5°C, but how temperature influences spawning is unknown. Spawning is not reported in the California Current, and no larvae have been found there. Interestingly, juveniles smaller than 40 cm are documented repeatedly in waters off San Diego and further north (Nakatsubo et al. 2007; Thys, oceansunfish.org, unpublished data).

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on the population productivity of mola. However, climate change may benefit mola given the potential for increasing jelly populations with warming (Pope et al. 2009), and warming events that lead to habitat expansions. Mola migrates north and south in the California Current and expands migrations northward in warm-water years.

There is no direct evidence of vulnerability to ocean acidification for mola. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Mola is likely an opportunistic feeder, and young sunfish smaller than 50 cm preferentially eat benthic crustaceans. If their prey consumes prey with a calcareous shell, there may be an indirect trophic link with negative effects on abundance (Nakamura and Sato 2014; Pope et al. 2009).

Mola is a relatively long-lived fish with low population growth rates (Pope et al.

2009). Onshore and offshore migrations are poorly understood, but distributional shifts as a function of warmer water temperatures have been documented (Thys et al. 2015). Mola is a highly migratory species, and although it has preferred temperature ranges, individuals are likely able to use a suite of habitats (Thys et al. 2015).

Climate Vulnerability Rankings

Overall climate vulnerability for mola was **moderate** with 95% certainty from bootstrap analysis. Climate exposure was **high**, with two attributes contributing to this rank: *mean sea surface temperature* (3.6) and *ocean acidification* (4.0). Exposure to both factors occurred during all life stages. Biological sensitivity was **moderate**, with four attributes scoring above 2.5: *prey-specificity* (2.7), *population growth rate* (2.6), *spawning cycle* (2.6), and *early life history survival and settlement requirements* (2.6).

Distributional vulnerability and directional effect

For mola, vulnerability to distributional shift as a response to climate change was **very high**. Inverse scores of three attributes contributed to this rank, *adult mobility* (3.8), *dispersal of early life stages* (3.9), and *habitat specialization* (3.7). The directional effect of climate change on mola was expected to be **neutral** (0.31)

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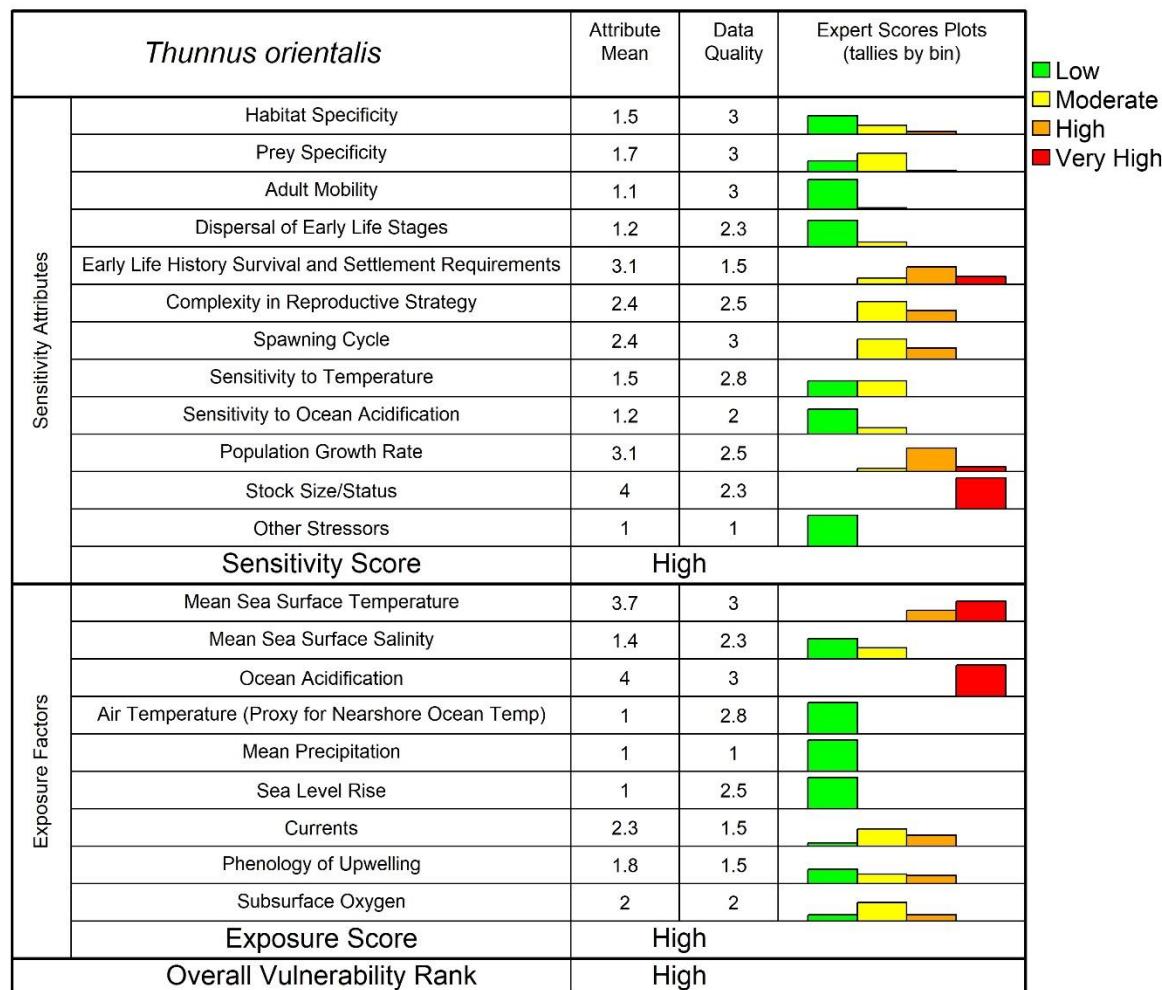
North Pacific Bluefin Tuna (*Thunnus orientalis*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2



Life History Synopsis

Bluefin tuna primarily occurs at latitudes of 20-40°N but may also occur in the tropics of the Western Pacific and in the southern hemisphere off New Zealand and Eastern Australia (ISC 2014; Fujioka et al. 2015). Spawning occurs in two regions of the Western Pacific, the East China Sea and the Sea of Japan. Hatching occurs within 24 h of fertilization. Bluefin begins feeding on copepod nauplii at 3 d post hatch, and larvae

are post-flexion by day 14. They grow rapidly to 30 cm FL within a few months (Fujioka et al. 2015).

Little is known about larval dispersion. Some models suggest movement in currents and eddies from spawning areas to nurseries along the coast of Japan and north in the Sea of Japan, perhaps via mesoscale eddies and the Kuroshio Current. There are likely physical features in both of these spawning regions that make them suitable for bluefin larval development. This specificity for two relatively constrained spawning areas makes bluefin tuna more of a specialist than many other highly migratory species like swordfish and yellowfin tuna. It is unclear whether the region is disturbed, given the lack of information on the suite of factors that may affect larval growth and development. However, these questions were beyond the scope of this analysis, which targets the California Current.

Juveniles smaller than 50 cm FL remain fairly close to Japan in warmer waters, but then disperse and utilize much of the temperate North Pacific, making extensive migrations. An unknown proportion of 1- to 2-year-old fish migrate to foraging grounds in the California Current; many of these individuals apparently stay and forage for several years before returning to the Western Pacific (Bayliff et al. 1991; Bayliff 1994; Rooker et al. 2001; Kitagawa et al. 2007; Boustany et al. 2010; Block et al. 2011; Madigan et al. 2013).

Most information on adult bluefin tuna comes from the spawning grounds where they are targeted by fishers. After spawning, adults typically move north, although a small portion of adults move south, where they are caught in both tropical waters and off New Zealand (Bayliff 1994; Kitagawa et al. 2007; Fujioka et al. 2015).

Juveniles smaller than 25 cm fork length eat a range of fish, squid, and crustaceans and appear to be opportunistic feeders, foraging on both epi- and mesopelagic prey items. They exhibit a diel movement cycle and are believed to forage both near the surface and in the deep scattering layer during daylight hours (Pinkas 1971; Kitagawa et al. 2004; Madigan et al. 2015; Shimose and Wells 2015).

Adults are also believed to be opportunistic predators. Common prey includes a range of squid, crustaceans, and fishes such as anchovies, sardine, flying fish, scad, and other tunas. In the relatively oligotrophic waters of the southwestern Pacific spawning area, even tunicates and amphipods have been found in adult bluefin stomachs (Shimose and Wells 2015; PFMC (2011) Highly Migratory Species FMP).

Climate Effects on Abundance and Distribution

Few studies have examined the effect of climate factors on population abundance for bluefin tuna. Predictions of distribution changes include a northward migration and an increase in the availability of potential habitat due to increases in productivity within

the North Pacific (Hazen et al. 2013). Bluefin tuna is highly migratory, and although it has preferred temperature ranges, the species can utilize a suite of habitats (Block et al. 2011).

Bluefin spawn in two distinct spawning grounds in the West Pacific and spawning in both areas is linked to temperature as in other tunas (Tan & Chen 1975; Tanaka 1999; Schaefer 2001; Chen et al. 2006; Kimura et al. 2010). This specificity for two relatively constrained spawning areas makes them more of a habitat specialist than many other highly migratory species like swordfish and yellowfin tuna, but exposure is not assessed as spawning areas are outside of the California Current.

There is no direct evidence of vulnerability to ocean acidification. However, acidification affects survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). The species does not directly consume prey with a calcareous shell. The copepod prey of larvae could be minimally impacted through indirect effects of ocean acidification on their food. However, given that calcareous phytoplankton do not appear to be an important prey item for copepods in tropical waters where most highly migratory species spawn, this effect will likely be limited (Uotani et al. 1990; Graham et al. 2007; Rossoll et al. 2012. A. Leising pers. comm.).

Climate Vulnerability Rankings

For bluefin tuna, overall climate vulnerability was **high** with 93% certainty and **moderate** with 7% certainty from bootstrap analysis. Climate exposure was **high**, with two attributes accounting for this rank: *ocean surface temperature* (3.7) and *ocean acidification* (4.0). Biological sensitivity was also **high**, with three sensitivity attributes scoring above 3: *early life history survival and settlement requirements* (3.1), *population growth rate* (3.1), and *stock size/status* (4.0). Bluefin Tuna is overfished, with a very low population level. Meeting established catch limits has been challenging, in part due to its high market value.

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **low** for bluefin tuna. Inverse scores from three distributional attributes contributed to this rank: *adult mobility* (3.9), *dispersal of early life stages* (3.8), and *habitat specificity* (3.5). The directional effect of climate change on bluefin tuna was expected to be **negative** (-0.38).

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Shortfin Mako Shark (*Isurus oxyrinchus*)

Overall Vulnerability Rank = Low

Habitat Sensitivity = Low

Climate Exposure = High

Data Quality = 76% of scores ≥ 2

<i>Isurus oxyrinchus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.2	2.8	
	Prey Specificity	1.7	3	
	Adult Mobility	1.2	3	
	Dispersal of Early Life Stages	1.1	2.5	
	Early Life History Survival and Settlement Requirements	1	2.8	
	Complexity in Reproductive Strategy	1.7	1.8	
	Spawning Cycle	1.6	2.8	
	Sensitivity to Temperature	1.2	3	
	Sensitivity to Ocean Acidification	1.4	2.3	
	Population Growth Rate	3.7	2.3	
	Stock Size/Status	1.3	2.5	
	Other Stressors	1	1.5	
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.6	3	
	Mean Sea Surface Salinity	1.3	2.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.5	
	Currents	1.4	1.3	
	Phenology of Upwelling	1.4	1.5	
	Subsurface Oxygen	2	2	
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Shortfin mako shark is a highly migratory oceanic species found in the North Pacific Ocean around 10-50°N (Holts and Bedford 1993; Semba et al. 2011; Joung and Hsu 2005; Lyons et al. 2015; Urbisci et al. 2013). This species can make regular vertical excursions into deep water and can tolerate temperatures of 28-7°C. Tagging data from the Eastern Pacific Ocean shows that mako generally remains at temperatures of 14-26°C

(Block et al. 2011; Hazen et al. 2013; Kai et al. 2015; Urbisci et al. 2013; Semba et al. 2011; Joung and Hsu 2005). In the Eastern Pacific Ocean, mako shark moves broadly, but mako has a core abundance in the Southern California Bight and off Baja, Mexico during summer; individuals disperse offshore in fall and winter (Wells et al. 2013; Block et al. 2011; Kai et al. 2015; Urbisci et al. 2013). Although shortfin mako shark appears to prefer clear, temperate waters away from the continental shelf, it is a generalist, and habitat specificity is likely not a concern.

