APPENDIX F
to the
Fishery Management Plan
For U.S. West Coast Fisheries for
Highly Migratory Species

U.S. WEST COAST HIGHLY MIGRATORY SPECIES:
LIFE HISTORY ACCOUNTS AND
ESSENTIAL FISH HABITAT DESCRIPTIONS
(Originally Appendix A to the FMP)

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1 Introduction

1.1 Review of Methods

Essential fish habitat (EFH) is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity" (i.e., covers a species' full life cycle). EFH designations are based on a range of sources including fisheries dependent data (e.g., catch and conventional tagging data), electronic tag data, observations, life history studies and expert opinion. Although highly migratory species (HMS) require broad distributions to complete their life cycle, areas beyond the U.S. Exclusive Economic Zone (EEZ) cannot be designated as EFH [600.805(b)(2)]. Therefore, while the full range of each species is provided for context, the textual descriptions of EFH for each species within the U.S. EEZ are ultimately determinative of the limits of EFH [50 CFR 600.815(a)(1)(iv)(B)]. Fishery Management Plans (FMPs) must also include maps of the geographic locations of EFH [50 CFR 600.815(a)(1)(i)]. For each species, two sets of maps were created, one for their entire range and a second as a supplement to the textual descriptions outlining the EFH in the U.S. EEZ. The global range maps were created from existing species geographic range data as well as expert opinion with the underlying shapefiles acquired from www.iucnredlist.org. The maps of the EFH in the U.S. EEZ were created using data acquired from 1) existing species distributions in the eastern North Pacific from published sources including the initial EFH descriptions, 2) expert opinion and 3) a review of fisheries data. Given the resolution of the available information, just north of Point Conception, the northern bound of the Southern California Bight (SCB), was selected to represent the northern bound of the warmer-water species. The SCB is an ecoregion with similar oceanography and oceanographic conditions tend to dictate the distribution of HMS. It should be noted that fisheries-dependent data has limitations. Data are collected only for species or size classes that are vulnerable to the gear, when and where fishing occurs. Thus, the absence of catch is not definitive proof that those species or size classes do not occur in the region. In the absence of comprehensive fisheries independent surveys for HMS, however, fisheries data represents the best available science and is the most commonly used data source for documenting occurrence.

The habitat included in EFH is, by definition, "essential" and does not include every location a fish has been reported. For example, while distribution may shift with climatic events such as El Niño, observations at higher latitudes for some species tend to be rare and these regions are not considered essential. Similarly, while HMS may occur in shallow water <12 m, they occur primarily in deeper waters, seaward of 12 m, and these shallow regions including closed bays and estuaries are not considered essential. While the sea surface temperature (SST) range for each species is provided, the use of SST can be a less suitable metric for defining EFH for many HMS for multiple reasons. 1) Temperature ranges tend to be very broad [e.g., yellowfin tuna ~16-29 °C (Schaefer, et al. 2011); swordfish 14-30 °C (Dewar, et al. 2011). 2) For some species such as bigeye tuna, temperature at depth is more important than SST (Lopez et al. 2019). 3) Many HMS are endothermic (tunas, swordfish, common thresher shark, and shortfin mako shark), and thus are less constrained by SST, especially at larger size classes (Dickson and Graham 2004; Schaefer, et al. 2009). 4) The HMS in the West Coast EEZ are foraging (Madigan, et al. 2012) and their distributions are influenced by a combination of their thermal constraints and those of their prey. 5) Given that the U.S. EEZ is only a small proportion of the range of most HMS, providing their SST range in the EEZ would provide a truncated view of their preferred range and tolerance. This becomes even less useful in a time of changing ocean conditions. For these reasons, SST thermal bounds are not included in the description and identification of EFH.

Where possible, EFH is provided for different life history phases. In some instances, separating out specific life history phases is difficult, specifically at the transition from subadult to adult. Distributional data does not always include the size data that would be needed to define the life history stage. In addition, for some HMS, the age at first reproduction (adulthood) differs for males and females and data on distributions rarely includes sex. Also, size at first reproduction can vary across subpopulations. Additionally, the threshold for adulthood is not a knife edge but a cline and consequently individuals of the same size and sex may have different status. Where possible, values for the age at first reproduction were taken from the U.S. EEZ or in

close proximity. Finally, latitudinal movements into cooler waters tend to be more associated with size than life history stage. Consequently, an adult male and subadult female of the same size may have the same range despite difference in life history stage.

