Pacific Islands Vulnerability Assessment
Shark Species Narrative

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The Pacific Islands Fisheries Science Center conducted a climate change vulnerability assessment for six species groups in the Pacific Islands region (Giddens et al. unpublished). This data report summarizes the following assessments of each species in the shark species group: overall climate vulnerability rank (certainty determined by bootstrap following Hare et al. 2016), climate exposure, biological sensitivity, distributional vulnerability rank, data quality, climate effects on abundance and distribution, and life history (see Morrison et al. 2015 for further details).

Biological sensitivity and climate exposure were evaluated and scored by experts for each species. Biological sensitivity is representative of a species' capacity to respond to environmental changes in reference to a biological attribute. The Shark Species Narrative is accompanied by the Shark Species Profile, which provides further information on each biological sensitivity attribute for each species. The Shark Species Profile was used to help experts evaluate biological sensitivity. Experts were also encouraged to use their own expertise and knowledge when evaluating. Climate exposure is defined as the degree to which a species may experience a detrimental change in a physical variable as a result of climate change. The inclusion of climate exposure variables followed these four guidelines: 1) the variables are deemed to be ecologically meaningful for the species and geography in question, 2) the variables should be available on the NOAA ESRL Climate Change Data Portal for consistency across different CVAs, 3) the variables are available in the temporal and spatial domains suitable for inclusion, and 4) the quality of the modeled product was judged to be adequate for inclusion. By following these guidelines, the exposure scoring was therefore a quantitative exercise, in that future values could be compared to historical values while incorporating observed patterns of natural variability. This allowed determination of likely severity of future changes in exposure on a species and area specific basis for each exposure variable. Scoring for biological sensitivity and climate exposure is based on scale from 1–4 (Low, Moderate, High, Very High) and scoring for data quality is ranked from 0–3 (No Data, Expert Judgement, Limited Data, Adequate Data). A high score for biological sensitivity and climate exposure indicates greater vulnerability. Expert Score Plots show the variation in expert scoring (5 experts per species). Scoring was completed in 2018. The mean score for each sensitivity attribute or exposure variable was calculated and a logic model was used to determine the component score for biological sensitivity and climate exposure. For example, if there are three or more attributes with a mean greater than or equal to 3.5, the sensitivity or exposure component score would be a 4 (Very High). Please, see Morrison et al. 2015 for remaining logic model's criteria. Overall climate vulnerability was determined by multiplying sensitivity and exposure component scores and the possible range of these scores was between 1 and 16. The numerical values for the climate vulnerability rank were the following: 1–3 (Low), 4–6 (Moderate), 8–9 (High), and 12–16 (Very High).

Hare JA, Morrison WE, Nelson MW, Stachura MM, Teeters EJ, Griffis RB, Alexander MA, Scott JD, Alde L, Bell RJ, et al. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS One. 11: e0146756.

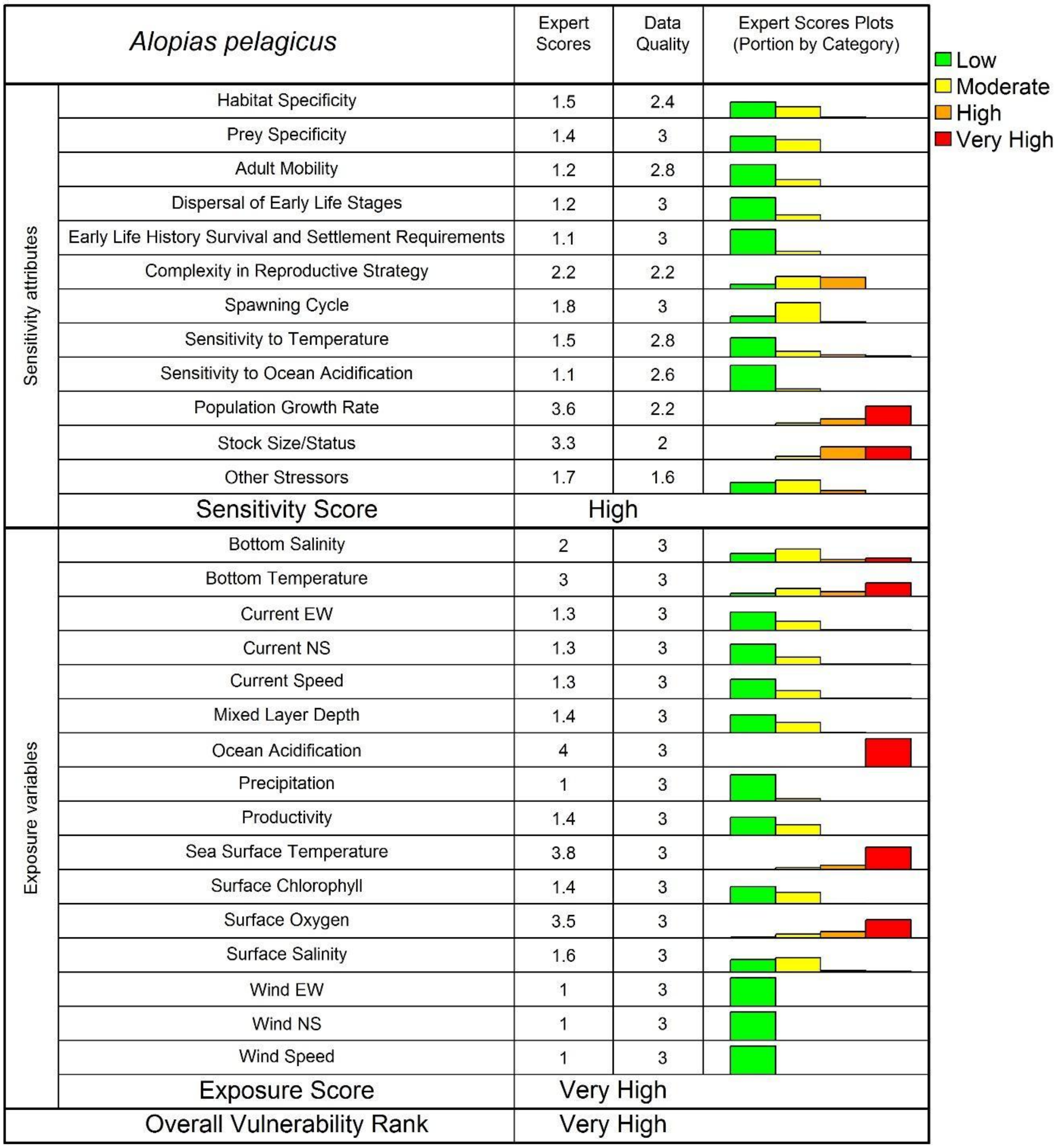
Morrison WE, Nelson MW, Howard JF, Teeters EJ, Hare JA, Griffis RB, Scott JD, Alexander MA. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept of Commer, NOAA. NOAA Technical Memorandum NMFS-OSF-3, 48 p.