The mating area of shortfin mako shark is hypothesized to be in Central Pacific subtropical regions 10-25°N. The Southern California Bight is presumed to be a nursery grounds where adult females come to drop their pups. Pups are born at about 70 cm FL and are highly mobile, making short seasonal migrations (Mollet et al. 2000; Semba et al. 2009). Maximum growth rate is 0.036-0.062 yr⁻¹ and von Bertalanffy growth factor *k* is 0.04-0.16 yr⁻¹. Age-at-maturity is over 8 years for females, maximum age is 25-40 years, and natural mortality ranges 0.08-0.24 (Chang and Liu 2009; Tsai 2014; Kai et al. 2015; Cailliet et al. 1983; Semba et al. 2009; Hsu et al. 2003; Ribot-Carballal et al. 2005)

Across age classes, shortfin mako feeds opportunistically on a large variety of fish and cephalopods. Adult diets include marine mammal prey, but the extent of visitation to rookeries to feed on marine mammal prey is unknown (Lyons et al. 2015; Preti et al. 2012). Prey availability is likely a key factor in distribution. While mako appears to forage less in the deep scattering layer than blue shark, tagging and diet data suggest that the deep scattering layer is also an important source of prey. Consequently, shoaling of the oxygen minimum zone may reduce access to forage (Bograd et al. 2008; Prince et al. 2006. McClatchie et al. 2010).

Shortfin mako shark is taken in a range of commercial fisheries, and the majority of catch consists of juveniles and subadults. Adults are rarely caught in fisheries, which is likely due to gear selectivity; however, the largest shortfin mako sharks are taken by recreational anglers off southern California and by longline fisheries in the south central and western North Pacific. Recent stock assessments indicate that the population is neither overfished nor subjected to overfishing (ISC 2015)

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on population abundance for shortfin mako. Based on temperature and chlorophyll projections, Hazen predicted an approximately 27% decrease in available habitat in the North Pacific (Hazen et al. 2013). Impacts associated with temperature will likely be compounded by food web changes.

Some studies suggest increases in temperature and ocean acidification will cause a shift to smaller, less energy-dense phytoplankton, which would likely have negative effects on coastal and pelagic food webs (Hoegh-Guldberg and Bruno 2010, Guinder and Molinero 2014). Potential reduction in productivity of coastal and pelagic habitats due to

a combination of factors would likely have an overall negative effect on the shortfin mako shark population (Polovina et al. 2008; Ainsworth et al. 2011, Donly et al. 2012, Guinder and Molinero 2014; Hoegh-Guldberg and Bruno 2010).

A reduction in subsurface oxygen is less likely to affect shortfin mako than blue shark, as mako diet is thought to be less dependent on species associated with the deep scattering layer, despite dive patterns consistent with foraging on the deep scattering layer (Lyons et al. 2015; Preti et al. 2012). Shortfin mako shark is a highly migratory species with a broad latitudinal distribution (Wells et al. 2013; Block et al. 2011; Kai et al. 2015; Urbisci et al. 2013). The species is able to use a suite of habitats in coastal and offshore waters; juveniles are probably the most vulnerable, as they tend to occupy nearshore waters over the continental shelf (Holts and Bedford 1993).

There is no direct evidence of shortfin mako shark vulnerability to ocean acidification; however, in some sharks, acidification affects survivorship at early life stages and is thought to affect odor tracking and foraging behavior (Dixon et al. 2015; Rosa et al. 2014). .

Climate Vulnerability Rankings

Overall climate vulnerability for shortfin mako shark was ***low*** with 100% certainty from bootstrap analysis. Climate exposure was ***high***, with two attribute scores accounting for this rank: *ocean surface temperature* (3.6) and *ocean acidification* (4.0). The exposure score for *subsurface oxygen* was low, at only 2.0. Biological sensitivity was ***low***, and *population growth rate* (3.7) was the only sensitivity attribute that scored above 2.5. This very high score was linked to the basic life history characteristics of sharks; all other biological sensitivity attributes scored 1.7 or less.

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***very high*** for shortfin mako shark. Inverse scores from three attributes contributed to this rank: *adult mobility* (3.8), *dispersal of early life stages* (3.9), and *habitat specificity* (3.8). The directional effect of climate change on shortfin mako shark in the Northeast Pacific was ***negative*** (-0.31).

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Striped Marlin (*Kajikia audax*)

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2

<i>Kajikia audax</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.6	3	  
	Prey Specificity	1.8	3	  
	Adult Mobility	1.1	3	 
	Dispersal of Early Life Stages	1.1	1.5	
	Early Life History Survival and Settlement Requirements	2.4	1.8	 
	Complexity in Reproductive Strategy	1.8	2.5	 
	Spawning Cycle	2.4	3	 
	Sensitivity to Temperature	1.9	3	  
	Sensitivity to Ocean Acidification	1.6	2	 
	Population Growth Rate	2.6	2.3	 
	Stock Size/Status	3.5	2.8	 
	Other Stressors	1.2	1.5	
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.8	3	 
	Mean Sea Surface Salinity	1.4	2.3	 
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.5	
	Currents	1.4	1.3	 
	Phenology of Upwelling	1.4	1.5	 
	Subsurface Oxygen	1.8	2	  
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Striped marlin adults are found primarily in the mixed layer of temperate, subtropical, and tropical waters of $\sim 20\text{--}25^\circ\text{C}$, where hypoxia is not present. In the western Pacific, striped marlin ranges from $\sim 15^\circ$ north to 40° south of the equator and from approximately 30°N to 30°S in the eastern Pacific (Brill & Lutuvage 2001; Lam et al. 2015; Domeier 2006; Howard & Ueyanagi 1965; Bromhead et al. 2004; Prince et al.

2006). In the North Pacific, larvae are found between the equator and 30°N, mostly at temperatures of 26-31°C. A peak in larval abundance occurs during April-June in the northwest and central Pacific. Larvae are also found in the eastern Pacific off Baja California from June to November (Nishikawa et al. 1985; Gonzalez-Armas et al. 1999; Gonzalez-Armas et al. 2006; Hyde et al. 2006. Bromhead et al. 2004).

Striped marlin is known to migrate from temperate foraging grounds to subtropical and tropical spawning grounds. Spawning migrations are thought to be triggered by temperature changes and reproductive fitness (Kopf et al. 2012; Domeier 2006; Gonzalez-Armas et al. 1999; Gonzalez-Armas et al. 2006). Spawning occurs in waters temperatures of 25°C and warmer. From the California Current, the nearest known spawning ground is around the mouth of the Gulf of California (Mexico). From this area, currents would be unlikely to transport eggs and larvae to U.S. West Coast waters (Gonzalez-Armas et al. 1999; Gonzalez-Armas et al. 2006).

Adults are opportunistic epipelagic predators, feeding mainly on prey that inhabit pelagic surface layers (Abitia-Cardenas et al. 1997; Bromhead et al. 2004). Larval diet likely compares with that of larval scombrids (tuna). During the rapid growth of pre-recruit life history phases, diets shift from copepods and larval crustaceans to small epipelagic teleosts. Once dispersed to feeding grounds, juveniles are epipelagic predators, feeding mainly on prey that inhabit pelagic surface layers (Graham et al. 2007; Abitia-Cardenas et al. 1997; Bromhead et al. 2004).

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate on the population productivity or reproductive potential of striped marlin off the West Coast. However, changes in distribution are linked to warming in the Pacific based on El Niño events, when they become more common in the southern California Bight (IATTC 2009). Su et al. (2013) predicted northward displacement of striped marlin under future warming scenarios for the North Pacific. Long-term climate projections for Australia suggest both poleward shifts and range contraction for this species (Hobday 2010; Robinson et al. 2015).

Striped marlin habitat is thought to be controlled by temperature and oxygen availability, and larvae require specific temperatures in surface waters. Perturbations to these conditions are expected to affect their distribution and abundance (Brill and Lutuvavage 2001; Bromhead et al. 2004; Prince et al. 2006). Little is known about larval prey and habitat requirements. However, anything that affects habitat, prey density, or distribution could affect larval success (Gonzalez-Armas et al. 1999; Gonzalez-Armas et al. 2006; Young and Davis 1990; Davis et al. 1990).

For example, climate-change effects on productivity of lower trophic levels may negatively impact striped marlin abundance. Though U.S. West Coast modeling results are not available, an Australian study (Griffiths et al. 2010), hypothesized future declines

in micronekton fish under climate change scenarios leading to declines in striped marlin abundance. For the Central North Pacific (e.g. region fished by Hawaii-based longlines), food-web modeling results suggest that biomass and fishery yield of billfish (including striped marlin) may decline under future scenarios of declining phytoplankton production (Howell et al. 2013).

Striped marlin has a broad distribution and is exposed to changing pelagic habitat throughout its range. Exposure to changing sea surface temperature and ocean acidification occurs during all life stages, although we considered exposure only in the California Current. Striped marlin migrates into the California Current to forage and is known to expand northward in warm water years.

Climate Vulnerability Rankings

For striped marlin, overall climate vulnerability was **moderate** with 85% certainty and **low** with 15% certainty from bootstrap analysis. Climate exposure was **high**, with two attribute scores contributing to this rank: *ocean surface temperature* (3.8), and *ocean acidification* (4). Biological sensitivity was **moderate**, with most sensitivity attributes scoring as such. Only *stock size/status* (3.5) was scored high or very high by all members of the panel. Striped marlin are both overfished and subjected to overfishing. Other sensitivity attributes scoring above 2 were *early life history survival and settlement requirements* (2.4), *spawning cycle* (2.4), and *population growth rate* (2.6).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **high** for striped marlin. Very high inverse scores from two attributes accounted for this rank: *adult mobility* (3.9) and *dispersal of early life stages* (3.9). The directional effect of climate change on striped marlin in the Northeast Pacific was expected to be **negative** (44% of expert scores).

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Swordfish (*Xiphias gladius*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Xiphias gladius</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	3	   
	Prey Specificity	1.7	3	   
	Adult Mobility	1.1	3	  
	Dispersal of Early Life Stages	1.1	2.3	  
	Early Life History Survival and Settlement Requirements	2.6	1.5	   
	Complexity in Reproductive Strategy	1.8	2.3	  
	Spawning Cycle	1.5	3	   
	Sensitivity to Temperature	1.2	3	  
	Sensitivity to Ocean Acidification	1.6	2.3	  
	Population Growth Rate	2.3	2.5	  
	Stock Size/Status	1.3	2.8	  
	Other Stressors	1.1	1.8	  
Sensitivity Score		Low		
Exposure Factors	Mean Sea Surface Temperature	3.6	3	   
	Mean Sea Surface Salinity	1.4	2.3	  
	Ocean Acidification	4	3	   
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.8	 
	Mean Precipitation	1	1	 
	Sea Level Rise	1	2.5	 
	Currents	1.8	1.3	  
	Phenology of Upwelling	1.3	1.5	  
	Subsurface Oxygen	2.4	2	  
	Exposure Score	High		
Overall Vulnerability Rank		Low		

Life History Synopsis

Swordfish is most commonly productive in coastal waters, in offshore frontal zones, and around seamounts (Nakamura 1985; Palko et al. 1981; Bigelow et al. 1999; Carey and Robison 1981). Preferred habitat is associated with oceanographic or bathymetric features concentrating prey. At coarse spatial scales, there is some suggestion that sea surface temperature and chlorophyll are proxies for factors driving

spatial distribution in the Pacific and Atlantic Oceans (Bigelow et al. 1999; Chang et al. 2013). Swordfish tolerates a broad temperature range and is found from 50°N to 45°S in the west Pacific Ocean and from 50°N to 35°S in the east. Sex- and size-specific spatial differences are found in its distribution, with larger fish (most commonly females) found at higher latitudes and in cooler waters (Nakamura 1985; Palko et al. 1981; Bigelow et al. 1999; Carey and Robison 1981).

For juveniles, catch data reveal that relatively smaller fish (females: <126 cm; males: <118 cm EFL) are caught south of 22°N. Few juveniles are caught in the Hawaii shallow-set longline fishery, and even fewer in the California drift gillnet fishery (Palko et al. 1981; Nakamura 1985; DeMartini 2000). Spawning can occur year-round in tropical waters between 20°N and 20°S at temperatures of 24-29°C (Palko et al. 1981; Nakamura 1985; DeMartini 2000).