There are essentially three categories of HMS in the Pacific Fishery Management Council's FMP. First, the sharks (common thresher, shortfin mako, and blue sharks) that occur in the EEZ across life history stages and for which this region serves both as nursery and foraging habitat. Second are the species that seasonally forage in the U.S. EEZ as juveniles and/or adults (albacore tuna, Pacific bluefin tuna, and swordfish). Finally, are the species that tend towards more tropical and sub-tropical distributions (bigeye tuna, skipjack tuna, yellowfin tuna, striped marlin, and dolphinfish,) where occurrence in the EEZ is more sporadic and dependent on temperature. For these warmer water species there is often limited information specific to the U.S. EEZ. For example, the vast majority of electronic and conventional tagging data as well as life history information is available for regions closer to the core of their habitats, which lie outside the U.S. EEZ. To examine the size frequency and prevalence of these species within the U.S. EEZ, we examined fisheries landings data from the California drift gillnet (DGN) observer program and the Recreational Fisheries Information Network (RecFIN). As mentioned above, fisheries data are limited by gear vulnerability, and consequently, it is possible that size classes that are not caught, occur in the U.S. EEZ.

1.2   Geographic Extent of EFH for all HMS Species Combined

Combining across the Management Unit Species (MUS) in the FMP, the EFH for HMS off the U.S. West Coast includes the entire U.S. EEZ from the U.S. Mexico to the U.S. - Canada borders, seaward of the 12 m depth contour, not including bays and estuaries. Within the U.S. EEZ, the EFH of most HMS tends to cover broad areas, most often out to the 200 nautical mile (nm) EEZ. This is due largely to the highly migratory nature of the species, their generally opportunistic foraging strategies, and the breadth, productivity, and dynamic nature of the California Current. The California Current encompasses the entirety of the U.S. EEZ (Ekstrom 2009). HMS often target ephemeral, dynamic features, such as fronts that are transient and not specific to a geographic location (Snyder, *et al.* 2017), rather than being primarily linked to bathymetry or specific benthic habitats. A broad range of fish, squid, and crustacean prey occur in the California Current and can be found across habitats from benthic to oceanic. While coastal waters tend to have a higher abundance of prey, documented prey species are also found far from shore including Pacific sardine (Zwolinski, *et al.* 2012) and species associated with the mesopelagic zone and the deep scattering layer (Netburn and Anthony Koslow 2015; Tont 1976). Consequently, the full longitudinal range of the EEZ is considered essential for foraging.

HMS EFH includes suitable habitat for breeding, feeding, or growth to maturity. While no species commonly spawn in this region, both shortfin mako and common thresher sharks are reportedly breeding in the California Current (Cartamil, *et al.* 2010b; Goldman 2005; Nasby-Lucas, *et al.* 2019). For all MUS, the EFH serves as a feeding ground with some species traveling long distances specifically to forage on the diverse assemblage of fish, squid, and crustaceans (Block, *et al.* 2011). Within the California Current, HMS forage occurs across a broad range of habitats (epipelagic and mesopelagic) and taxa. While coastal pelagic species (CPS) managed under the CPS FMP are found in diets, HMS demonstrate considerable variability in diets over time and space and a resilience to shifts in the forage base. CPS and other prey species are part of HMS EFH but their occurrence and distribution are highly variable, so prey was not used to define the geographic bounds of EFH areas. For those species that occur as juveniles and subadults (all MUS species other than skipjack, striped marlin, and dolphinfish) the EFH is important for growth to maturity. The relatively warm and shallow waters of the coastal shelf likely also provide a level of protection for juvenile sharks.

Note that this definition of EFH is relevant to current conditions in the U.S. EEZ. Potential shifts in EFH associated with climate change are beyond the scope of this document.

1.3   Definitions and Acronyms

Definitions

California current: The productive, cold water, Eastern Boundary Current that moves southward from southern British Columbia, Canada to southern Baja Peninsula, Mexico.

Epipelagic: Vertical habitat within the upper ocean water column from the surface to depths generally not exceeding 200 m [0-109 fathoms (fm)], i.e., above the mesopelagic zone.

Mesopelagic: Vertical habitat within the mid-depth ocean water column, from depths between 200 and 1000 m (109-547 fm).

Oceanic: Inhabiting the open sea, ranging beyond continental and insular shelves, beyond the neritic zone.

Neritic: Inhabiting coastal waters primarily over the continental shelf; generally over bottom depths equal to or less than 183 m (100 fm) deep.

North Pacific Transition Zone. This occurs at the boundary between the low chlorophyll subtropical gyres and the high chlorophyll subarctic gyres. The front extends 8000 km from east to west and seasonally shifts north and south about 1000 km (between 30-35º N for 40-45º N).

Oophagous: A means of nutrition by which the developing embryos of some sharks eat their 'potential siblings' while still in the mother's uterus.

Ovoviviparous: Producing young by means of eggs which are hatched within the body of the parent.

Southern California Bight: The Southern California Bight extends from Point Conception, California to Punta Colonet in Baja California, Mexico. The region is characterized by complex circulation and generally warmer waters largely due to the dramatic curvature in the coastline starting at Point Conception.

Viviparous: Bringing forth live young that have developed inside the body of the parent.