Contents

Pelagic Thresher Shark - *Alopias pelagicus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥
Data Quality = 96% of scores ≥ 2



Alopias pelagicus		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.5	2.4	
	Prey Specificity	1.4	3	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	1.2	3	
	Early Life History Survival and Settlement Requirements	1.1	3	
	Complexity in Reproductive Strategy	2.2	2.2	
	Spawning Cycle	1.8	3	
	Sensitivity to Temperature	1.5	2.8	
	Sensitivity to Ocean Acidification	1.1	2.6	
	Population Growth Rate	3.6	2.2	
	Stock Size/Status	3.3	2	
	Other Stressors	1.7	1.6	
	Sensitivity Score	High		
Exposure variables	Bottom Salinity	2	3	
	Bottom Temperature	3	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.3	3	
	Mixed Layer Depth	1.4	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	3.8	3	
	Surface Chlorophyll	1.4	3	
	Surface Oxygen	3.5	3	
	Surface Salinity	1.6	3	
	Wind EW	1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Pelagic Thresher Shark (*Alopias pelagicus*)

Overall Climate Vulnerability Rank: **[Very High].** (58% certainty from bootstrap analysis).

Climate Exposure: **[Very High].** Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[High]**. Two sensitivity attributes scored above a 3.0: Population Growth Rate (3.6) and Stock Size/Status (3.3).

Distributional Vulnerability Rank: **[Very High].** Three attributes indicated very high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 96% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

The pelagic thresher shark is a highly migratory species that is distributed widely in the Indo-Pacific Ocean in tropical and subtropical waters [1]. Despite its wide range, it is listed as Endangered by IUCN [2] with declining populations. In addition, two genetically distinct evolutionarily significant units (ESU) exist between the eastern and western Pacific Oceans with pelagic thresher sharks around Hawaiʻi composed of both eastern and western ESUs [3]. Uncertainty in the spatial/temporal distribution of these ESUs around Hawaiʻi [3] may result in increased vulnerability to localized depletion and the impacts of climate change and overexploitation.

This species has low reproductive potential with a low capacity to recover from exploitation and impacts from climate change. Pelagic thresher sharks are currently declining as they are captured in both target and bycatch fisheries with some fisheries unmanaged and/or catch undocumented [2].

Juveniles of the related common thresher shark (*Alopias vulpinus*) are distributed in shallow, nearshore habitats until age three when predation risk is reduced; they then migrate offshore [4]. No information is available on distribution of juvenile pelagic threshers; however, it is likely they use similar habitats. These nearshore habitats may be susceptible to climate change impacts such as temperature changes, coastal pollution, or other issues [5]. Adults may use atoll lagoons in the tropics but otherwise these sharks utilize epipelagic waters down to approximately 152 m in the subtropics and down into the mesopelagic in the tropics [1,6-10]. Pelagic threshers exhibit diel vertical migrations, moving to shallow waters at night and deeper during the day [11].

Temperature and oceanic currents influence pelagic thresher distribution, with known movements towards the equator in winter and away from it in summer [12]. One population in the eastern North Pacific around Baja California shifts distribution northwards during strong El Nino years [1,6-10]. The influence of currents and temperature on their distribution indicate warming temperatures or changes in current patterns may result in shifts in distributions in some populations.

Life History Synopsis**:**

Pelagic thresher sharks have low potential for recovery from climate or anthropogenic impacts with life history characteristics of slow growth (von Bertalanffy growth coefficients, K, are estimated at 0.085 per year for females and 0.118 per year for males from a population around Taiwan) [13], late maturation (8.0–9.2 years for females and 7–8 years for males for a population around Taiwan) [13], and low reproductive potential (1–2 pups per litter) [2]. Their natural mortality has been estimated based on the average of the age-specific natural mortality from Taiwan waters to be 0.140 [14]. The estimated potential annual rate of population increase under sustainable fishing is very low—0.033 [2].

Pelagic thresher mating may be affected by warming temperatures because mating is cued by temperature; they breed from October to March [15]. With a gestation period thought to be about a year [16], this ovoviviparous species gives birth to one to two pups [2] in the spring or summer [15]. Juveniles remain in nearshore, shallow habitats for three years until they are sufficiently large that predation risk is low enough to migrate into less protected waters [4]. Juveniles may be preyed upon by makos, reef sharks, or even other pelagic threshers [4]. These nearshore, juvenile habitats are at high risk from pollution, increased sea surface temperature, and decreased oxygen availability [5].

Shifts in prey for some pelagic thresher shark populations may occur due to climate change and warming temperatures if prey distribution or abundance change. Pelagic threshers found in warmer waters feed primarily on anchovies, whereas in cooler waters, they feed primarily on squid and sardines. They may also feed on other prey in deep waters, such as mackerel, hake, and red crab [9,17].

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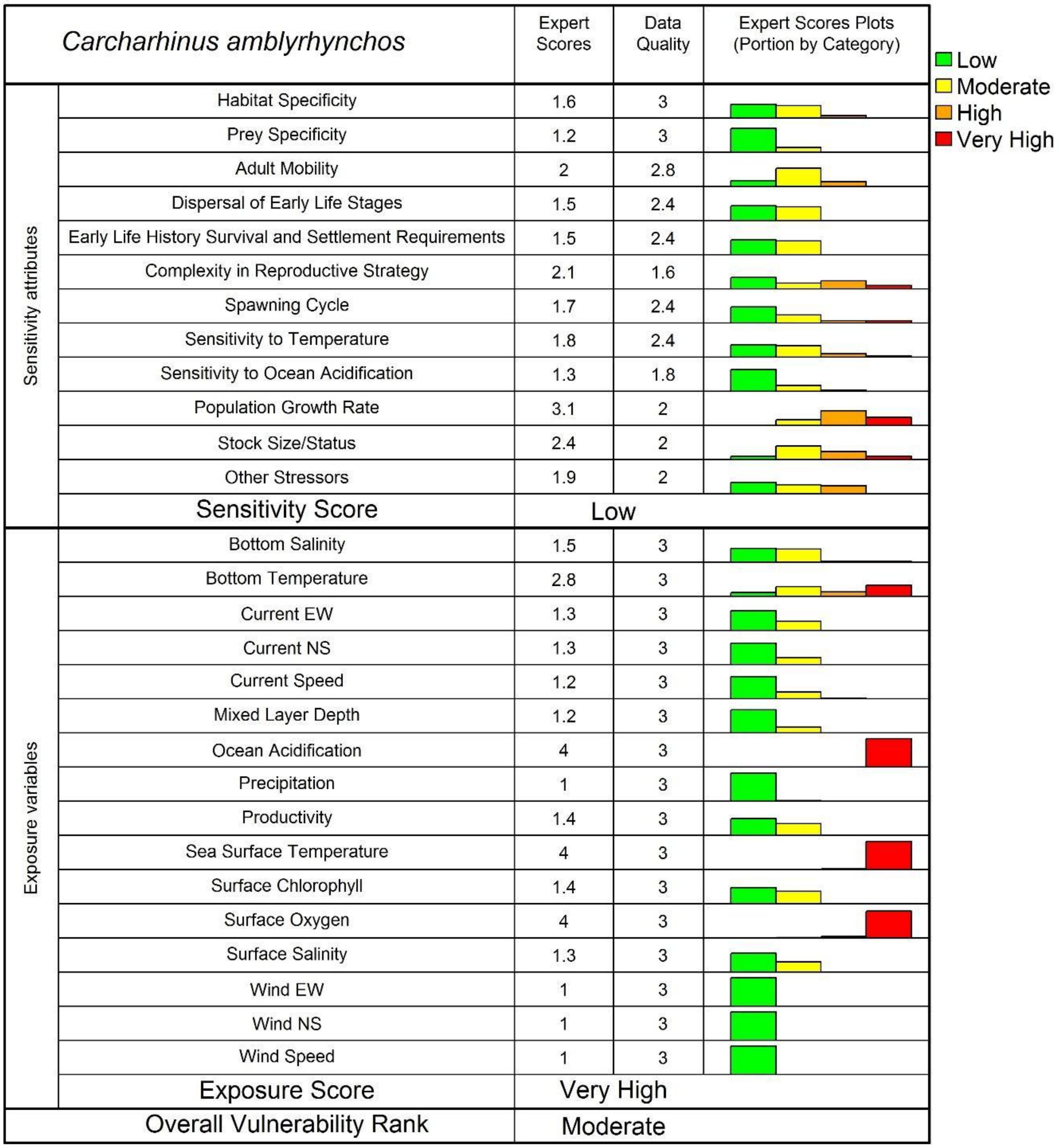
Gray reef shark - *Carcharhinus amblyrhynchos*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥
Data Quality = 93% of scores ≥ 2