Given its broad distribution of larvae in tropical waters, swordfish is a habitat generalist for which suitable habitats are not rare (Rooker et al. 2012). Swordfish consumes a broad range of prey including fish, squid and crustaceans taken from epipelagic, mesopelagic, and benthic habitats. Nevertheless, the deep scattering layer is a key food source. Research off Australia indicates that swordfish diet shifts from mainly fish to mainly squid at larger sizes (Young et al. 2006).

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on swordfish population abundance. Swordfish occurs over a broad range of sea surface temperatures, and distribution appears to be tied more to patterns in foraging than to surface temperature (Dewar et al. 2011). Thus, distribution will likely be linked to food web changes.

Some studies suggest that increases in temperature and reductions in pH will cause a shift to smaller, less energy-dense phytoplankton, and this shift will likely have negative effects on coastal and pelagic food webs (Hoegh-Guldberg and Bruno 2010). Though projections of climate change effects on swordfish off the U.S. West Coast are lacking, an example from Australia suggests that if temperature does explain swordfish distribution (even as a proxy for forage availability), long-term climate projections suggest both poleward shifts and range contraction for this species (Hobday 2010).

Similarly, in a separate Australian modeling study (Griffiths et al. 2010), swordfish abundance declined under climate change scenarios due to hypothesized future declines in micronekton fish. For the Central North Pacific (e.g. region fished by Hawaii-based long liners), food web modeling results suggest that biomass and yield of billfish (including swordfish) may decline under future scenarios of declining phytoplankton production (Howell et al. 2013).

While swordfish has a diverse diet, electronic tagging data and stomach content

analysis show it is highly dependent on the deep scattering layer (Dewar et al. 2011; Preti et al. 2015; Young et al. 2006; Palko et al. 1981; Nakamura 1985). If the deep scattering layer becomes less accessible due to shoaling of the oxygen minimum zone, swordfish may be constrained to waters above this zone, reducing an important portion of their forage base (Bograd et al. 2008; Prince et al. 2006; McClatchie et al. 2010).

Although there is no direct evidence of vulnerability to ocean acidification, acidification impacts survivorship and development of other larval teleosts (Frommel et al. 2012; Munday et al. 2009). Potential reductions in productivity of coastal and pelagic habitats may have an overall negative effect on the population (Polovina et al. 2008; Ainsworth et al. 2011; Doney et al. 2012; Guinder and Molinero 2014; Hoegh-Guldberg and Bruno 2010).

Climate exposure factors were considered only for the juvenile and adult life history phases, although a lack of understanding about stock structure in the Pacific complicates efforts to characterize the full range of swordfish occupying the California Current. Nevertheless, temperature and pH changes across the Pacific are very high. A more complete assessment of vulnerability requires additional examination of exposure including early life history phases, eggs, and larvae that occur outside the California Current.

At present, given their high mobility, generalist foraging strategy, and lack of habitat specialization, the biological sensitivity of swordfish was considered to be low (Palko et al. 1981; Nakamura 1985; DeMartini 2000; Preti et al. 2015; Bigelow et al. 1999; Carey and Robison 1981; Dewar et al. 2011). Swordfish is a highly migratory species with a broad latitudinal distribution and is clearly able to use a suite of habitats in coastal and offshore waters (Nakamura 1985; Palko et al. 1981; Bigelow et al. 1999; Carey and Robison 1981). Biological vulnerability was likely highest at the egg and larvae stage, but these stages occur outside the area of study and were not assessed here (Frommel et al. 2012; Munday et al. 2009).

Pelagic fishes have complex habitat requirements during the larval phases (Rooker et al. 2012; Frommel et al. 2012; Munday et al. 2009). These larvae often have specific prey and temperature requirements, as well as reliance on physical forcing mechanisms to concentrate their prey. Recruitment for pelagic fish can be highly variable. Any of these characteristics may impact swordfish abundance and distribution in an altered climate.

Climate Vulnerability Rankings

For swordfish, overall climate vulnerability was ***low*** with 94% certainty and ***moderate*** with 6% certainty from bootstrap analysis. Climate exposure was ***high***, with scores from two exposure attributes contributing to this rank: *ocean surface temperature* (3.6) and *ocean acidification* (4.0). Biological sensitivity was ***low***, with only the attribute

of *early life history survival and settlement requirements* scoring above 2.5.

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **very high** for swordfish. Inverse scores from three distributional vulnerability attributes accounted for this rank: *adult mobility* (3.9), *dispersal of early life stages* (3.9), and *habitat specificity* (3.6). The directional effect of climate change on swordfish in the Northeast Pacific was expected to be **neutral** (-0.31). T

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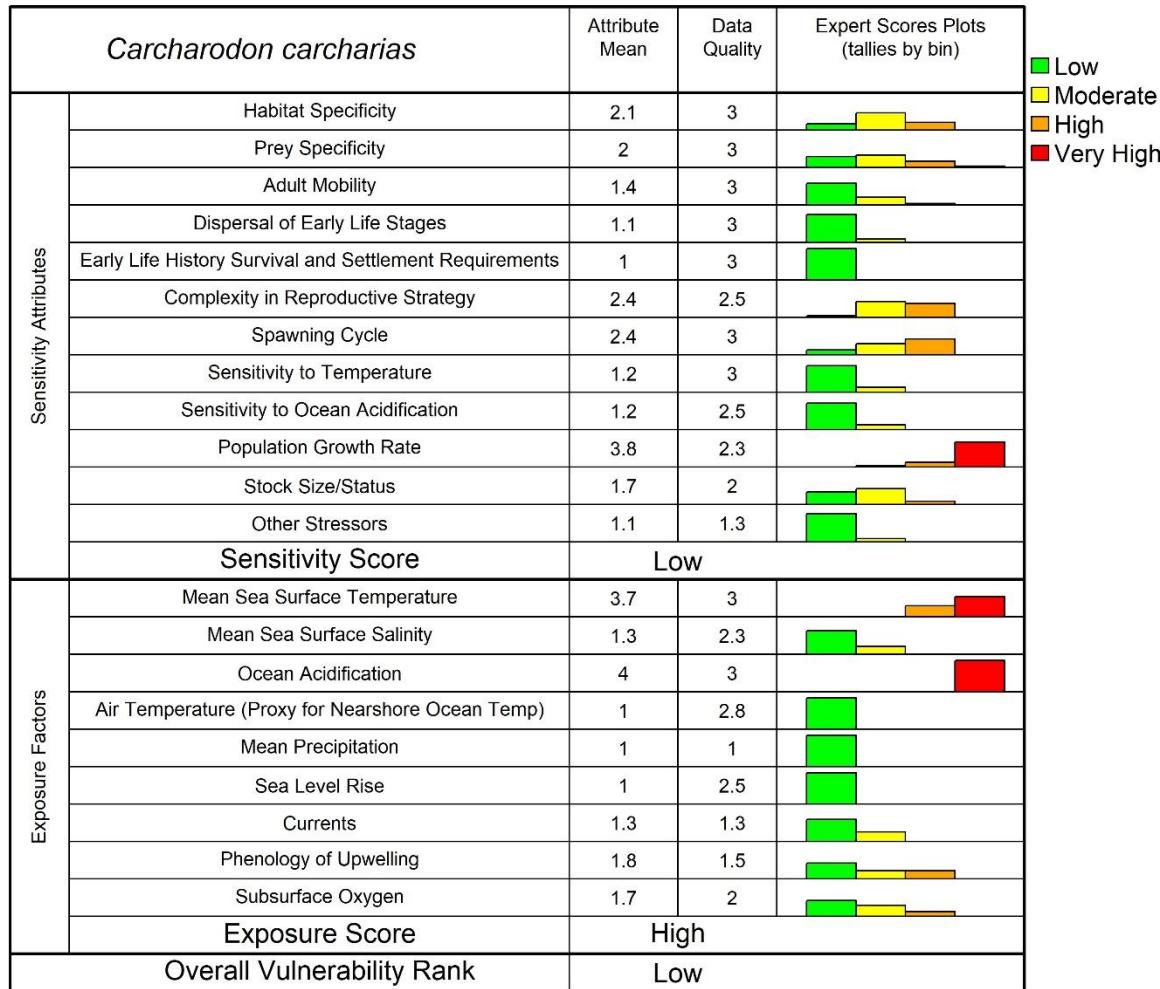
White Shark (*Carcharodon carcharias*)

Overall Vulnerability Rank = Low

Habitat Sensitivity = Low

Climate Exposure = High

Data Quality = 81% of scores ≥ 2



Life History Synopsis

White shark is a slow-growing, long-lived coastal pelagic species that is distributed broadly across the Northeast Pacific. For young-of-the-year and juvenile white shark, the key nursery region appears to extend from Point Conception to Sebastián Vizcaino Bay. Adults range from south of Alaska to the tip of the Baja California peninsula and out to the Hawaiian Islands, making regular migrations between coastal

and offshore habitats.

Male white sharks reach maturity at 8-10 years whereas females reach maturity later, at 12-15 years. White shark maximum growth rate was reported at 0.04 to 0.056 yr⁻¹, and von Bertalanffy growth rate, k, at 0.58 yr⁻¹. Age-at-maturity is at least 8 years, and maximum age 73 years (Cailliet et al. 1985; Smith et al. 1998; Wintner and Cliff 1999).

Coastal aggregation sites are associated with pinniped rookeries, where both white shark foraging and mating occur. Males make annual migrations, moving between a “shared offshore foraging area” and coastal waters in fall and early winter. Females leave the aggregation site and typically remain offshore for 2 years, after which they return to the coast, presumably to pup. Litter sizes are around nine pups.

Two important prey types for adult white shark are pinnipeds such as seals, sea lions, and elephant seals, and fishes, including other sharks and rays. Less common items found in stomach contents include marine reptiles (sea turtles), larger cephalopods, gastropods, and crustaceans. Juvenile white sharks feed primarily on invertebrates, demersal teleosts and small elasmobranchs, as well as squid and epipelagic fish.

In 2013, the National Oceanic and Atmospheric Administration conducted an official status review in response to a petition for listing of Northeast Pacific white shark under the U.S. Endangered Species Act. The NOAA status review concluded that listing was not warranted, and that while white shark populations have been depressed in the past few decades, several lines of evidence support recovery of these populations (Dewar et al. 2013). While there is no targeted fishery for white shark, it is taken as bycatch, the majority of which appear to occur in Mexico, although regulations are in place to protect them.

Climate Effects on Abundance and Distribution

White shark is a highly migratory species with a broad latitudinal distribution and clear ability to use a suite of habitats in coastal and offshore waters (Klimley 1985; Martin 2004; Weng et al. 2007a and b, Domeier and Nasby-Lucas 2008; Galván-Magaña et al. 2010; Jorgensen et al. 2010; Domeier 2012). Although there is some separation of habitat among sex and life history stage, exposure to warming temperature and ocean acidification occurs across habitats occupied during all life history stages (Dewar et al. 2004; Weng 2007a, Domeier and Nasby-Lucas 2008). Juveniles may be most vulnerable, as they tend to occupy nearshore waters over the continental shelf. White shark exhibits a somewhat complex reproductive strategy with a need for internal fertilization and for aggregation of adults at specific sites to reproduce (Weng 2007a, Domeier and Nasby-Lucas 2008; Domeier and Nasby-Lucas 2013),

Few studies examine the effect of climate change on abundance of white shark. Based on temperature and chlorophyll, Hazen et al. (2013) predict an approximately 7% increase in available habitat in the North Pacific. However, any positive impacts from expanded habitat will likely be countered by deleterious food web changes. Some studies suggest that increases in temperature and reductions in pH will cause a shift to smaller, less energy-dense phytoplankton, and this shift would likely have negative effects on coastal and pelagic food webs (Hoegh-Guldberg and Bruno 2010; Guinder and Molinero 2014). Loss of juvenile habitat may also be associated with shoaling of the oxygen minimum zone (Bograd et al. 2008). A reduction in subsurface oxygen is less likely to affect adults, as they appear to forage in association with the deep scattering layer offshore and on nearshore marine mammals. There is no direct evidence of vulnerability to ocean acidification; however, acidification affects odor tracking and foraging behavior of some sharks (Dixon et al. 2015; Rosa et al. 2014).