Acronyms

BEUTI	Biologically Effective Upwelling Transport Index
CPS	Coastal Pelagic Species
DGN	Drift Gillnet
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EFL	Eye Fork Length
FADs	Fish Aggregating Devices
FL	Fork Length
FMP	Fishery Management Plan
HMS	Highly Migratory Species
ISC	International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean
LJFL	Lower Jaw Fork Length
MUS	Management Unit Species

nm	nautical miles
PCL	Pre-Caudal Length
RecFIN	Recreational Fisheries Information Network
SCB	Southern California Bight
SST	Sea Surface Temperature
TL	Total Length
YOY	Young of the Year

2   Sharks

2.1   Common Thresher Shark (*Alopias vulpinus*)

2.1.1   General Distribution

Common thresher sharks (*Alopias vulpinus*) are epipelagic in neritic and oceanic waters. They inhabit from tropical to cold-temperate waters in the Atlantic Ocean, Mediterranean Sea, Indian Ocean, and Pacific Ocean (Ebert*, et al.* 2013) (Figure 1a). Across their range, they are most abundant over continental and insular shelves and slopes (Compagno 1984). In the eastern North Pacific, they occur along the West Coast of North America, and are seasonally distributed in coastal waters from Washington to central Baja California, Mexico. While they have been documented as far north as Alaska, landings north of Washington are rare (McFarlane*, et al.* 2010).

The highest concentration of common thresher sharks occurs in the SCB, which extends from Point Conception, California (34.4° N) to Cabo Colonet, Mexico (31° N) (Hanan*, et al.* 1993; Smith*, et al.* 2008b). Their abundance was once thought to decrease rapidly beyond 40 nm from the coast, (Litvinov 1990; Strasburg 1958) but data indicate catches 100 nm offshore and beyond are not uncommon. This species is often associated with areas characterized by high biological productivity (i.e., 'green' water), the presence of strong frontal zones separating regions of upwelling and adjacent waters, and strong horizontal and vertical mixing of surface and subsurface waters—habitats conducive to production and maintenance of schooling pelagic prey upon which it feeds (Gubanov 1978; Kronman 1998).

Adults, juveniles, and postpartum pups occur within the U.S. West Coast EEZ (Figure 1a), although common thresher sharks show some separation by age class. Young prefer near-shore, coastal waters (Dubsky 1974; Eschmeyer*, et al.* 1983) with high concentrations of schooling prey on which they feed. There is no evidence of pupping and nursery grounds outside of the SCB (Cartamil*, et al.* 2010b; Smith*, et al.* 2008a). Juvenile threshers primarily utilize continental shelf waters, with a geographic range extending from Punta Eugenia in Baja California, Mexico (27.8° N) north to Morro Bay, California (35.3° N). The habitat of subadults and adults extends northward up the coast as the summer season progresses and may extend to the waters off Oregon and Washington (J. Fisher, comm. driftnet fisher, 3/5/02, PMFC briefing materials, (ODFW 2002 , unpublished data).

Off the U.S. West Coast during 1997-99, a period spanning warm and cool water years, common thresher shark catches were associated with SSTs from 13 to 25 °C, with highest catches between 15° and 22 °C (NMFS unpublished observer data, 2000). An electronic tagging study of adults and subadults found that common thresher sharks tagged in the SCB inhabited SSTs from 16 to 21 °C (Cartamil*, et al.* 2011). In a recent study in the Atlantic, Kneebone*, et al.* (2020) analyzed 3478 fishery-dependent catch records from 1964-2019 for common thresher sharks. The overall SST ranged from 4–31 °C (mean $\pm$ SD;17$\pm$ 4).

Cartamil*, et al.* (2011) reported on the vertical habitat use of electronically tagged sharks. Similar to many other HMS, the sharks had a diel vertical movement pattern. At night, they were limited to waters above the thermocline (15 to 20 m) and were significantly deeper during the day when they exhibited one of two general modes, either remaining in the upper 20 m or making frequent vertical excursions below the thermocline. The difference in daytime modes was assumed to be associated with vertical shifts in prey availability. Maximum dive depth was 320 m.

2.1.2   Growth and Development

Size at birth for the common thresher shark varies considerably, ranging from 115 cm to 156 cm total length (TL) (76 cm to 97 cm fork length (FL)), with only slight variation among geographical regions around the world (Bigelow and Schroeder 1948; Hixon 1979; Moreno*, et al.* 1989). Compagno (2001) reported that

the maximum size worldwide was at least 573 cm TL (312 cm FL); off the U.S. West Coast the largest reported is 550 cm TL (301 cm FL) (Eschmeyer, *et al.* 1983). The species has been variously estimated to reach a maximum age of from 25 to 50 years (Cailliet and Bedford 1983; Natanson, *et al.* 2016; Smith, *et al.* 1998).