	Carcharhinus amblyrhynchos	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.6	3	
	Prey Specificity	1.2	3	
	Adult Mobility	2	2.8	
	Dispersal of Early Life Stages	1.5	2.4	
	Early Life History Survival and Settlement Requirements	1.5	2.4	
	Complexity in Reproductive Strategy	2.1	1.6	
	Spawning Cycle	1.7	2.4	
	Sensitivity to Temperature	1.8	2.4	
	Sensitivity to Ocean Acidification	1.3	1.8	
	Population Growth Rate	3.1	2	
	Stock Size/Status	2.4	2	
	Other Stressors	1.9	2	
	Sensitivity Score	Low		
Exposure variables	Bottom Salinity	1.5	3	
	Bottom Temperature	2.8	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.2	3	
	Mixed Layer Depth	1.2	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.4	3	
	Surface Oxygen	4	3	
	Surface Salinity	1.3	3	
	Wind EW	1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Grey Reef Shark (*Carcharhinus amblyrhynchos*)

Overall Climate Vulnerability Rank: **[Moderate].** (70% certainty from bootstrap analysis).

Climate Exposure: **[Very High].** Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during the life stages.

Biological Sensitivity: **[Low]**. Population Growth Rate (3.1) was the only sensitivity attribute that scored above a 3.0. The next highest scores were for Complexity in Reproductive Strategy (2.1) and Stock Size/Status (2.4).

Distributional Vulnerability Rank: **[High].** Three attributes indicated high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 93% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

Although grey reef sharks are widespread throughout inshore reefs in the subtropical and tropical Pacific and Indian Oceans and Red Sea [1-4], this species has demonstrated declines in local populations in the Hawaiian Islands and has been assessed as Near Threatened by the IUCN [3,5]. The low reproductive potential, strong site fidelity, and preference for inshore, vulnerable habitats may result in this shark being susceptible to changes in abundance and distribution from anthropogenic events and climate change.

Both adult and juvenile grey reef sharks rely on vulnerable lagoon and coral reef habitats [5-8]. Coral reef fishes compose the majority of grey reef shark's diet [5,9]. Coral reefs worldwide are threatened by warming temperatures, decreased oxygen availability, and pollution from coastal development and marine sources [3,10,11]. In addition, climate change may increase the frequency of storms that have the potential to damage reef and lagoon habitats and increase turbidity. Furthermore, the strong site fidelity exhibited by these sharks through their territorial behavior [2,12] and relatively small home range (< 10 km^2) [13] increases their susceptibility to localized impacts that may occur from climate change and other anthropogenic inputs. It is uncertain if these sharks have the resiliency to relocate or expand their habitats if their territory is damaged or experiences a decline in productivity that affects prey availability.

Life History Synopsis**:**

Grey reef sharks mature at a relatively late age and have low fecundity and long reproductive cycles—all contributing to a low reproductive potential. These sharks live about 25 years and reach maturity at 7–7.5 years of age [6] with reproduction occurring every other year [5,14]. The von Bertalanffy growth rate *K* has been estimated at 0.29 for the population in the Northwestern Hawaiian Islands (NWHI) [15] and 0.05 for an unfished population in Palmyra [16]. Natural mortality is not reported for this species. Mating and fertilization occur from March to May around the Hawaiian Islands with no known mating aggregations, although sharks are social, forming groups daily [5,14]. After a 12-month gestation period, females give birth to live pups with a litter of one to six 46–60 cm pups [12]. Lagoons are utilized as nursery grounds while adults use lagoons, reefs, reef passes, and drop-offs to deeper water [2,5-8]. Specific diet requirements are not known for juveniles; adults rely mostly on coral reef fishes but also eat crustaceans, squid, and octopi [5,9]. Predation risk for grey reef sharks decreases with size, yet adults are still vulnerable to predation by other sharks and orcas [6].