Climate Vulnerability Rankings

Overall climate vulnerability for white shark was ***low*** with 56% certainty and ***moderate*** with 44% certainty from bootstrap analysis. Climate exposure was ***high***, with scores from two attributes accounting for this rank: *ocean surface temperature* (3.7) and *ocean acidification* (4.0). Despite some potential juvenile exposure, concerns about reductions in *subsurface oxygen* were not ranked high (1.7).

Biological sensitivity was ***low***. The only high sensitivity attribute score was *population growth* (3.8), which is linked to basic life history characteristics of sharks. Other sensitivity attributes of concern included *complexity in reproductive strategy* and *spawning cycle* due to the need for internal fertilization and the aggregation of adults at specific sites to reproduce; however, neither of these attributes scored above 2.5.

Distributional vulnerability and directional effect

For white shark, vulnerability to distributional shift as a response to climate change was ***high***. Inverse scores from three attributes supported this rank: *adult mobility* (3.6), *dispersal of early life stages* (3.9), and *habitat specificity* (2.9). The only low inverse score was that for *sensitivity to temperature*. The directional effect of climate change on white shark in the Northeast Pacific was expected to be ***negative*** (-0.50).

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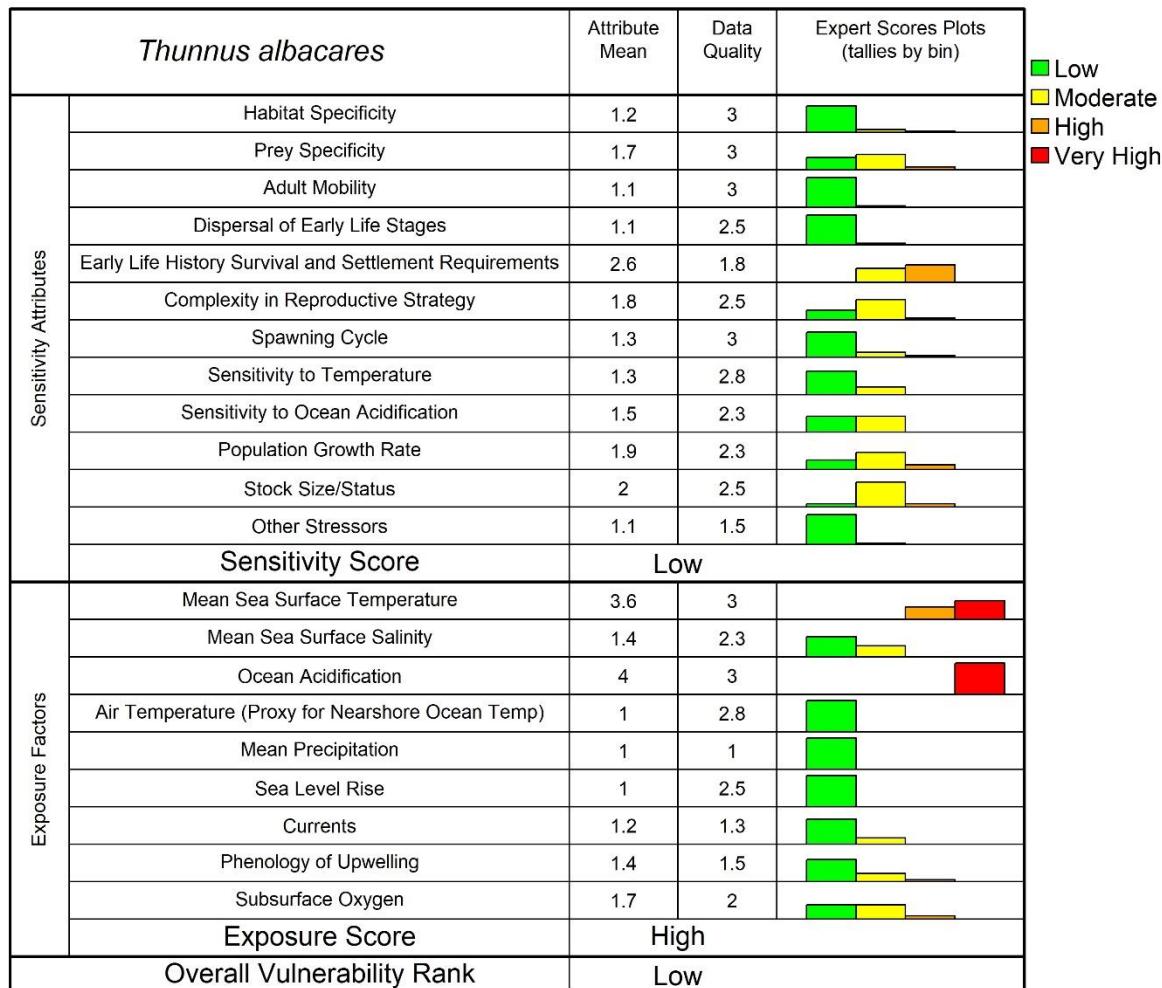
Yellowfin Tuna (*Thunnus albacares*)

Overall Vulnerability Rank = Low 

Habitat Sensitivity = Low 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2



Life History Synopsis

Yellowfin tuna is a tropical to sub-tropical species with abundant physical and biological habitats. Yellowfin is found globally at temperatures of 15 to 31°C and within a range of approximately 59°N to 48°S (Collette and Nauen 1983). Like other tuna species, yellowfin uses the California Current to forage and is encountered there as waters warm in spring and summer (Block et al. 2011). Yellowfin tuna occupy pelagic

ocean waters, and although it has preferred temperature ranges and likely targets fronts, it appears able to use a suite of pelagic habitats (Collette and Nauen 1983, Block et al. 2011).

Yellowfin is a generalist predator on fish, cephalopods, and crustaceans associated with both epipelagic water and the deep scattering layer (Kuhnert et al. 2012; Madigan et al. 2015; Snodgrass et al. in prep). Yellowfin tuna can live up to 7 to 9 years (Au et al. 2008; Aires-da-Silva and Maunder 2012). Females reach 50% maturity at age 2 or 92 cm; males mature at smaller sizes, with 50% mature by 69 cm (Schaefer 2001). Adult yellowfin is perhaps somewhat less mobile than temperate tunas like albacore or Pacific bluefin and may be geographically confined to maximum ranges of about 1800 km based on tagging studies (Schaefer et al. 2011; Minte-Vera et al. 2015).

As a generalist in terms of habitat use, yellowfin tuna is a batch spawner that spawns throughout the year and in multiple locations throughout the Pacific (Wexler et al. 2011; Snodgrass in prep). Spawning occurs at night in pelagic waters with sea surface temperatures exceeding 24°C. In equatorial waters, spawning occurs year-round, while in northern latitudes, spawning occurs only in summer (Schaefer 2001). Eggs and sperm are broadcast into the water column every few days (Kailola et al. 1993; Schaefer 2001), and eggs hatch within one day of fertilization. By ten day post-fertilization (at sizes 8-10 mm), larvae are strong swimmers (Wexler et al. 2007).

During spring through summer, larvae inhabit tropical and subtropical waters in the upper 50 m of the water column at temperatures of 25 to 31°C. Laboratory studies suggest temperature limits for survival between 21 and 33°C, and lethal conditions at dissolved oxygen levels below 2.2 mg O₂ L⁻¹ (Wexler et al. 2011). Not much else is known about larval habitat requirements, but it is common for pelagic larvae to occur in areas where physical forcing concentrates prey (Nishikawa et al. 1985). Larvae are generalist planktivores, feeding on copepods, larval pelagic tunicates, and cladocerans (Uotani et al. 1981; Snodgrass et al. in prep). Both their physical and biological habitat is patchy in distribution, sometimes abundant, and for the most part undisturbed.

Climate Effects on Abundance and Distribution

Few studies examine the effect of climate factors on population abundance for yellowfin tuna. A pilot study demonstrated significant changes in growth, survival, and hatch time of yellowfin tuna larvae at pH levels predicted in the next 100 years (Bromhead et al. 2015). Ocean acidification impacts survivorship, development, and behavior of other larval teleosts (Frommel et al. 2012; Munday et al. 2009).

However, changes in distribution are predicted to include a northward migration and increased availability of potential habitat due to an increase in the subtropical gyre within the North Pacific (Hazen et al. 2013). Yellowfin habitat is mostly controlled by temperature and oxygen availability. Perturbations to these conditions would be expected

to affect their distribution and abundance, but exposure was not assessed as it was outside of the California Current (Prince and Goodyear 2006).

Climate Vulnerability Rankings

For yellowfin tuna, overall climate vulnerability was **low** with 100% certainty from bootstrap analysis. Climate exposure was **high**, with two attribute scores accounting for this rank: *mean sea surface temperature* (3.6) and *ocean acidification* (4). Biological sensitivity was **low**, with only one sensitivity attribute scoring above 2.5: *early life history survival and settlement requirements* (2.6).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **very high** for yellowfin tuna. Inverse scores from three attributes contributed to this rank: *adult mobility* (3.9), *dispersal of early life stages* (3.9), and *habitat specificity* (3.8). The directional effect of climate change on yellowfin tuna was **neutral** (-0.31) due to high adult mobility, abundant pelagic habitat, broad dispersal of larvae, a generalist feeding strategy, and high reproductive output.

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Protected Species

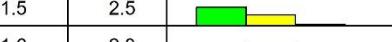
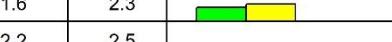
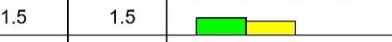
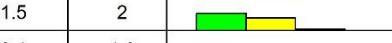
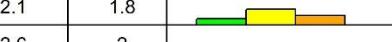
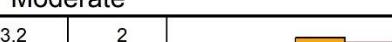
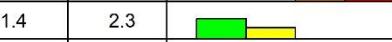
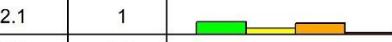
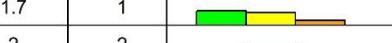
Eulachon (*Thaleichthys pacificus*) - Southern Distinct Population Segment

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Moderate 

Climate Exposure = High 

Data Quality = 71% of scores ≥ 2

<i>Thaleichthys pacificus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.5	2.5	
	Prey Specificity	1.5	2.5	
	Adult Mobility	1.6	2.3	
	Dispersal of Early Life Stages	2.2	2.5	
	Early Life History Survival and Settlement Requirements	2.5	2.3	
	Complexity in Reproductive Strategy	3.1	2.3	
	Spawning Cycle	2.9	2.8	
	Sensitivity to Temperature	2.4	2.3	
	Sensitivity to Ocean Acidification	1.5	1.5	
	Population Growth Rate	1.5	2	
	Stock Size/Status	2.1	1.8	
	Other Stressors	2.6	2	
Sensitivity Score		Moderate		
Exposure Factors	Mean Sea Surface Temperature	3.2	2	
	Mean Sea Surface Salinity	1.4	1	
	Ocean Acidification	3.8	2.5	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1.4	2.3	
	Mean Precipitation	2.1	1	
	Sea Level Rise	2.5	2.3	
	Currents	1.7	1	
	Phenology of Upwelling	2	2	
	Subsurface Oxygen	1.8	1.3	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

Life History Synopsis

Eulachon is anadromous; however, it spends about 95% of its life at sea, returning to spawn above saltwater intrusion in coastal rivers fed by snowmelt or glacial runoff. Eulachon spawns in snow-dominated rivers from northern California to the southeastern

Bering Sea coast of Alaska (Hay and McCarter 2000; Willson et al. 2006). Adult eulachon typically spawn at ages 2-5, when they are 160-250 mm fork length. The spawning migration typically begins at river temperatures of 0-10°C, which usually occur between December and June (Willson et al. 2006). Most eulachon are semelparous, with fecundity ranging from 7,000 to 60,000 eggs. Milt and eggs are released over sand or coarse gravel. Eggs become adhesive after fertilization and hatch in 3-8 weeks depending on temperature.

Newly hatched larvae are about 4-8 mm total length and are transported to estuaries rapidly by spring freshets (Hay and McCarter 2000; Willson et al. 2006). Juvenile eulachon of 30-100 mm in length disperse within the first year of life to open, marine waters on the continental shelf, where they reside near the bottom, commonly at 50-200 m depths (Hay and McCarter 2000; Gustafson et al. 2010). Juvenile 1+ year old and 2+ year old eulachon are encountered as bycatch in offshore ocean shrimp trawl fisheries that fish at depths of 91-256 m (50-140 fathoms) during daylight hours and typically operate over well-defined beds of green mud or green mud and sand off Oregon, Washington, and British Columbia. Eulachon likely also occurs over other substrates, but its ocean habitat is generally unknown. Eulachon is not thought to undergo diel vertical migrations from its preferred depths of 100-200 m.