Size at first maturity in the eastern North Pacific needs re-examination. There is a substantial difference in the estimated median age and size of maturity between the eastern North Pacific and western North Atlantic Oceans. Smith, *et al.* (2008b) estimated that the female common thresher sharks in the Pacific Ocean reach maturity at about 5.3 years of age (~160 cm FL). While Gervelis and Natanson (2013) estimated that the median size of maturity for females in the western North Atlantic Ocean was ~216 cm FL and 188 cm FL for males and estimated female age at maturity at 13 years. Aryafar, *et al.* (2017, Appendix B) subsequently re-evaluated the reproductive biology of this stock and found that the conclusions of Smith, *et al.* (2008b) were uncertain due to: 1) potential misidentification of pelagic thresher sharks (*Alopius pelagicus*) as common thresher sharks; and 2) inconsistency between observers' records on the presence of egg capsules or fetuses, and subsequent examination of the same specimens. Therefore, Aryafar, *et al.* (2017, Appendix B) recommended that until further studies occur, the age and size at maturity, and breeding periodicity for this stock should be based on Gervelis and Natanson (2013) from the western North Atlantic Ocean.

TL to FL conversion from Gervelis and Natanson (2013) is:

FL (cm) = 0.5168 x (TL, cm) +16.466

Using the von Bertalanffy equation where a is age, k is the growth coefficient, t_0 is the theoretical age when size is zero, and L∞ is asymptotic size.

$$L(a) = L∞(1 - e^{-K(a - t0)})$$

Smith, *et al.* (2008a) estimated the following parameters for male and female common thresher sharks – Male: $L∞$ = 221.5 cm, K = 0.189 yr^{-1}, and t_0 = -2.08 y; Female: $L∞$ = 247.3 cm, K = 0.124 yr^{-1}, and t_0 = -3.35 yr, where L∞ is FL, common thresher sharks in the western North Atlantic Ocean appeared to follow a relatively similar growth curve, albeit with slightly higher asymptotic lengths (Natanson and Gervelis 2013).

2.1.3   Trophic Interactions

The diets of common thresher sharks are dominated by small schooling fish. This is linked to their use of their caudal fin to stun prey during feeding (Aalbers, *et al.* 2010). Stomach contents from large juveniles and adults were sampled between 1998 and 2014. While over the whole time period, northern anchovy (*Engraulis mordax*) and Pacific sardine (*Sardinops sagax*) were identified as the most important prey (Preti 2020; Preti, *et al.* 2012), their importance declined significantly starting in ~2007. As anchovy and sardine decreased in importance, market squid (*Doryteuthis opalescens*) increased. Other important prey included Pacific hake (*Merluccius productus*), Pacific mackerel (*Scomber japonicus*), Pacific saury (*Cololabis saira*), jack mackerel (*Trachurus symmetricus*) and duckbill barracudina (*Magnisudis atlantica*). Pelagic red crab (*Pleuroncodes planipes*) was the most frequently occurring crustacean (Preti 2020; Preti, *et al.* 2001; Preti, *et al.* 2004; Preti, *et al.* 2012). The importance of northern anchovy, Pacific sardine, market squid, Pacific hake, and Pacific mackerel in the diet varied significantly across years and different oceanographic conditions (Preti 2020). Stomachs collected during the warm-water period of 1998 from the California-Oregon DGN fishery, revealed a varied diet of primarily northern anchovy, Pacific hake, and Pacific mackerel; secondarily sardine, market squid, pelagic red crab, and Louvar (*Luvarus imperialis*); and less importantly, jack mackerel, shortbelly rockfish (*Sebastes jordani*), California grunion (*Leuresthes tenuis*) and other atherinids, white croaker (*Genyonemus lineatus*), queenfish (*Seriphus politus*), and Pacific sanddab (*Citharichthys sordidus*) (Preti, *et al.* 2001). In contrast, during a cool water period, the number of prey taxa decreased from 20 to only 8. Those included in order of importance northern anchovy, market squid, unidentified teleosts, Pacific sardine, Pacific hake, and Pacific mackerel (Preti, *et al.* 2004). Regional

differences in diets were also apparent. Northern anchovy, Pacific sardine, Pacific hake, and Pacific mackerel were significantly more important within the SCB than beyond the SCB where Pacific saury were the most important (Preti 2020). Diet was found to diversify with age/size, with northern anchovy being more important among juvenile fish less than 160 cm FL (Preti 2020; Preti, *et al.* 2001). Thus, while common thresher sharks are more specialized than other HMS in the California Current, their diets vary across region, size and environmental conditions (Preti 2020) and overall encompass a broad range of prey.

2.1.4   Migrations, Movements, and Stock Structure

Common thresher sharks along the west coast of North America are assumed to be a single, well mixed stock, which is supported by genetics and tagging data. Genetic analyses of tissue biopsies collected off the U.S. West Coast and Mexico, comparing samples from off Oregon/Washington with samples collected off California and Baja California, Mexico, showed no significant differences in haplotype frequencies, indicating a single homogenous West Coast population (Eitner 1999; Trejo 2005). Limited tagging data also support the assumption that there is a local population of common thresher sharks limited to the coastal waters of the west coast of North America including the U.S. and Mexican EEZ. (Cartamil, *et al.* 2010a; Cartamil, *et al.* 2011; Smith and Aseltine-Neilson 2001).