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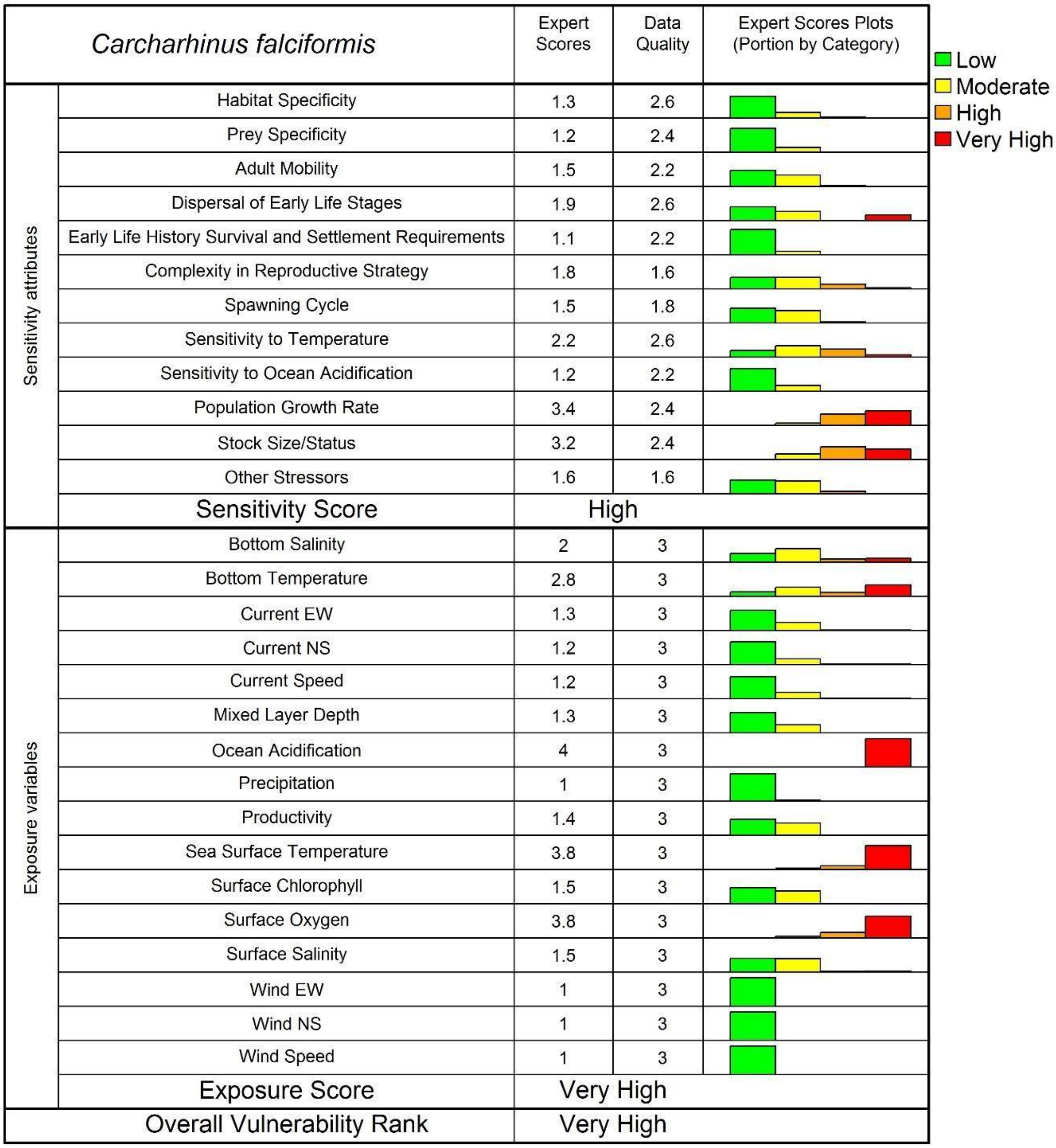
Silky shark - *Carcharhinus falciformis*

Overall Vulnerability Rank = Very High🟥

Biological Sensitivity = High🟧
Climate Exposure = Very High🟥
Data Quality = 89% of scores ≥ 2



	Carcharhinus falciformis	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.3	2.6	
	Prey Specificity	1.2	2.4	
	Adult Mobility	1.5	2.2	
	Dispersal of Early Life Stages	1.9	2.6	
	Early Life History Survival and Settlement Requirements	1.1	2.2	
	Complexity in Reproductive Strategy	1.8	1.6	
	Spawning Cycle	1.5	1.8	
	Sensitivity to Temperature	2.2	2.6	
	Sensitivity to Ocean Acidification	1.2	2.2	
	Population Growth Rate	3.4	2.4	
	Stock Size/Status	3.2	2.4	
	Other Stressors	1.6	1.6	
	Sensitivity Score	High		
Exposure variables	Bottom Salinity	2	3	
	Bottom Temperature	2.8	3	
	Current EW	1.3	3	
	Current NS	1.2	3	
	Current Speed	1.2	3	
	Mixed Layer Depth	1.3	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	3.8	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.8	3	
	Surface Salinity	1.5	3	
	Wind EW	1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Silky Shark (*Carcharhinus falciformis*)

Overall Climate Vulnerability Rank: **[Very High].** (86% certainty from bootstrap analysis).

Climate Exposure: **[Very High].** Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[High]**. Two sensitivity attributes scored above a 3.0: Population Growth Rate (3.4) and Stock Size/Status (3.2).

Distributional Vulnerability Rank: **[Very High].** All four attributes indicated very high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, relatively high habitat specialization, and sensitivity to temperature.

Data Quality: 89% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

Few studies examined the effect of climate factors on the population productivity or distribution of silky sharks. There is evidence that water temperature significantly impacts the vertical movements of Silky Sharks in the Pacific Ocean suggesting there is behavioral thermoregulation to remain in waters with temperature ranges of 26–30 °C [1]. Because temperature appears to be correlated with movement decisions in the vertical and horizontal regions of the water column, we can expect that there will be changes to the distributions and fishery vulnerability to capture of silky sharks in the future. Catch rates of silky sharks have been shown to be correlated with oceanographic conditions [2] and may impact vulnerability to capture in the future.

Life History Synopsis**:**

The silky shark, *Carcharhinus falciformis*, is a cosmopolitan, circumtropical species inhabiting both coastal and pelagic waters [3] and occurs in all tropical oceans where water temperatures are warmer than 23 °C [4]. This results in a narrow latitudinal distribution between 20°N and °S [4] and tends to overlap with most of the commercial fishing effort targeting tuna. As such, silky sharks make up a large component of the elasmobranch bycatch in both purse seine and longline fisheries worldwide [5-8]. In tuna purse seine fisheries, juvenile silky sharks comprise greater than 90% of the shark bycatch in the western and central Pacific Ocean (WCPO) [9]. Silky shark catch rates increased in the 1980s when the demand for dolphin safe canned tuna from the market drove most commercial purse seine fishers to switch from fishing on porpoise schools in the eastern tropical Pacific (ETP) to fishing on drifting fish aggregating devices (FADs) [10]. Juvenile silky sharks aggregate in large numbers around these drifting objects and become incidentally caught in purse seines targeting skipjack tuna, *Katsuwonus pelamis*, for the cannery [8,11]. Demographic analyses of this species have shown that high mortality in the juvenile life stage has a disproportionately negative impact on population growth rates making high juvenile mortality at FADs in the purse seine industry of particular concern. Further assessment of Pacific populations has found regional structure [2] which has been corroborated by a genetic study that found significant population structure across five regions in the Pacific Ocean [12]. Life history estimates across the Pacific also reveal large differences and ambiguity in parameter estimates where large differences in generation time and age-specific reproductive contributions complicates conservation management [13].