For eulachon larvae, juveniles, and adults, the primary and secondary prey are mostly crustaceans with chitinous exoskeletons. Diets of post larval and juvenile eulachon (20-157 mm FL) include barnacle and copepod eggs and nauplii, adult copepods, cladocerans, ostracods, mysids, gammaridean amphipods, and larvaceans (Barraclough 1967; Barraclough and Fulton 1967; Robinson et al. 1968a, 1968b). Adult eulachon are reported to consume euphausiids, cumaceans, and copepods (Smith and Saalfeld 1955; Hart 1973; Scott and Crossman 1973), with euphausiids being the primary prey (Hay 2002).

Initial eulachon survival during the critical transition period between larval and juvenile stage is likely linked to the intensity and timing of upwelling in the northern California Current. Successful larval recruitment may rely on the presence of preferred cold-water copepods. Adults may hold for days to weeks in the lower sections of the estuary prior to ascending the river to spawn. Spawning habitat is abundant, but can be disturbed in many ways, including dredging, degraded water quality, and modified flow and temperature regime.

Both water temperature and river discharge rate are factors that may initiate upriver migration of adult eulachon in local river basins. The temperature at which eulachon spawning runs commence varies by geographic area. Differences in spawn timing result in variable spawning temperatures, with some populations spawning at temperatures as low as 0-2°C (Nass River) and others at temperatures of 4-10°C (Cowlitz River). Thus, eulachon spawning in rivers on the north coast of British Columbia (e.g.,

Nass River) typically experiences significantly colder temperatures at spawning (often spawning under ice) compared to conspecifics spawning to the south, particularly in the Klinaklini, Fraser, and Columbia Rivers (Gustafson et al. 2010, 2012).

Climate Effects on Abundance and Distribution

No studies examine the effect of climate factors on the distribution and population productivity of eulachon. However, there are already indications, perhaps in response to warming conditions or altered streamflow timing, that adult eulachon are returning earlier in the season to several rivers within the southern DPS. These include the Bella Coola (Moody and Pitcher 2010), Kemano (Pickard and Marmorek 2007), and Columbia Rivers (Gustafson et al. 2010). Significant changes in southern eulachon spawning distribution were observed, with decadal gaps in spawning occurrence and/or very low spawner abundance. These changes were linked to warming temperatures.

Almost all rivers that support eulachon populations are fed by extensive snowmelt or glacial runoff; therefore, elevated temperatures, changes in snowpack, and changes in the timing and intensity of stream flows will likely have impacts on eulachon. Spawn timing was temperature dependent, and in most rivers, eulachon typically spawn well before the spring freshet, near the seasonal flow minimum. This strategy typically results in egg hatch coinciding with peak spring river discharge. Alteration in stream flows may result in earlier spawning or in larvae being flushed out of rivers at an earlier date.

Early juvenile migration may result in a mismatch between entry of larval eulachon into the ocean and coastal upwelling, which could have a negative impact on marine survival during this critical transition period. Warmer ocean conditions, such as off the Pacific Northwest in 2005, may contribute to a mismatch between eulachon life history and preferred prey species. According to Barth et al. (2007, p. 3), there was a “1-month delay in the 2005 spring transition to upwelling-favorable wind stress in the northern California Current,” and during May-July, upwelling-favorable winds were at their lowest levels in 20 years and “nearshore surface waters averaged 2°C warmer than normal.”

This potential shift in peak upwelling to one month later than normal may result in a temporal mismatch between eulachon larval ocean entry and the presence of preferred prey, whose productivity is dependent on the initiation of upwelling. Adult returns of eulachon to rivers in the southern DPS were poor during the period of unfavorable oceanic conditions from 2004 to 2008 (Gustafson et al. 2010). These conditions may portend how eulachon will respond to warming ocean conditions.

Larvae reside in estuarine environments, which are especially susceptible to environmental change. Exposure to sea surface temperature and ocean acidification occur during the juvenile and adult pre-spawning stages. Because juveniles and adults are highly mobile, populations are likely to shift with changes in ocean temperature.

Climate Vulnerability Rankings

Overall climate vulnerability for eulachon was **moderate** with 79% certainty and **high** with 21% certainty from bootstrap analysis. Climate exposure was ranked **high**, with the primary drivers of this rank including *ocean acidification* (3.8) and *mean sea surface temperature* (3.2). Biological sensitivity was ranked **moderate**, and the primary drivers of this ranking were *complexity in reproductive strategy* (3.1), *spawning cycle* (2.9), *other stressors* (2.6), and *early life history survival and settlement requirements* (2.5).

Distributional vulnerability and directional effect

For eulachon, vulnerability to distributional shift as a response to climate change was **moderate**. Inverse scores from three attributes contributed to this rank: *adult mobility* (3.4), *dispersal of early life stages* (2.8), and *habitat specificity* (2.5). *Sensitivity to temperature* was the only attribute scored with low potential for distributional shift. For southern eulachon, the overall directional effect of climate change was **negative** (-0.50).

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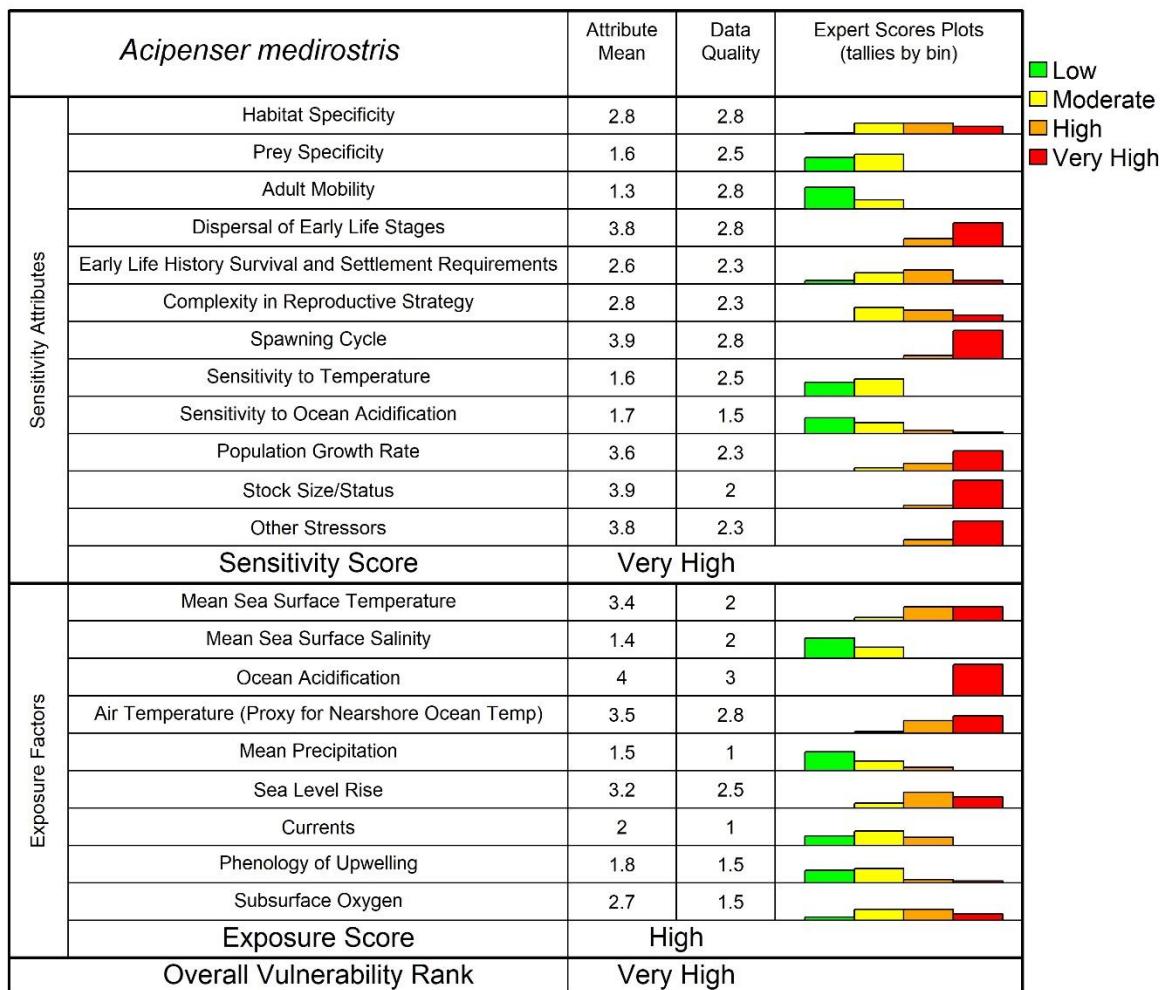
Green Sturgeon (*Acipenser medirostris*)

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = Very High ■

Climate Exposure = High ■

Data Quality = 76% of scores ≥ 2



Life History Synopsis

As anadromous fish, green sturgeon use various environments, but individuals spend most of their lives in the coastal ocean (Bemis and Kynard 1997). Green sturgeon likely utilizes bottom habitats with high seafloor complexity, especially where a greater proportion of the substrate consists of boulders (Huff et al. 2011). Green sturgeon are anadromous, spawning in freshwater, developing in freshwater and estuarine habitats,

and feeding as adults primarily in estuarine and marine habitats.

In the coastal ocean, green sturgeon extends from Baja Mexico to the Bering Sea, although it is commonly found from Haida Gwaii, Canada to San Francisco Bay, California (Huff et al. 2012). Green sturgeon is primarily found in marine habitats at depths of 20-60 m and at temperatures from 9.5-16.0°C (Huff et al. 2011). Green sturgeon presently spawns in three North American river systems: the Klamath, Rogue, and Sacramento.

After emergence from the gravel, juveniles move downstream from spawning areas over several weeks and generally spend their first 2 years in freshwater before migrating to estuary and marine habitats (Moyle 2002; Kynard et al. 2005; Erickson and Hightower 2007). Their migration cycles appear relatively regular and predictable along defined routes, which tend to terminate in winter aggregations off the coast of Canada between Vancouver Island and Haida Gwaii (Lindley et al. 2008; Huff et al. 2012).

These recurrent aggregations of green sturgeon in nearshore zones indicate that suitable habitats are likely limited in number (Erickson and Hightower 2007). The determinants of green sturgeon oceanic distribution are unclear, although the species ranges from Baja, Mexico to the Bering Sea. However, broad-scale physical conditions interacting with migration behavior likely play an important role (Huff et al. 2012). Green sturgeon may travel distances of more than 40 km/day, which include northward migrations in fall followed by southward migrations in spring, although individuals exhibit diverse migratory behaviors (Lindley et al. 2008; Lindley et al. 2011). Adults and subadults commonly visit bays and estuaries during summer and early autumn (Moser and Lindley 2007; Lindley et al. 2011).

At about age 15, individuals may return to natal rivers to spawn during spring. Spawning appears to be temperature dependent (Erickson and Webb 2007). Spawners migrate long distances upstream in rivers and aggregate in pools at depths of over 5 m (Benson et al. 2007; Heublein et al. 2009). Green sturgeon often continue to spawn periodically every 2-4 years after its first spawning migration (Benson et al. 2007; Erickson and Webb 2007; Heublein et al. 2009) and individuals may live over 50 years (Moyle 2002).

Climate Effects on Abundance and Distribution

Some climate signals imply that warmer winters would result in shorter incubation, higher freshwater flows, and greater sedimentation, which could result in higher egg and juvenile mortality, a threat similar to that faced by anadromous salmon. Green sturgeon has a complex life history that renders it vulnerable to numerous threats in both freshwater and marine environments (Adams et al. 2007; Anonymous 2010).

Green sturgeon are of rising conservation concern, with the southernmost of the two distinct population segments of the species listed as threatened under the U.S.

Endangered Species Act (ESA). At present, this threatened segment has an estimated adult population size of around 2,100 individuals (More et al. 2018). The northernmost population is a species of concern under the ESA. Canada also considers the green sturgeon a *Species of Special Concern* under the Canadian Species at Risk Act (National Oceanic and Atmospheric Administration 2008, 2010).