A combination of fisheries and tagging data reveal seasonal movements in the California Current with variability depending on life history stage. Both tagging and catch data suggest a seasonal north-south migration between San Diego/Baja California Mexico and Oregon and Washington (Kinney, *et al.* 2020). Juvenile common thresher sharks have an overall range that extends from Morro Bay, California to Bahia Sebastian Vizcaino, Baja California Sur, Mexico (Cartamil, *et al.* 2016). Although they are found most frequently in shallow, nearshore areas over the continental shelf, especially within the SCB, which is an important nursery area (Cartamil, *et al.* 2010b). Subadult members of the stock appear to arrive in southern California waters during early summer, and as summer progresses move up the coast as far north as San Francisco, with some moving as far north as the Columbia River area. In fall, these subadults are thought to move south again, arriving in the Channel Islands area. Bedford (1992) proposed that large adult common thresher sharks pass through southern California waters in early spring of the year, remaining in offshore waters from one to two months during which time pupping occurs. Pups are then thought to move into shallow coastal waters. The adults then continue to follow warming water and perhaps schools of prey northward, and by late summer, arrive off Oregon and Washington. Little is known about the presumed southward migration of the large adults, which do not appear along the coast until the following spring.

2.1.5   Reproduction

Common thresher sharks are ovoviviparous with small litter sizes, usually giving birth to two to six pups, and have an annual or biennial reproductive cycle (Bedford 1992; Cailliet and Bedford 1983; Gubanov 1978; Natanson and Gervelis 2013). The developing fetuses are oophagous (Bedford 1992; Gilmore 1993; Gubanov 1978; Moreno, *et al.* 1989). Mating presumably takes place in midsummer along U.S. West Coast EEZ with a gestation period of about 9 months (Goldman 2005; Smith, *et al.* 2008b); parturition is thought to occur in the spring months off California, judging from the cluster of postpartum-sized pups taken in the catch at this time (Bedford 1992; NMFS drift net observer data).

2.1.6   Essential Fish Habitat for Common Thresher Shark

Common thresher shark EFH is defined using a combination of data sources provided in the previous sections on common thresher sharks as well as expert opinion (see Figure 1b). While common thresher sharks may occur in shallow water <12 m, they occur primarily in deeper waters, seaward of 12 m, and these shallow regions including enclosed bays and estuaries are not considered essential. Including all age classes, common thresher shark EFH includes the U.S. West Coast EEZ from the U.S.-Mexico border to the U.S.-Canada border, to approximately 100 nautical miles offshore, seaward of the 12 m depth contour. While small schooling fish appear to be their preferred prey, diets vary temporally and spatially and include squid and crustaceans. The high productivity and presence of diverse small schooling fish, squid, and

crustacean species and relatively warm shallow shelf waters make the California Current, out to approximately 100 nm, a suitable habitat for feeding and growth to maturity for common thresher sharks.

- Neonate and Early Juveniles (<102 cm FL): In shallow neritic water over the continental shelf, with a geographic range extending from the U.S.-Mexico border north to Morro Bay, California (35° N), but found most frequently in the SCB. Little is known of the food of early juveniles; they presumably feed on small northern anchovy and other small, schooling fishes and invertebrates. The broad continental shelf and relatively warmer waters in the SCB make this region a suitable nursery habitat for common thresher sharks.
- Late Juveniles and Subadults (males > 102 cm FL and < 188 cm FL; females >1 cm FL and < 216 cm FL): Epipelagic, neritic, and oceanic. Habitat of subadults extends northward up the coast, as far north as 48° N. They are found most frequently in nearshore areas over the continental shelf, especially within the SCB. Known to feed primarily on northern anchovy, Pacific sardine, Pacific hake, Pacific mackerel, and market squid; secondarily on a variety of other fishes, squid, and pelagic red crab (in warm water years). Northern anchovy was a more important prey component for juvenile fish < 160 cm FL.
- Adults (males > 181 cm FL; females > 216 cm FL): Epipelagic, neritic, and oceanic waters along the West Coast of North America, seasonally distributed in coastal water from the U.S. - Mexico border to the U.S. - Canada border. Known to feed primarily on northern anchovy, Pacific sardine, Pacific hake, Pacific mackerel, and market squid; secondarily on a variety of other fishes, squid, and pelagic red crab (warm water years).

2.2 Shortfin Mako Shark (*Isurus oxyrhinchus*)

2.2.1 General Distribution

Shortfin mako sharks (*Isurus oxyrhinchus*) (referred to as mako sharks below) are epipelagic and mesopelagic in neritic and oceanic waters, found in warm-temperate and tropical seas worldwide (Figure 2a). In the Eastern Pacific they range from Chile to the U.S.-Canada border.