In the central west Pacific region, a study of 553 sharks by Grant et al. [14] found females range in length from 65.0 to 253.0 cm total length (TL), with the oldest estimated at 28 years. Males range in length from 68.4 to 271.3 cm TL and are aged to a maximum of 23 years. A logistic model provided the growth estimates; length at birth L_0 = 82.7 cm TL, growth coefficient g = 0.14 year^{-1}, and asymptotic length L_∞ = 261.3 cm TL for the sexes combined. Females reached sexual maturity at 204 cm TL and 14.0 years, whereas males reached maturity at 183 cm TL and 11.6 years. The average litter size from 28 pregnant females was 8 (range of 3–13) [14]. In Japan, an earlier study of 298 sharks found combined sex von Bertalanffy growth equations of : $L_t=216.4(1-e^{-0.148(t+1.76)})$ where L_t is precaudal length in cm at age t. A mature size for males was considered to be approximately 135–140 cm (precaudal length), with an estimated age of 5–6 years, whereas corresponding values for females were 145–150 cm and 6–7 years, respectively. Birth size ranged from 48 to 60 cm [15]. In the waters off northeastern Taiwan, a study of 469 specimens (213 females and 256 males) used the von Bertalanffy growth function (VBGF) to model the observed length at age: (L_∞) = 332.0 cm TL, growth coefficient (k) = 0.0838 year^{-1}, age at zero length (t_0) = −2.761 year (n = 250, $p < 0.01$). Size at 50% maturity for males was estimated to be 212.5 cm based on the logistic curve, which corresponds to 9.3 years. Females matured at 210–220 cm, which corresponds to 9.2–10.2 years. The length at birth was estimated to be 63.5–75.5 cm TL. The number of embryos per litter was 8–10 and sex ratio of embryos was 1:1 [16]. On the other side of the Pacific, in Baja California Sur, a study of 252 sharks with total length (TL) of females was 88–230 cm and males 142–260cm. Estimated ages for sampled females were 2–16 years and 3–14 years for males. Estimated parameters of the von Bertalanffy growth model for genders combined were L_∞=240 cm TL, k = 0.14 per year, and t_0 = −2.98 years. Females and males were found to reach sexual maturity between 7 and 8 years [17]. These differences in vital rates across studies around the Pacific Ocean could be due to methodologies used and or human error but have large consequences in population assessments and need to be resolved to improve conservation management.

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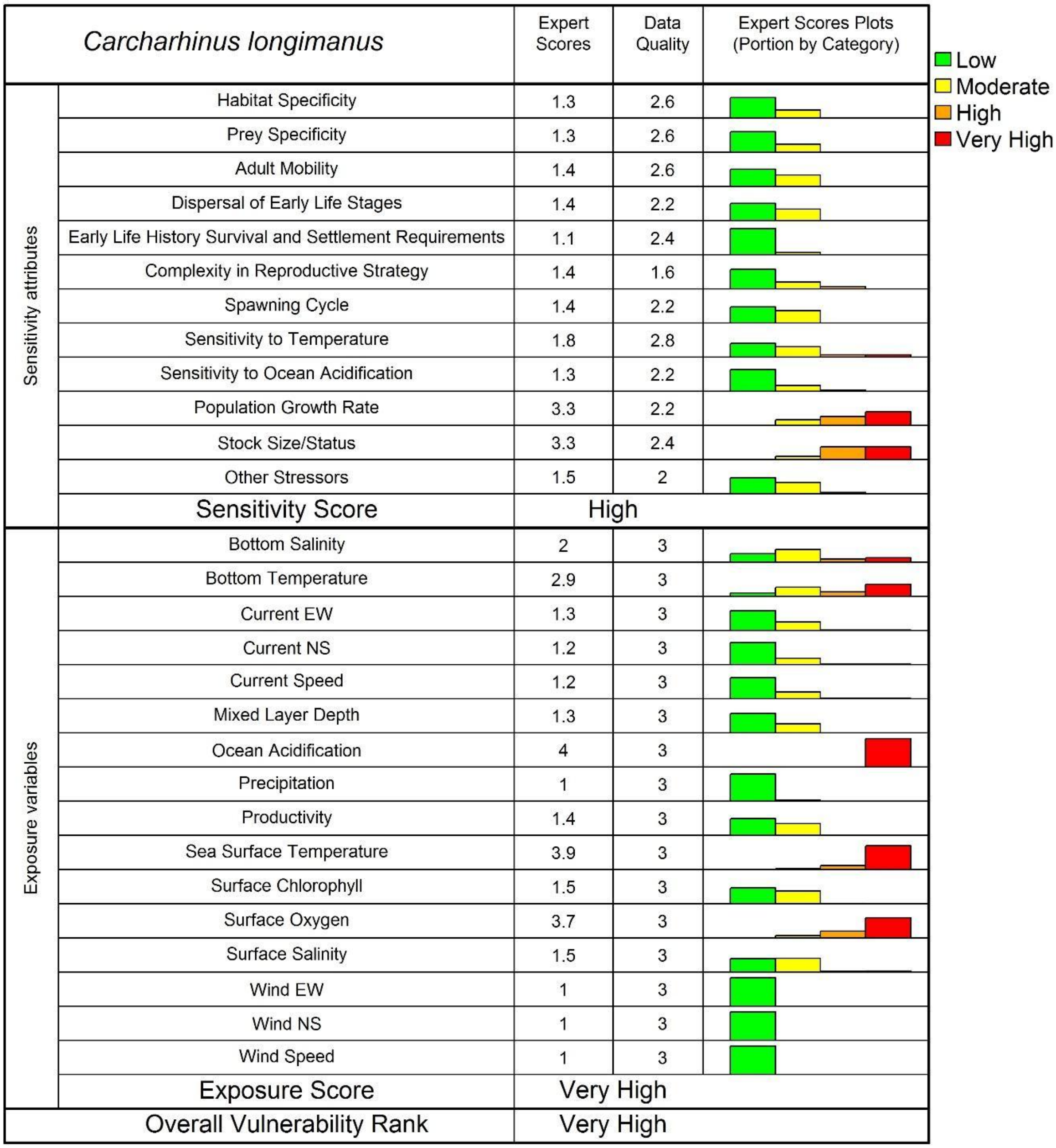
Oceanic whitetip shark - *Carcharhinus longimanus*

Overall Vulnerability Rank = Very High🟥

Biological Sensitivity = High🟧
Climate Exposure = Very High🟥
Data Quality = 96% of scores ≥ 2



	Carcharhinus longimanus	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.3	2.6	
	Prey Specificity	1.3	2.6	
	Adult Mobility	1.4	2.6	
	Dispersal of Early Life Stages	1.4	2.2	
	Early Life History Survival and Settlement Requirements	1.1	2.4	
	Complexity in Reproductive Strategy	1.4	1.6	
	Spawning Cycle	1.4	2.2	
	Sensitivity to Temperature	1.8	2.8	
	Sensitivity to Ocean Acidification	1.3	2.2	
	Population Growth Rate	3.3	2.2	
	Stock Size/Status	3.3	2.4	
	Other Stressors	1.5	2	
	Sensitivity Score	High		
Exposure variables	Bottom Salinity	2	3	
	Bottom Temperature	2.9	3	
	Current EW	1.3	3	
	Current NS	1.2	3	
	Current Speed	1.2	3	
	Mixed Layer Depth	1.3	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	3.9	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.7	3	
	Surface Salinity	1.5	3	
	Wind EW	1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Oceanic Whitetip Shark (*Carcharhinus longimanus*)

Overall Climate Vulnerability Rank: **[Very High].** (90% certainty from bootstrap analysis).

Climate Exposure: **[Very High].** Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[High]**. Two sensitivity attributes scored above a 3.0: Population Growth Rate (3.3) and Stock Size/Status (3.3).