Causes of decline in this species are likely associated with degradation of freshwater and estuarine habitats, but may also result from a variety of threats encountered during extended migrations within coastal, estuarine, and riverine environments. Dams also may limit freshwater distribution (Mora et al. 2009). It is important to note that while green sturgeon use a wide range of habitats, it is obligated to use them all to complete the life cycle.

Climate Vulnerability Rankings

Overall climate exposure was ranked ***high***, with four exposure attributes contributing to this score: *sea surface temperature* (3.4), *ocean acidification* (4.0), *air temperature* (3.5), and *sea level rise* (3.2). Biological sensitivity was ranked ***very high***, with five sensitivity attributes contributing to this score: *dispersal of early life stages* (3.8), *population growth rate* (3.6), *spawning cycle* (3.9), *stock size/status* (3.9) and *other stressors* (3.8).

Overall climate vulnerability was ***very high*** with 100% certainty from bootstrap analysis. Four biological sensitivity attributes contributed to this score: *dispersal of early life stages* (3.8), *spawning cycle* (3.9), *stock size/status* (3.9) and *other stressors* (3.8). Three climate exposure attributes contributed to this score: *sea surface temperature* (3.5), *ocean acidification* (4.0) and *air temperature* (3.5).

Distributional vulnerability and directional effect

For green sturgeon, vulnerability to distributional shift as a response to climate change was considered ***low***. Inverse scores contributing to this rank included low *dispersal of early life stages* (1.2), *habitat specificity* (2.2), and *sensitivity to temperature* (3.4). Although the inverse score for *adult mobility* was high (3.7), green sturgeon exhibit high spawning-site fidelity in freshwater rivers; therefore, early life stages prevent flexibility in distributional shifts. The directional effect of climate change on green sturgeon was ***negative***, with very high certainty (-1.00).

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Pacific Salmon (*Oncorhynchus* spp.)

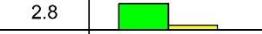
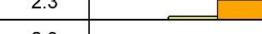
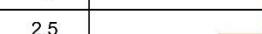
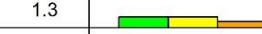
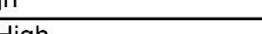
Chinook Salmon (*Oncorhynchus tshawytscha*)

Overall Vulnerability Rank = Very High 

Habitat Sensitivity = Very High 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Oncorhynchus tshawytscha</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.9	2.8	
	Prey Specificity	1.8	2.8	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	3.9	3	
	Early Life History Survival and Settlement Requirements	2.8	3	
	Complexity in Reproductive Strategy	3.5	2.8	
	Spawning Cycle	3.5	3	
	Sensitivity to Temperature	2	2.8	
	Sensitivity to Ocean Acidification	1.8	1.5	
	Population Growth Rate	1.7	2	
	Stock Size/Status	2	2	
	Other Stressors	3.5	2.5	
	Sensitivity Score	Very High		
Exposure Factors	Mean Sea Surface Temperature	3.2	2.3	
	Mean Sea Surface Salinity	1.4	2.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	3.5	2.5	
	Mean Precipitation	1.6	1	
	Sea Level Rise	2.6	2.8	
	Currents	1.9	1	
	Phenology of Upwelling	2.1	1.3	
	Subsurface Oxygen	1.7	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Very High		

Life History Synopsis

Chinook salmon has an anadromous life history that includes a juvenile migration from streams and rivers to coastal or oceanic habitats for extended rearing periods, followed by an adult return migration to natal rivers for maturation, spawning, and death. Across its historical distribution, Chinook salmon has exhibited broad variation in spawn

timing, with spring, summer, fall, late-fall, and winter spawning runs in different portions of the range. Coastal populations tend to migrate as adults in summer and fall, while the spawning migrations of interior populations tend to occur in spring, late fall, and winter (Myers et al. 1998). However, exceptions to these general rules occur throughout the species range, with interior fall-run and coastal spring-run populations.

Juvenile Chinook salmon exhibit highly variable but generally extended rearing in freshwater and estuary environments. Eggs are laid by adults in redds, often located in main stem rivers (Quinn 2005), and emerging juveniles may remain in freshwater habitats for less than 1 week to over 1 year (Healey 1991).

Extended freshwater residency tends to coincide with high elevations and snowmelt hydrographs, while short freshwater residency is more likely to occur in coastal stocks. Populations exhibiting short freshwater residency often exhibit extended juvenile rearing periods in estuaries (weeks to months; Healey 1991). Nevertheless, juvenile migration timing is generally compressed across the range, varying from April to July (Myers et al. 1998).

Many Chinook salmon undergo extensive ocean migrations into the Gulf of Alaska and subarctic North Pacific Ocean, with an absolute thermal range of 0-18.5°C for all seasons, and a frequently observed range of 1-10°C during spring through fall and of 1.5-12°C in winter (reviewed in Aziz et al. 2011). Other populations make more restricted migrations in coastal waters of the California Current, where cool temperatures are maintained by southward transport of subarctic waters and wind-driven upwelling during spring and summer. Chinook salmon are neotrophs, zooplanktivores, and piscivores, with strong ontogenetic prey switching (Davis et al. 2009).

Climate Effects on Abundance and Distribution

Because Chinook salmon is an anadromous, cold-water species, it is vulnerable to climate impacts at multiple life stages and in different habitats. Many spawning populations are both sensitive to and increasingly exposed to warming freshwater temperatures during adult migration, spawning, incubation, and juvenile rearing. Negative effects of higher temperatures and altered flow during the adult migration (Crozier et al. 2020) and juvenile rearing stages are documented (Crozier et al. 2010; Ward et al. 2015; Munsch et al. 2019, Michel 2019). Nonetheless, impacts in the marine stage may ultimately have the most severe consequences for population viability (Crozier et al. 2021; Welch et al. 2020).

Long-distance freshwater migration in early summer puts adults at risk of migration blockages or prespawn mortality associated with elevated temperatures and pathogen outbreaks (Bowerman et al. 2016). Furthermore, migration and holding in sublethal temperatures by spring and summer runs may degrade the quality of both male and female gametes (McCullough et al. 2001; Lahnsteiner and Kletzl 2011). During

incubation, eggs may be exposed to high temperatures (e.g., winter-run Chinook salmon that spawn in summer) or to scouring by high flows or floods in fall and winter (e.g., Puget Sound populations).

After incubation, access to productive shallow-water rearing habitats confers significant growth and likely survival benefits (Sommer et al. 2001; Woodson et al. 2010). Rising temperatures and changes in precipitation may restrict optimal early rearing conditions in freshwater, while higher temperatures and sea level rise during late spring and summer may impact juveniles residing in estuary habitats.

In marine phases, Chinook salmon may be increasingly exposed to changing temperatures and circulation patterns, as well as increasing ocean acidification. Marine survival is lower during warm phases of the Pacific Decadal Oscillation for populations off the coasts of Washington and Oregon (Mantua et al. 1997, Mueter et al. 2005). Rising sea surface temperatures could resemble the cyclic warm ocean conditions characteristic of low survival. Life cycle model results that incorporate projected future rises in SST indicate severe declines in Chinook populations are very likely (Crozier et al. 2021). Chinook salmon is a notable predator of crab larvae and forage fish during marine residence; this diet may confer some relative resilience to impacts of ocean acidification. However, such effects remain highly uncertain due to unknown cascading impacts of acidification upon the food web. Effects on Chinook that are similar to those documented for Coho salmon are also likely (Williams et al 2019).

Climate projections by Aziz et al. (2011) on distributions of open ocean thermal habitat for Chinook salmon found that under an ensemble average of climate model outputs under a moderate emissions scenario (A1B), summer habitat area for Chinook salmon will decline by 86% for the 2080s, with the largest habitat losses in the eastern half of the Gulf of Alaska.

With reductions at the southern end of the historical range offset somewhat by habitat area gains in the southern Bering Sea, winter habitat losses represent 10% of the existing range. It is unknown if a general northward and westward displacement of the most frequently observed thermal habitat for Chinook salmon in the open ocean will have substantial impacts on life-cycle productivity or spawning distribution for the species. However, Chinook salmon are likely vulnerable to the projected displacement of high seas thermal habitat.

Climate Vulnerability Rankings

Overall climate vulnerability was ***very high*** with 51% certainty and ***high*** with 49% certainty from bootstrap analysis. Climate exposure of Chinook ranked ***high***. Four exposure attributes contributed to this score: *ocean acidification* (4.0), *air temperature* (3.5), *mean sea surface temperature* (3.2), and *sea level rise* (2.6). Exposure to *ocean acidification* occurred during both juvenile and adult life stages, while exposure to

summer stream temperature and hydrological regime occurred mainly during the adult migration and fry stage.

Biological sensitivity of Chinook salmon was ranked **very high**, with four sensitivity attributes scoring 3.5 or above: *early life history survival and settlement requirements* (3.9), *complexity in reproductive strategy* (3.5), *spawning cycle* (3.5), and *other stressors* (3.5).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was **high**, with a very high inverse score for *adult mobility* (3.8) and a high inverse score for *habitat specificity* (3.1). Chinook salmon have high spawning site fidelity, which limits the ability of discrete populations to shift distribution, although evidence of limited straying does exist (Lin et al. 2011). Eggs and developing larvae remain in nests (redds) in streambeds for several months. Different populations had very specific habitat requirements for spawning and early juvenile rearing (Quinn 2005). The directional effect of climate change on Chinook salmon was negative (-0.81), although the degree of exposure and extent of directional response varied by population.

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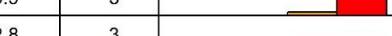
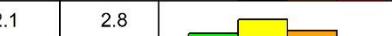
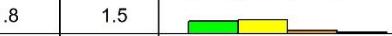
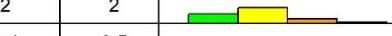
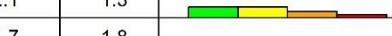
Chum Salmon (*Oncorhynchus keta*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Oncorhynchus keta</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	2.8	
	Prey Specificity	2	2.8	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	3.9	3	
	Early Life History Survival and Settlement Requirements	2.8	3	
	Complexity in Reproductive Strategy	3.1	2.8	
	Spawning Cycle	3.5	3	
	Sensitivity to Temperature	2.1	2.8	
	Sensitivity to Ocean Acidification	1.8	1.5	
	Population Growth Rate	1.7	2	
	Stock Size/Status	2	2	
	Other Stressors	3.4	2.5	
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.2	2.3	
	Mean Sea Surface Salinity	1.4	2.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	3.4	2.3	
	Mean Precipitation	1.5	1	
	Sea Level Rise	3.1	2.8	
	Currents	1.9	1	
	Phenology of Upwelling	2.1	1.3	
	Subsurface Oxygen	1.7	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Chum salmon has a generalized life history that includes migration to oceanic habitats for extended rearing periods and a return to natal waters for maturation, spawning, and death. Chum salmon seek upwelling groundwater for spawning, and eggs and developing larvae remain in nests (redds) in streambeds for several months. West Coast chum salmon primarily spawn during fall and winter; although Hood Canal

summer chum salmon (a threatened ESU) spawns in summer.

Chum salmon relies less on freshwater habitats than most other species of Pacific salmon. Freshwater stages comprise a generalized life history that includes incubation, hatching, and emergence from interstitial gravel spaces, with a rearing period generally less than 2 weeks. Juveniles enter saltwater at small size and tend to rear for extended periods near estuaries, shorelines, and other nearshore habitats. These habitats may be disturbed for various spawning populations (Salo 1991).

West Coast chum salmon undergo extensive ocean migrations into the Gulf of Alaska and subarctic North Pacific Ocean, with an absolute thermal range of 0-15.6°C for all seasons, and a frequently observed range of 1-13°C during spring to fall and of 1.5-10°C in winter (Aziz et al. 2011).

Chum salmon eats a wider variety of prey than other Pacific salmon species (Davis et al. 2009). Chum is a micronectivore, zooplanktivore, and piscivore. Prey preferences include zooplankton, squid, and fish. Specific prey includes euphausiids, hyperiid amphipods, squid, pteropods, fish, appendicularians, ostracods, and heteropods, as well as a large proportion of gelatinous zooplankton.