Mako sharks across size classes occur in the U.S. EEZ (Figure 2a). The SCB ecoregion has long been considered a pupping and nursery area for mako sharks (Hanan, *et al.* 1993; Nosal, *et al.* 2019; O'Brien and Sunada 1994; Taylor and Bedford 2001). Observer data examined from the California DGN fishery from 1990-2017 show that young-of-the-year (YOY) and age-1 mako sharks were captured almost exclusively south of Point Conception, California (34.4° N) in the SCB (Nosal, *et al.* 2019). Based on both catch and tagging data, the mako shark nursery extends along the continental margins of the SCB ecoregion, south to the tip of the Baja California peninsula (approximately 23.4−34.5° N). Mature females are caught in the SCB by recreational fishermen (Lyons, *et al.* 2015). In addition, a satellite tagging study of mature females shows that they are present in the SCB May-August. In addition, satellite tagging data from one mature female mako shark indicated that the shark was present in the SCB June-September (Nasby-Lucas, *et al.* 2019).

A tagging study of 105 mako sharks including subadults and adults in the eastern North Pacific from 2002-2014 showed a latitudinal range from 3° N to 47° N, from Washington State to just south of Puerto Vallarta, Mexico, along the coast and as far south as 3° N offshore. Overall regions occupied included the entire California Current; the Sea of Cortez; and offshore in the areas of the North Pacific Subtropical Gyre, North Pacific Transition Zone, and North Equatorial Current (Nasby-Lucas, *et al.* 2019). Within that range sharks moved seasonally (see below). Overall mako sharks had a broad thermal tolerance (SST ranged from 11 to 31 °C) although the majority of the time SST was between 15 and 25 °C.

Satellite tags also provide insight into vertical habitat use. In general, tagged mako sharks exhibited diel vertical migration patterns, remaining in the mixed layer at night and diving to deeper depths (as deep as 700 m) during the day (Nasby-Lucas, *et al.* 2019). Overall, tagged mako sharks spent around 99% of their time in the top 150m of the water column in the coastal region from California to Washington remaining

shallower than 50 m >90% of time. Maximum dive depth recorded in the coastal region was 350m north of Point Conception, California; 528 m in the SCB; and >700 m off the coast of Baja California, Mexico, and in offshore waters (Nasby-Lucas, *et al.* 2019).

2.2.2   Growth and Development

Maximum size reported for mako sharks worldwide is a ~445 cm TL (Weigmann 2016). The largest documented mako shark off the U.S. West Coast was a 373 cm TL (340 FL) female (Lyons, *et al.* 2015). To determine age, band pairs in vertebrae are counted. The periodicity of band-pair deposition for mako sharks has been examined using oxytetracycline. Up to at least five years of age mako sharks lay down two band pairs per year (Wells, *et al.* 2013a). At some point they transition to laying down only one band pair, although the exact timing of this transition has not been determined and thus, ages for sharks over five years cannot be accurately estimated. Kinney, *et al.* (2016) hypothesized that the transition from one to two band pairs occurred at or near the point at which they reach sexual maturity. Males reach sexual maturity at 164-191 cm FL (Conde-Moreno and Galván-Magaña 2006; Joung and Hsu 2005) whereas females are not mature until 253-280 cm FL (Joung and Hsu 2005; Semba, *et al.* 2011). An accurate age at first reproduction cannot be determined at this point for the reasons mentioned above.

Using the von Bertalanffy equation where L1 and L2 are the sizes associated with ages near a first age (A1) and second age (A2), L∞ is the theoretical maximum length, and K is the growth coefficient.

$$L2 = L_\infty + (L1 - L\infty)\, e^{-K(A2-A1)}$$

Takahashi, *et al.* (2017) estimated the following parameters for male and female mako sharks with K at 0.128 yr^{-1} for female and L1 and L2 at 60.0 cm and 293.1 cm PCL for A1 (age 1 yr) and A2 (age 31 yr), and K at 0.174 yr^{-1} for male and L1 and L2 at 60.0 cm and 232.8 cm PCL for A1 (age 1 yr) and A2 (age 31 yr).

2.2.3   Trophic Interactions

Overall, mako sharks are generalist foragers feeding primarily on epi- and mesopelagic fish and squid. Humboldt squid (*Dosidicus gigas*), when available, are an important prey item for mako sharks (Preti 2020; Preti, *et al.* 2012; Vetter, *et al.* 2008) as well as Pacific saury, Pacific sardine, Pacific mackerel, striped mullet (*Mugil cephalus*), and jack mackerel (Preti 2020; Preti, *et al.* 2012). Mako sharks can also prey on elasmobranchs and marine mammals (Lyons, *et al.* 2015; Preti 2020; Preti, *et al.* 2012). Diets have been shown to vary regionally. Pacific sardine, Pacific mackerel, and striped mullet were significantly more important within the SCB, whereas jumbo squid and jack mackerel were significantly more important outside the SCB (Preti 2020). Prey composition also varied over time. Jumbo squid was the most important in 2003 – 2007, 2009 and 2010, but not in 1998, 2011 or 2013. Pacific saury was the most important in 2002, 2008 and 2011 - 2013, but not present during 1998 and 2010 (Preti 2020).