Distributional Vulnerability Rank: **[Very High].** Three attributes indicated very high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 96% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

Few studies have examined the effect of climate factors on the population productivity of oceanic whitetip sharks. There is evidence that waters warmer than 28 °C significantly impact the vertical movements of oceanic whitetip sharks in the Atlantic Ocean suggesting there is behavioral thermoregulation to avoid warmer temperatures [1]. Thus, increasing sea surface temperature and decreased oxygen availability as a result of warming oceanic provinces could affect the availability of preferred habitat for this species [2]. Because temperature appears to be correlated with movement decisions in the vertical and horizontal regions of the water column, we can expect that there will be changes to the distributions of oceanic whitetip sharks in the future.

Life History Synopsis**:**

The oceanic whitetip shark is a large, pelagic species found circumglobally in tropical and subtropical waters between 20° N and 20° S. Oceanic whitetips generally remain offshore in the open ocean, but are also known to inhabit outer continental shelves around oceanic islands and near seamounts in water depths greater than 200 m. The species is highly migratory and is capable of making excursions of several thousand km. Oceanic whitetips have a strong affinity for the surface mixed layer in waters above 20 °C [3] and are therefore considered a surface-dwelling species. While oceanic whitetip sharks are wide-ranging, their distribution and abundance are not well known. Historical fisheries data and observations suggest that the species was once one of the most common and ubiquitous shark species in tropical waters around the world. More recently, however, numerous studies have shown significant population declines, resulting in stocks that are deemed overfished with current fishing mortality rates (F) higher than F at maximum sustainable yield in the western and central Pacific Ocean indicating that the stock is currently undergoing overfishing [4]. High rates of fishing mortality driven by bycatch in commercial fisheries as well as demands of the international trade in shark fins remain the largest threats to the species.

The life history of oceanic whitetip sharks remains understudied, but the species is generally considered a long-lived, slow growing, and late maturing species that has low to moderate productivity [5]. Reproduction is placental viviparous with litter sizes of 1–15 pups (mean = 6) and litter size increases with female size; gestation period is thought to be 10–12 months [6-9]. They are generally thought to breed every two years during the spring or summer, but it is currently unknown whether oceanic whitetips reproduce annually or biannually [10]. Further parturition does not appear to follow a tight seasonality. In the North Pacific, birthing occurs from February to July. In the central Pacific, females with small embryos have been found throughout the year and non-breeding adult females have been found to outnumber gravid females in the equatorial central Pacific [9].

Oceanic whitetips may grow to lengths over 3.5 m and live up to 25 years. There is regional variation in age and growth estimates that significantly impacted the last stock assessment because growth was a key source of uncertainty [4]. Age at reproductive maturity may be different for males and females and has been estimated to occur between 4–16 years and sizes of 170–240 cm in length. Female age-at-maturity is 4.5–8.8, 6.5, and 15.8 years, and maximum age is 11, 17, and 24.9 years in Northwest Pacific, Southwest Atlantic, and Western Central Pacific, respectively [9,11-14]. Studies have verified annual periodicity of band formation but none have yet validated the age estimates. The rate of population increase is very low and has been estimated at 0.039–0.067 [15] or 0.110 [16], although these may be overestimates as they are based on younger age-at-maturity and maximum age than has since been reported.

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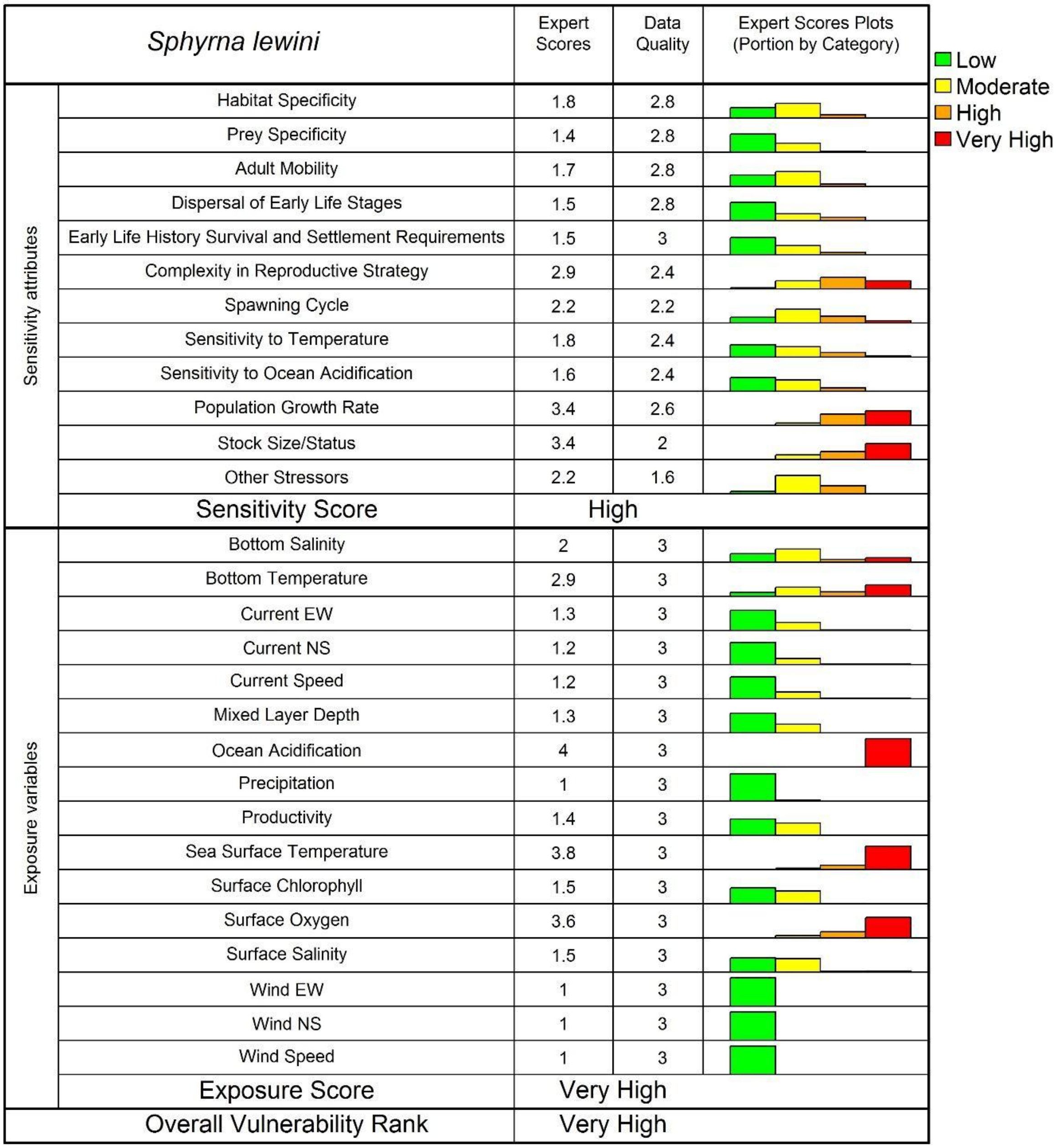
Scalloped hammerhead - *Sphyrna lewini*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥
Data Quality = 96% of scores ≥ 2