Climate Effects on Abundance and Distribution

A relatively small number of studies examine the effect of climate factors on abundance, distribution, or productivity of West Coast chum salmon. Eaton and Scheller (1996) found that the maximum weekly average temperature marking the upper thermal tolerance for chum was 21°C. Early marine climate signals such as coastal sea surface temperature and the Pacific Decadal Oscillation explain a small proportion of the variation in total productivity for chum salmon off Washington and the west coast of Vancouver Island. Increased productivity is associated with warmer coastal sea surface temperatures and a positive signal for the Pacific Decadal Oscillation a few months prior to and during the early marine rearing period of chum salmon (Mueter et al. 2005).

Mantua et al. (2010) suggests that the unique life history of Hood Canal summer chum makes this population especially vulnerable to climate change impacts. This population historically spawns in small, shallow streams during late summer, with eggs incubating during fall and early winter and fry migrating to sea in late winter. Predicted climate change effects for low-elevation Hood Canal streams include multiple negative impacts to chum salmon. These impacts stem from warmer water temperatures and reductions in streamflow during summer, as well as potential redd-scouring peak flow magnitudes in fall and winter.

Aziz et al. (2011) modeled spatially explicit representations of thermal habitat for chum salmon in the open ocean. They found that under a multimodel ensemble average of climate model outputs using the A1B emissions scenario, summer habitat area for

chum declined 29% by the 2080s, with the largest habitat losses in the eastern half of the Gulf of Alaska. With reductions at the southern end of the historical range offset somewhat by habitat area gains in the southern Bering Sea winter habitat area losses are 19%. It is unknown if a general northward and westward displacement of the most frequently observed thermal open ocean habitat for chum salmon will have substantial impacts on the life-cycle productivity or spawning distribution for the species, but it seems likely that West Coast chum salmon populations are vulnerable to the projected displacement of high seas thermal habitat.

Climate Vulnerability Rankings

Overall climate vulnerability was ***high*** with 86% certainty and ***very high*** with 13% certainty from bootstrap analysis. Climate exposure for chum salmon was ranked ***high***, with four attributes contributing to this score: *ocean acidification* (4.0), *air temperature* (3.4), *mean sea surface temperature* (3.2), and *sea level rise* (3.1). Exposure to *ocean acidification* occurred during juvenile ocean entry and adult ocean residency. Exposure to summer stream temperature and hydrological regime occurred largely during the adult migration and fry stages. Exposure to sea level rise may occur during early marine rearing, when juveniles rely on estuarine and nearshore rearing habitats.

Biological sensitivity of chum salmon was ranked ***very high***. Two sensitivity attributes were scored 3.5 or higher: *dispersal of early life stages* (3.9) and *spawning cycle* (3.5); two attributes scored 3.0 or higher: *other stressors* (3.4), and *complexity in reproductive strategy* (3.1).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***moderate*** for chum salmon. The inverse attribute score contributing most to this rank was *dispersal of early life stages* (3.9). However, chum has high spawning-site fidelity, which limits the ability of discrete populations to shift distribution, despite evidence of limited straying (Tallman 1994; Lin et al. 2011). The directional effect of climate change on West Coast chum salmon was ***negative*** (-0.69), although the degree of exposure and extent of directional response varied by population.

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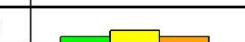
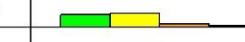
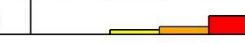
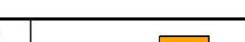
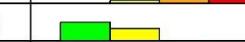
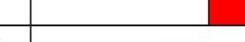
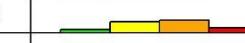
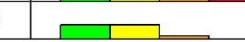
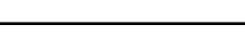
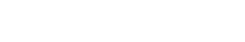
Coho Salmon (*Oncorhynchus kisutch*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Oncorhynchus kisutch</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	2.8	
	Prey Specificity	1.8	2.8	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	3.9	3	
	Early Life History Survival and Settlement Requirements	2.8	3	
	Complexity in Reproductive Strategy	3.5	2.8	
	Spawning Cycle	3.5	3	
	Sensitivity to Temperature	2	2.8	
	Sensitivity to Ocean Acidification	1.8	1.5	
	Population Growth Rate	1.7	2	
	Stock Size/Status	2	2	
	Other Stressors	3.5	2.5	
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.2	2.3	
	Mean Sea Surface Salinity	1.4	2.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	3.4	2.8	
	Mean Precipitation	1.6	1	
	Sea Level Rise	2.6	2.8	
	Currents	1.9	1	
	Phenology of Upwelling	2	1.3	
	Subsurface Oxygen	1.7	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Coho salmon has an anadromous life history that includes migration to oceanic habitats for extended rearing periods and return to natal rivers for maturation, spawning, and death. Adults return predominantly at age-3 after about 16 months at sea, although males may return after less than 1 year, as ~2-year-old *jacks* (Weitkamp et al. 1995).

Most populations return to natal coastal rivers in fall and winter after seasonal precipitation has started and when river flows become higher and cooler and floodplain habitats are more connected. Spawning can occur between September and January, with later spawning occurring in more southerly populations. Adults tend to spawn and construct egg redds in small tributaries and side-channels in floodplains, where high flow events have less energy (Clark et al. 2015).

Juvenile coho rear extensively in freshwater and estuary environments. Incubation lasts several months, and juveniles emerge throughout late winter and spring. Juveniles exhibit a range life histories and habitat associations while in freshwater. A majority resides about one year in freshwater before migrating to sea in spring (Spence and Hall 2010). However, some juveniles have made extensive use of estuary habitats when they are available (Wainwright and Weitkamp 2013, Jones et al. 2014). A small fraction of juveniles spends a second year in freshwater before migrating to sea (Bell 2001, Gallagher et al. 2014).

Coho salmon undergoes a relatively short ocean migration, and tag recovery data from hatchery populations suggest that coho stays with a marine region fairly near the river of origin (Pearcy & Fisher 1988; Weitkamp & Neely 2002; Quinn & Myers 2004). Coho salmon in the ocean exhibit an absolute thermal range of 3-16.5°C during all seasons, a frequently observed range of 6-13°C from spring to fall, and a range of 5.5-9°C in winter. (Aziz et al. 2011). Coho salmon eats a wide variety of pelagic prey, including zooplankton, squid, and fish (Davis et al. 2009).

Climate Effects on Abundance and Distribution

Because coho salmon are anadromous cold-water species; they are vulnerable to climate impacts in different habitats at multiple life stages. While climate effects on spawning and incubation are likely to be relatively modest due to their fall and winter timing, these life stages may nevertheless be affected by warm spring and summer conditions in different portions of their range. For example, drought conditions in California may compromise freshwater breaching dynamics of sand bars blocking stream access, thereby delaying or preventing adult migration.

Juvenile life stages are expected to be particularly vulnerable to changes in stream temperature and other environmental conditions. Because juveniles typically spend at least 1 year in freshwater, they can be exposed to stress from warm summer conditions or low flows (Ebersole et al. 2009, Ohlberger et al. 2018), as well as fall and winter flooding, which may displace them, reducing winter survival (Nickelson et al. 1992). Warming temperatures and reduced stream flows are expected to further stress coho freshwater and estuary rearing stages (Mantua et al. 2010).

Reduced summer rearing capacity from low flows and temperature increases may shift more coho migrants into estuarine-dependent life history types. Estuary systems will likely be affected by sea level rise with climate change. Reduced quality of estuarine habitat is expected to negatively affect growth rates and subsequent marine survival.

Marine survival of coho salmon populations across Oregon and California appears to be sensitive to some aspects of the Pacific Decadal Oscillation. These include timing of the spring transition, strength of upwelling, and sea-surface temperatures (Mantua et al. 1997, Lawson 1997, Beamish et al. 2000, Koslow et al. 2002, Logerwell et al. 2003). Although these relationships are complex, poor marine survival is associated with warming temperatures and associated environmental indices (Mantua et al. 1997, Mueter et al. 2005), so ocean warming is likely to have deleterious effects on coho salmon.

Aziz et al. (2011) projected climate impacts on distributions of thermal habitat for coho salmon in the open ocean. They found that under an ensemble average of climate model outputs with a moderate emissions scenario (A1B), coho summer habitat area would decline by 30% by the 2080s, with the largest habitat losses in the eastern half of the Gulf of Alaska. Winter habitat area losses were 1%, with reductions at the southern end of the range offset somewhat by habitat area gains in the southern Bering Sea.

A general northward and westward displacement of the most frequently observed thermal habitat for coho salmon in the open ocean may have substantial impacts, but the nature and degree of such impacts is not known. Coho tends to occur over the continental shelf, and populations on the coasts of Washington, Oregon, and California benefit from relatively cool upwelling environments.

Exposure to ocean acidification is expected during juvenile ocean entry and adult ocean residency. Experimental treatments of projected CO₂ levels impaired olfactory-mediated behavior by interrupting neural signaling and gene expression within the olfactory system (Williams et al 2019). Exposure to sea level rise impacts may occur during the early marine stage, when juveniles rely on estuarine and nearshore rearing habitats.

Climate Vulnerability Rankings

Overall climate vulnerability for coho salmon was ***high*** with 52% certainty and ***very high*** with 48% certainty from bootstrap analysis. Climate exposure was ranked ***high***, with four attributes contributing to this score: *ocean acidification* (4.0), *air temperature* (3.4), *mean sea surface temperature* (3.2), and *sea level rise* (2.6). Biological sensitivity was ranked ***high***, with four attributes scoring 3.5 or above: *dispersal of early life stages* (3.9), *complexity in reproductive strategy* (3.5), *spawning cycle* (3.5), and *other stressors* (3.5).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ranked ***moderate***. The inverse score was very high for *dispersal of early life stages* (3.9). However, coho salmon had high spawning site fidelity, which limits the ability of discrete populations to shift distribution. Directional effect of climate change on coho salmon was expected to be ***negative*** (-0.88), although the degree of exposure and extent of directional response varied by population.

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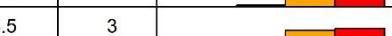
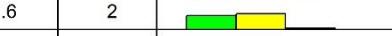
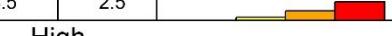
Sockeye Salmon (*Oncorhynchus nerka*)

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 76% of scores ≥ 2

<i>Oncorhynchus nerka</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	2.8	
	Prey Specificity	2	2.8	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	3.9	3	
	Early Life History Survival and Settlement Requirements	2.8	3	
	Complexity in Reproductive Strategy	3.5	2.8	
	Spawning Cycle	3.5	3	
	Sensitivity to Temperature	2.1	2.8	
	Sensitivity to Ocean Acidification	1.8	1.5	
	Population Growth Rate	1.6	2	
	Stock Size/Status	2.1	2.3	
	Other Stressors	3.5	2.5	
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.2	2.3	
	Mean Sea Surface Salinity	1.4	2.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	3.4	2.8	
	Mean Precipitation	1.6	1	
	Sea Level Rise	2.3	2.8	
	Currents	1.9	1	
	Phenology of Upwelling	2	1.3	
	Subsurface Oxygen	1.7	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Sockeye spawning and juvenile habitat requirements are complex and vary substantially among populations across the North Pacific. Sockeye may spawn in lakes or rivers, and freshwater rearing ranges from a few weeks to three years. Sockeye feeds in the ocean one to four years before returning to spawn in freshwater. Landlocked populations of sockeye are known as *kokanee*.

In the Pacific Northwest, sockeye salmon typically spends one to two years in freshwater. Juveniles rear in rivers, streams, sloughs, lakes, ponds, and/or estuaries meeting the required physical and biological habitat conditions. Saltwater juveniles require physical habitats in intertidal areas off beaches, in bays, nearshore areas, and on continental shelf-waters of the northern California Current and eastern Bering Sea (Burgner 1991; Echave et al. 2012).

On the shelf, juveniles are usually distributed vertically from near the surface to a depth of 15 m. Juvenile saltwater habitats include areas with depths of 36 to 462 m, sea surface temperatures of 7.3-14.6°C, and salinities of 22.8 to 32.1. Adults remain in the ocean 1-4 years and then return to natal freshwater rivers, streams, sloughs, ponds, or lakes for spawning. Ocean habitats include areas with sea surface temperatures of 7.4-14.6°C, salinities of 24-32.9, and depths of 42 to 3,207 m (Echave et al. 2012; Walker et al. 2007).

Freshwater juveniles are insectivores and planktivores with prey preferences including copepods, bosminids, Daphnia, chironomids, dipterans, and stoneflies. Saltwater juveniles are primarily planktivores and piscivores. Prey preferences in saltwater include copepods, amphipods, squid, mysid, euphausiid, and fish. Adults eat copepods, amphipods, squid, insects, and fish. In the eastern Bering Sea, adults consume more euphausiids during cold years and more juvenile pollock during warm years.