In addition to temporal and spatial shifts in diet, Preti (2020) reported that diets also change with size. Small sharks (<150 cm) fed primarily on small schooling fish including Pacific saury, Pacific sardine, Pacific mackerel, and striped mullet. The larger sharks (FL≥150 cm) fed on jumbo squid as their main prey item during the years mentioned above, but also consumed marine mammals. Lyons, *et al.* (2015) found that the stomach of a 373 cm female contained a four-year-old female California sea lion *(Zalophus californianus)*. The number of taxa consumed increased with body size, demonstrating an ontogenetic expansion of diet rather than a shift in prey types.

2.2.4   Migrations, Movements, and Stock Structure

Based on genetics, tagging studies and catch data there is a single population of shortfin mako sharks in the North Pacific (Michaud, *et al.* 2011; Schrey and Heist 2003).

In the eastern North Pacific, sharks move seasonally between the California Current; the Sea of Cortez; and offshore in the North Pacific Subtropical Gyre, North Pacific Transition Zone, and North Equatorial Current (Nasby-Lucas, *et al.* 2019). Seasonal movements north and south within the California Current coincided with periods of higher primary productivity and chlorophyll-a, and SSTs between 15 and 25 °C. Within the California Current, the SCB is an important habitat for all size classes from late spring to early fall. Juvenile mako sharks appear to expand their northward and southward range with increasing size. In late summer and fall, juvenile and adult sharks disburse either north or south with the largest sharks moving offshore as far as the Hawaiian Islands (Nasby-Lucas, *et al.* 2019; Nosal, *et al.* 2019). When sharks were tracked for a year or more, most returned to the region of the SCB in the spring and summer.

2.2.5   Reproduction

Mako sharks are ovoviviparous and oophagous, the fetuses feeding on a supply of eggs continuously ovulated by the female. Little is known about the reproductive cycle and there are few records of pregnant females. There is a wide range in estimates of fecundity, which may be due to stock differences, female size sampled, and/or fetuses being aborted on capture. Based on the available information, litter sizes range from 4-25 with most reports in the range of 8-18 (Branstetter 1981; Mollet, *et al.* 2000; Stevens 1983; Taniuchi 1997). Using data from several studies, Mollet, *et al.* (2000) calculated the mean litter size as 12.5. The gestation period has been variously estimated at from 12 to 18 months (Bedford 1992; Cliff, *et al.* 1990; Mollet, *et al.* 2000; Pratt and Casey 1983). Mollet, *et al.* (2000) report that litter size increases with maternal size, and present evidence for a three-year reproductive cycle, although a two-year cycle could not be ruled out.

2.2.6   Essential Fish Habitat for Shortfin Mako Shark

Shortfin mako shark EFH is defined using the combination of data sources provided in the previous sections on shortfin mako sharks as well as expert opinion (see Figure 2b). Combining all age classes, mako shark EFH includes the entire U.S. West Coast EEZ seaward of the 12 m depth contour. While mako sharks may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. Studies have shown that mako sharks of all sizes can feed opportunistically on a high diversity of prey. The high productivity and presence of diverse fish, squid, and crustacean species and relatively warm and shallow shelf waters make the California Current a suitable habitat for feeding and growth to maturity for shortfin mako sharks.

- Neonate and Early Juveniles (< 100 cm FL): The SCB ecoregion has long been considered a pupping and nursery area for mako sharks based primarily on the prevalence of juveniles in this region. Current data show that the mako shark nursery extends along the continental margins of the SCB ecoregion, south to the U.S.- Mexico border. The broad continental shelf and relatively warmer waters in the SCB make this region a suitable nursery habitat. A range of coastal pelagic fish species are important prey for small mako sharks. Pacific saury was the most important prey item for juvenile sharks (FL < 110 cm), followed by Pacific sardine, Pacific mackerel, and jumbo squid with diets varying over time.
- Late Juveniles and Subadults (males > 100 cm FL to < 180 cm FL; females >1 cm FL to < 249 cm FL): Epipelagic, neritic, and oceanic waters from the U.S.- Mexico border to the U.S.-Canada border offshore to the 200 nm EEZ boundary. Mako sharks of this size feed opportunistically on a high diversity of prey.
- Adults (males > 180 cm FL; females > 249 cm FL): Epipelagic, neritic, and oceanic waters from U.S.-Mexico border to the U.S.-Canada border offshore to the 200 nm EEZ boundary. Studies have shown that adult mako sharks feed opportunistically on a high diversity of prey including larger and faster prey, such as marine mammals and small sharks.