	Sphyrna lewini	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.8	2.8	
	Prey Specificity	1.4	2.8	
	Adult Mobility	1.7	2.8	
	Dispersal of Early Life Stages	1.5	2.8	
	Early Life History Survival and Settlement Requirements	1.5	3	
	Complexity in Reproductive Strategy	2.9	2.4	
	Spawning Cycle	2.2	2.2	
	Sensitivity to Temperature	1.8	2.4	
	Sensitivity to Ocean Acidification	1.6	2.4	
	Population Growth Rate	3.4	2.6	
	Stock Size/Status	3.4	2	
	Other Stressors	2.2	1.6	
	Sensitivity Score	High		
Exposure variables	Bottom Salinity	2	3	
	Bottom Temperature	2.9	3	
	Current EW	1.3	3	
	Current NS	1.2	3	
	Current Speed	1.2	3	
	Mixed Layer Depth	1.3	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	3.8	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.6	3	
	Surface Salinity	1.5	3	
	Wind EW	1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Scalloped Hammerhead (*Sphyrna lewini*)

Overall Climate Vulnerability Rank: **[Very High].** (86% certainty from bootstrap analysis).

Climate Exposure: **[Very High].** Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[High]**. No sensitivity attributes scored above a 3.0. The highest scores were for Population Growth Rate (3.4) and Stock Size/Status (3.4).

Distributional Vulnerability Rank: **[High].** Three attributes indicated high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may temper the mitigate of the species to shift distribution.

Data Quality: 96% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

There has been no explicit study of the impacts of climate change on the distribution of scalloped hammerhead sharks (*Sphyrna lewini*) throughout the Pacific. However, predicted changes to oceanic upwellings, water chemistry, biological productivity, current patterns, and phenology with global climate change [1] may have potential consequences for the abundance and distribution of *S. lewini* in the future, especially early life stages. Although pelagic, *S. lewini* are highly selective of habitat and show strong site fidelity to oceanic seamounts or atolls where they are known to form aggregations; they also exhibit strong site fidelity to the specific coastal environments for parturition. For example, in Hawaiʻi, *S. lewini* have been shown to make repeated seasonal movements into Kaneohe Bay across numerous years to give birth [2]. In addition, other embayments around the archipelago are also known to support young-of-the-year scalloped hammerheads, including Honolulu and Pearl Harbor, Hawaiʻi Kai, and Hilo Bays. Studies investigating the influence of anthropogenic stressors on juvenile hammerheads are limited; however, flooding events that increase sedimentation and/or sea surface temperature in these semi-protected nursery areas may have significant implications for their growth and survival of juvenile hammerheads.

Studies have also shown that *S. lewini* are particularly susceptible to stress after tagging events and to fishing [3]. Their physiological vulnerability to stress as well as their strong fidelity to specific habitats for parturition may make this species more susceptible to changing environmental conditions.

Life History Synopsis**:**

The scalloped hammerhead shark, *Sphyrna lewini*, is a large coastal and semi-oceanic pelagic shark, with a circumglobal distribution in warm-temperate and tropical waters [4]. *S. lewini* are highly mobile and are likely the most abundant of the hammerhead species, although robust data on their population size are limited [5]. Because of their long life span (~30 years), relatively slow growth rates, and late age at maturity [6,7], *S. lewini* have a life history that makes them susceptible to overfishing [8]. They are highly mobile and aggregate in large schools, sometimes segregated by age and sex [9-14]. They are seasonally migratory in parts of their range and resident in other areas. They are found in 35 of the Spalding et al. [15] provinces. They are typically found at 26 °C and 46° N–36° S, 180° W–180° E. In the

Gulf of Mexico (GOM), males mature at 180 cm TL (10 yr); females at 250 cm TL (15 yr). Von Bertalanffy parameter estimates for combined sexes of this species were L∞ = 329 cm TL, K = 0.073, to = −2.2 yr. [16]. Growth rate in Atlantic: 0.05–0.09; Gulf of Mexico (GOM): 0.09–0.13; Western Pacific Ocean: 2.2–2.25; Indian Ocean: 0.076. Size at maturity also varies among regions: Atlantic: 300–303 cm; GOM: 180–250 cm; Western Pacific Ocean:198–210 cm; Indian Ocean: 140–200 cm. The average age of fecundity is approximately 20 years, maximum 40 years. Their maximum lifespan in the Atlantic is 21–32 years, 30.5 years in the GOM and 14 years in the western Pacific Ocean.

In Hawai'i, *S. lewini* have been shown to make seasonal movements into sheltered coastal areas and embayments for parturition between April and October [2,17]. It is thought that scalloped hammerheads breed every other year and have between 2 and 41 pups [18]. Although *S. lewini* are relatively fecund compared to other large sharks, the generation period is greater than 15 years in the GOM [18];their life-history characteristics make them vulnerable to exploitation. Neonates and juveniles shoal in confined coastal pupping areas for up to two years before moving out to adult habitat. Important pupping areas throughout their Pacific range include Kaneohe Bay on Oahu, Hilo Bay, Hawaiʻi [2,17], and more recently a nursery ground was discovered in a river estuary in Fiji [19]. This suggests that human activities that alter important nursery habitats may have disproportionate effects on the success of some year classes.