Adults spawn in freshwater cobble and gravel substrates. Spawners seek their natal habitat for spawning. Historical straying of adults is low (0.6-1.5%).

Climate Effects on Abundance and Distribution

As with other anadromous salmon, some climate signals imply warmer winters that would result in shorter incubation periods, higher freshwater flows, and greater sedimentation, which could result in higher egg-and juvenile mortality. Sockeye salmon depends primarily on lake habitats for spawning and therefore has a less uniform distribution across the North Pacific than other salmon species. Sockeye has a narrow latitudinal range relative to other salmon. This is thought to be a result of temperature sensitivity and dependence on glaciated areas with abundant lakes (Augerot and Foley 2005).

Sockeye salmon are anadromous, spawning in freshwater, developing in freshwater and estuarine habitats, and feeding as adults primarily in marine habitats. Sockeye is exposed to mean sea surface temperatures at life stages ranging from juvenile ocean entry through adult ocean residency.

Ocean acidification is likely to affect organisms that depend on calcified structures for shells, etc. Some of these organisms provide important food sources for

salmon or forage fish that salmon feed on. It is possible that ocean acidification will affect the prey base for sockeye salmon, but this potential impact is poorly understood. Air temperature could affect all freshwater stages, including eggs, juveniles, and spawning adults.

Freshwater habitat is generally impacted by human activities, and the smolt migration of Columbia River salmon involves passage over numerous dams. From ESA listing documents, only 5% of historically accessible nursery lake habitats in the Columbia Basin are accessible to sockeye salmon today (pre-1900; Mullan 1986).

Present restoration actions are focused on reducing passage barriers and restoring rearing habitat. A serious threat to productivity is thermal stress or migration blockage due to high temperatures during the spawning migration or during pre-spawn holding periods. Egg viability is also reduced when adults are exposed to extended periods of high temperature. . The southernmost population of sockeye salmon (Snake River Sockeye) is critically endangered and experiences severe mortality during warm-water periods over their ~1400 km migration. Survival of upstream migrants to natal lakes in Idaho is projected to decline by 80% under conservative climate projections (Crozier et al 2020), threatening persistence of the anadromous life history in this ESU.

Because fecundity is directly related to body size at maturity, reduced growth at sea may lead to delayed maturation, lower reproductive potential, or increased risk of predation (Tucker et al. 2009). In warm years, smolts leave freshwater earlier and enter the ocean earlier (Peterman et al. 1998). Warmer ocean temperatures have mixed effects on growth and survival (Ruggerone et al. 2005). Most inland sockeye populations are extirpated as a result of dams in the Columbia River (Augerot and Foley 2005). Lake spawners are more vulnerable to localized threats and at greater risk of losses in life history and genetic diversity.

Climate Vulnerability Rankings

Overall climate vulnerability was ***high*** with 56% certainty and ***very high*** with 44% certainty from bootstrap analysis. Overall climate exposure ranked ***high***, with three attributes contributing to this score: *sea surface temperature* (3.2), *ocean acidification* (4.0), and *air temperature* (3.4). Biological sensitivity was also ranked ***high***. Four sensitivity attributes contributed to this score: *dispersal of early life stages* (3.9), *spawning cycle* (3.5), *complexity in reproductive strategy* (3.5) and *other stressors* (3.5).

Distributional vulnerability and directional effect

Vulnerability to distributional shift as a response to climate change was ***moderate*** for sockeye salmon. There was a high inverse score for *adult mobility* (3.8). However, inverse scores were low for *dispersal of early life stages* (1.1), high for *habitat specificity* (2.7), and moderate for *sensitivity to temperature* (2.1). Although adults are highly

mobile in the marine environment, they exhibit high spawning-site fidelity to natal rivers; therefore, early life stages preclude flexibility in distributional shifts. The expected directional effect of climate change on sockeye salmon was **negative** (-0.75).

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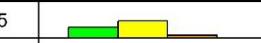
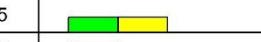
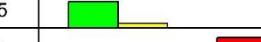
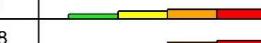
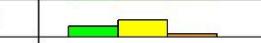
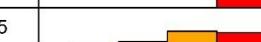
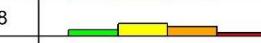
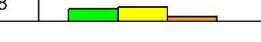
Steelhead (*Oncorhynchus mykiss*)

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 71% of scores ≥ 2

<i>Oncorhynchus mykiss</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	2.5	
	Prey Specificity	1.5	2.5	
	Adult Mobility	1.2	2.5	
	Dispersal of Early Life Stages	3.9	3	
	Early Life History Survival and Settlement Requirements	2.8	3	
	Complexity in Reproductive Strategy	3.5	2.8	
	Spawning Cycle	3.2	3	
	Sensitivity to Temperature	1.9	2.8	
	Sensitivity to Ocean Acidification	1.8	1.5	
	Population Growth Rate	1.8	2	
	Stock Size/Status	1.9	1.8	
	Other Stressors	3.5	2.5	
Sensitivity Score		High		
Exposure Factors	Mean Sea Surface Temperature	3.1	2.5	
	Mean Sea Surface Salinity	1.4	2.3	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	3.2	2.5	
	Mean Precipitation	1.6	1	
	Sea Level Rise	2.3	2.8	
	Currents	1.9	1	
	Phenology of Upwelling	2.1	1.3	
	Subsurface Oxygen	1.8	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		High		

Life History Synopsis

Steelhead is an anadromous and iteroparous form of rainbow trout. Adults spawn in late winter or spring, typically in natal rivers and streams, and deposit eggs in gravel nests. Eggs incubate for several months, depending on water temperature, and alevins remain in the gravel before emerging as fry to begin feeding. Juveniles rear in freshwater for 1-3 years before undergoing the physiological and morphological transformation to

the smolt stage and migrating to the North Pacific Ocean.

In most populations, juveniles migrate directly to the open ocean, but in some populations, they remain in coastal waters near their natal river (Teo et al. 2011). While at sea, steelhead is restricted to near-surface waters in a relatively narrow and well-defined thermal band (Welch et al. 1998), where they feed on squid, fish, and krill (Manzer 1968; Atcheson et al. 2012). Juvenile steelhead rear in marine waters for 2-4 years before returning to natal rivers for spawning. Winter stocks mature in the ocean and spawn soon after river entry, while summer stocks enter rivers in summer and mature and hold for several months before spawning. Summer steelhead thermoregulate behaviorally more extensively than other salmon, interrupting their upstream migration for extended periods while they reside in cool-water tributaries (Keefer et al. 2009). This behavior has stabilized annual survival rates despite record high temperatures that have occurred recently in the Columbia River Basin during their upstream migration (Siegel et al. in press).

In some steelhead populations, a small fraction of fish survives spawning and returns to the sea for a second cycle of growth and reproduction. This fraction of repeat spawners varies by population, but individuals rarely complete more than two spawning cycles. In some populations, a portion of the population may complete the life cycle in freshwater (Satterthwaite et al. 2010). This life history diversity, which is under complex genetic control (Thompson et al. 2020), presumably buffers populations from the effects of variable ocean and freshwater conditions.

In certain populations, another migratory pattern is exhibited—the *half-pounder* life history—where juveniles enter the ocean in spring and return the following autumn, possibly exploiting unusual patterns of river and sea-surface temperature in and near the river basins supporting this life history type (Hayes et al. 2016). Hayes et al. (2016) hypothesize that as the narrow band of thermally-suitable marine habitat shifts northward, it may disconnect from the coastal waters where steelhead exit and enter natal rivers, preventing populations from completing the life cycle.

Climate Effects on Abundance and Distribution

Because of their wide distribution and complex and variable life history, climate effects on the abundance and distribution of steelhead are difficult to generalize at the species level. In general, the geographic distribution of steelhead is not controlled by thermal tolerance at various life stages (Richter and Kolmes 2005). However, anadromous steelhead appear to be under strong thermal control (Welch et al. 1998), so warming surface temperature is expected to shift anadromous steelhead distribution northward.

Hayes et al. (2016) hypothesizes that this northward shift could disconnect ocean rearing and migration corridors from spawning rivers, precluding some steelhead populations from exhibiting anadromy or causing other changes to life history. Similarly,

juvenile steelhead rear in freshwater in summer, and rising temperatures will cause local extirpations where these temperatures exceed thermal tolerance, contracting the southern limit of the species range. There may be corresponding range extensions to northern and high-elevation areas that are too cold at present.

The net effect of the carrying capacity and productivity of habitats used across the life cycle of populations and life history types determines steelhead abundance.

Variations in steelhead and other species of Pacific salmon abundance are attributed to ocean climate variability (Beamish 1993; Mantua et al. 1996; Smith and Ward 2000).

The mechanisms linking climate and abundance are unclear, but likely include changes in production of food, thermal effects on energetics, and altered interactions with predators.

Several studies predict how juvenile growth will respond to rising temperature in freshwater habitats, with effects varying depending on present thermal conditions (Beer and Anderson 2013; Falke et al. 2013). Changing flow regimes may also affect steelhead abundance through changes in mean flow (Falke et al. 2013) and extreme high flows (Mantua et al. 2010; Goode et al. 2013), which may scour eggs and alevins.

Climate, especially temperature, plays a strong role in determining the productivity of habitats, which could increase or decrease under climate change scenarios. Steelhead populations are expected to adapt to these changes through phenotypic plasticity and natural selection, although the extent and pace of adaptation is hard to predict (Crozier et al. 2008).

Steelhead rears for 1-3 years in freshwater, and juveniles and adults feed in a seasonally variable but tightly delimited band of thermally suitable ocean surface water (Teo et al. 2001; Welch et al. 1998). Ocean surface waters are expected to become undersaturated by aragonite by 2100 (Orr et al. 2005), which will stress steelhead prey such as squid (Fabry et al. 2008), as well as plankton with aragonite shells that directly (e.g., pteropods) or indirectly support steelhead.

Juveniles rear in freshwater for at least one summer, and cannot tolerate temperatures over 25°C. Adults may also spend time in freshwater during summer, either before or after spawning. This makes them vulnerable to rising air and stream temperatures, which may exceed thermal tolerance unless access to thermal refuges is maintained and these refuges are protected from overfishing

In river basins where summer temperatures are already stressful for rearing juveniles, warming stream temperatures will likely depress productivity, possibly extirpating populations and contracting the species' southern range limit. Warming temperatures at higher latitudes and elevations may increase productivity in some populations that are currently limited by cold temperatures, and northern range expansion is possible. The distribution of suitable ocean habitat is likely to contract and shift

northward (Abdul-Aziz et al. 2011).

Over its life cycle, steelhead occupies a variety of habitats, and movement through these habitats is governed by development, which is sensitive to temperature, environmental cues, and windows of habitat suitability. Climate variability can disrupt each of these, making steelhead exceptionally sensitive to climate variation. However, compared to some Pacific salmon populations, steelhead is potentially more resilient, with a life history more flexible in terms of timing and habitat specificity.

Like Pacific salmon, and in spite of its relatively flexible life history, steelhead must spawn and rear for extended periods in freshwater habitats, which in many cases have been modified and degraded by dams, channel modifications, altered hydrographs, pollution, and myriad other factors that reduce productivity and options for expressing potential life history variation (Good et al. 2005). Such pervasive reduction in habitat quality reduces population productivity and thereby increases sensitivity to climate impacts (Battin et al. 2007).

Climate Vulnerability Rankings

Overall climate vulnerability for steelhead was ***high*** with 71% certainty and ***very high*** with 27% certainty from bootstrap analysis. Climate exposure was ranked ***high***, with three attributes contributing to this score: *mean sea surface temperature* (3.1), *ocean acidification* (4), and *air temperature* (3.2). Biological sensitivity was also ranked ***high***, with four attributes influencing this score: *dispersal of early life stages* (3.9), *complexity in reproductive strategy* (3.5), *spawning cycle* (3.2), and *other stressors* (3.5).

Distributional vulnerability and directional effect

Inverse scores of two attributes led to a ***high*** probability of steelhead distributional vulnerability due to climate change: very high *adult mobility* (3.8), and high *habitat specificity* (3.2). Directional effect of climate change on steelhead in the Pacific Ocean was expected to be ***negative*** (63% of expert scores).

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