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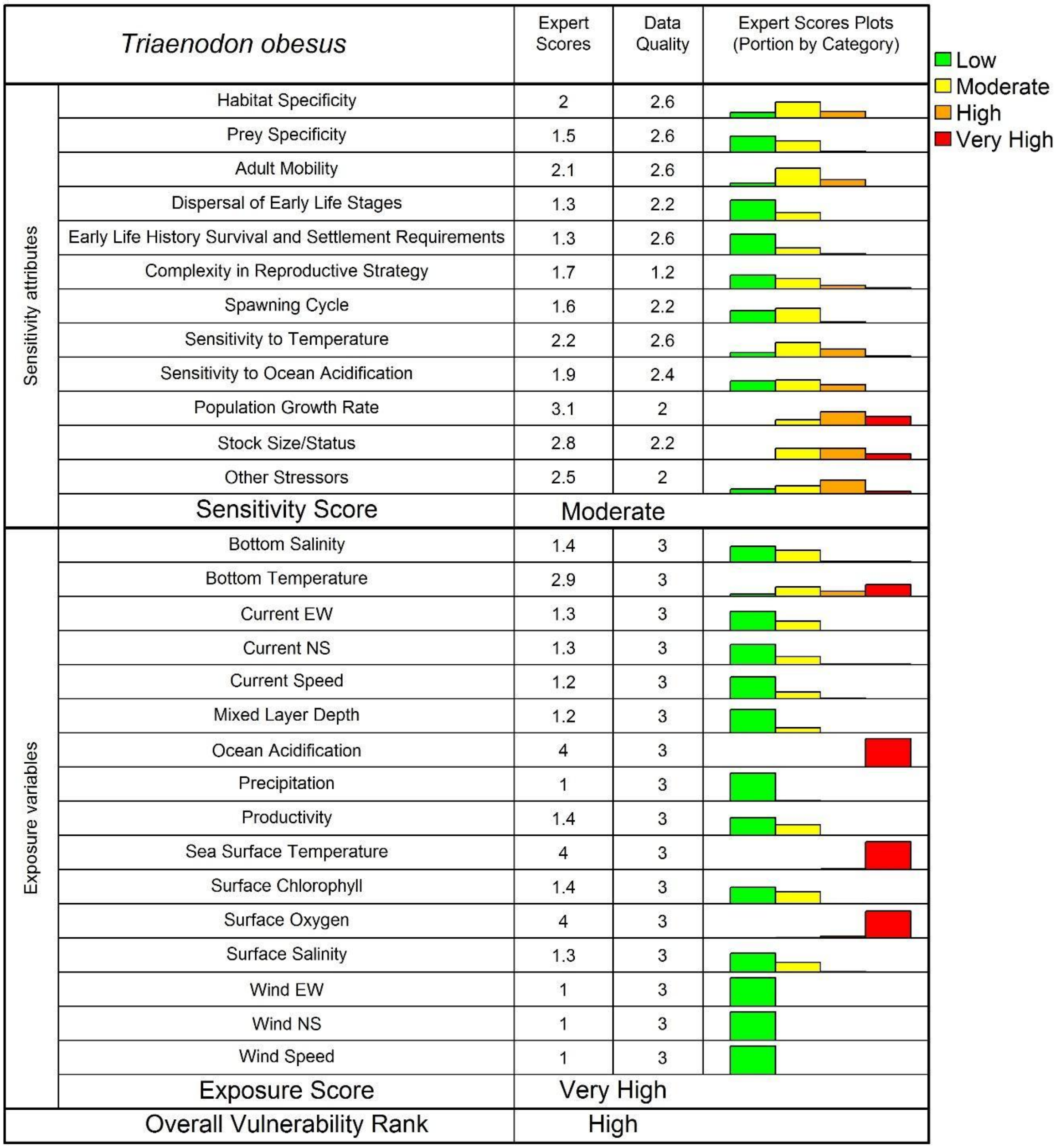
White-tip reef shark - *Triaenodon obesus*

Overall Vulnerability Rank = High🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High🟥
Data Quality = 96% of scores ≥ 2



	Triaenodon obesus	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	2	2.6	
	Prey Specificity	1.5	2.6	
	Adult Mobility	2.1	2.6	
	Dispersal of Early Life Stages	1.3	2.2	
	Early Life History Survival and Settlement Requirements	1.3	2.6	
	Complexity in Reproductive Strategy	1.7	1.2	
	Spawning Cycle	1.6	2.2	
	Sensitivity to Temperature	2.2	2.6	
	Sensitivity to Ocean Acidification	1.9	2.4	
	Population Growth Rate	3.1	2	
	Stock Size/Status	2.8	2.2	
	Other Stressors	2.5	2	
	Sensitivity Score	Moderate		
Exposure variables	Bottom Salinity	1.4	3	
	Bottom Temperature	2.9	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.2	3	
	Mixed Layer Depth	1.2	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.4	3	
	Surface Oxygen	4	3	
	Surface Salinity	1.3	3	
	Wind EW	1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

White-tip Reef Shark (*Triaenodon obesus*)

Overall Climate Vulnerability Rank: **[High].** (89% certainty from bootstrap analysis).

Climate Exposure: **[Very High].** Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Moderate]**. One sensitivity attribute scored above a 3.0, and that is Population Growth Rate (3.1). The next highest score was for Stock Size/Status (2.8).

Distributional Vulnerability Rank: **[Moderate].** All four attributes indicated moderate vulnerability to distribution shift: adult mobility, limited early life stage dispersal, relatively high habitat specialization, and sensitivity to temperature.

Data Quality: 96% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

There have been no studies specifically examining the effect of climate factors on the population, distribution, and abundance of the white-tip reef shark, *Triaenodon obesus*. White-tip reef sharks are a common coral reef mesopredator broadly distributed in the tropical and subtropical Pacific Ocean [1]. *T.obesus* tend to have relatively small, restricted populations but occupy high trophic levels and may play a key role in maintaining healthy reef ecosystems through predator-prey interactions [2-4]. Ultimately, climate driven changes in the abundance and distribution of white-tip reef sharks will be dictated by environmental disturbances on the health and functioning of coral reefs [5-7]. Given white-tip reef sharks' dependency on coral reefs and their slow life history characteristics (e.g., slow growth and slow population turnover), this species may be more vulnerable to climate impacts (particularly those that affect coral reefs directly such as increased sea surface temperature and cyclones) compared to highly mobile species. Further, female *T.obesus* have shown a tendency to inhabit shallow sites during late stages of gestation [1] as a possible strategy to increase metabolic rate and embryonic development [8,9]. Therefore, any increase in sea surface temperature due to global warming may have implications for the reproductive function and timing for *T. obesus*.

Life History Synopsis**:**

The broad distributional range of the white-tip reef shark is surprising considering their strong association to coral reefs and small home ranges. *T. obesus* are slow-growing (i.e., fast initial growth and decreasing continuous growth throughout the remainder of life) with low reproductive output and slow population turnover. Though limited, studies on *T. obesus* focus primarily on populations from the Pacific Ocean [1,10,11]. A study from the Great Barrier Reef, Australia, estimated their lifespan as 14–19 years, with males being shorter lived than females [11]. Von Bertalanffy parameter estimates for female *T. obesus*: L∞ = 207.8 cm TL, K = 0.05, T_o = −9.8 yr; male *T. obesus*: L∞ = 150.9 cm TL, K = 0.10, T_o = −6.6 yr [12] in the tropical Indo-Pacific. Similarly, data on the reproductive dynamics of *T.obesus* are sparse and primarily limited to anecdotal or captive observations [10,13] or from the Great Barrier Reef [11]. Size at maturity varies between sexes: females = 114–122 cm TL (8 yr), males = 112–116 cm TL (7 yr). Litter sizes range between 1–5 pups, with an average of 2.07 pups per litter [11], an extremely low level of fecundity compared to other charcharhinids [14]. Average age of fecundity is 8 years, and age at first birth is estimated at 9 years. The gestation period for the white-tip reef shark is thought to be at least 5 months [10], and in Hawaiʻi, a community-based photo identification study revealed females lay their pups in the shallows during April–May. Pupping season is May through early June [1] although specific pupping areas have not been identified. *T.obesus* have a biennial breeding cycle (i.e., once every two years)[15]; however, the actual frequency of parturition is unknown. These data are primarily drawn from studies on the Great Barrier Reef (n = 125). There is no evidence that *T.obesus* exhibit sexual segregation [11], although females often show higher philopatry than males often returning to the same locality.

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