2.3 Blue Shark (*Prionace glauca*)

2.3.1 General Distribution

Blue sharks (*Prionace glauca*) are globally distributed from tropical to temperate waters occurring in epipelagic, neritic, and oceanic waters (Figure 3a). In the Eastern Pacific, the blue shark occurs from the Gulf of Alaska to Chile, although abundance is low in equatorial waters. In the eastern North Pacific, they are commonly found in offshore and coastal waters of the western United States, Canada, and Mexico (Compagno 1984).

Across the North Pacific there is considerable segregation by sex and size. Based on an analysis of catch data on the high seas, Nakano and Seki. (2003) reported that mating takes place in early summer at 20-30° N in the North Pacific Transition Zone. The pupping and nursery grounds areas are located in the Subarctic Boundary and Transition Zone where there is a large prey biomass for the juveniles. On reaching maturity, blue sharks apparently migrate to the subtropics and tropics to join the reproductively active population.

Analysis of both catch and tagging data reveals that while sharks across sex and size classes occur in the U.S. EEZ (Figure 3a), segregation is also apparent in the California Current (Maxwell, *et al.* 2019; Nosal, *et al.* 2019; Sippel, *et al.* 2016; Urbisci, *et al.* 2013). Juvenile blue sharks are found along the entire California Current region from Canada to the tip of Baja with the larger sharks occurring from California south. Among adult-sized sharks, females dominate in the observed DGN catch north of Monterey Bay, and adult males predominate to the south, especially in the SCB (Urbisci, *et al.* 2013).

The SCB ecoregion has long been considered a pupping and nursery area for blue sharks (Hanan, *et al.* 1993; Holts, *et al.* 2001) based primarily on the prevalence of pups and small juveniles in this region. However, Nosal, *et al.* (2019), in combination with previous studies, suggest that the nursery area extends to the waters off Oregon (approximately 27.7−46.2° N) primarily over the continental margin, but off the continental shelf.

Blue sharks are tolerant of a relatively wide range of water temperatures. Satellite tagging data showed that blue sharks in the eastern North Pacific were found in SST between 9° and 29 °C with adults in the warmer temperatures and subadults in the cooler temperatures (Nasby-Lucas, *et al.* 2023). Late juveniles/subadults that occur off Canada were found in SST from 9 to 29 °C (average 18 °C) while adult blue sharks were found in SST from about 14 to 29 °C (average 20 °C) (Nasby-Lucas, *et al.* 2023).

2.3.2 Growth and Development

Maximum reported size for the blue shark is 396 cm TL (326 cm FL) (Bigelow and Schroeder 1948), but blue sharks taken off the U.S. West Coast average much smaller (Cailliet and Bedford 1983) and are seldom over 260 cm TL (214 cm FL) (Strasburg 1958, OR/CA drift net observer data). For blue shark in the Pacific Ocean, Fujinami, *et al.* (2017) reports size and age at 50% maturity in males is 175.1 cm FL and ~5 years old, and for females at 170.5 cm FL and ~5 years old. Maximum age is estimated to be at least 20 years (Cailliet, *et al.* 1983; Nakano 1994; Skomal and Natanson 2003).

FL to TL and TL to pre-caudal length (PCL) conversions are (Sippel, *et al.* 2016):

TL = (FL * 1.189) + 3.192

PCL = (TL * 0.748) + 1.063

Using the Von Bertalanffy equation where a is age, k is the growth coefficient, t_0 is the theoretical age when size is zero, and L∞ is asymptotic size.

$L(a) = L\infty(1 - e^{-k(a - t0)})$

Fujinami, *et al.* (2019) estimated parameters of the von Bertalanffy growth function: for males, L∞ was 284.9 cm PCL, k was 0.117 yr^{-1}, and t_0 was −1.35 yr, and, for females, L∞ was 257.2 cm PCL, k was 0.146yr^{-1}, and t_0 was −0.97 yr.

2.3.3   Trophic Interactions

Blue sharks forage on a broad range of prey including fish, squid, and crustaceans and are considered generalists (Preti 2020). In coastal waters off the U.S. West Coast, blue sharks feed on anchovy, jack mackerel, Pacific hake, flatfishes, spiny dogfish (*Squalus acanthias*), squids, and pelagic crustaceans including euphausiids (Brodeur, *et al.* 1987; Harvey 1989; Preti 2020; Tricas 1979). Harvey (1989), sampling predominantly immature blue shark (most 130-190 cm TL) in Monterey Bay, California (N=150), found blue sharks seasonally fed predominantly on northern anchovy, euphausiid swarms, (primarily *Thysanoessa spinifera*), and Pacific hake. Spiny dogfish, Pacific herring (*Clupea pallasii*), and five genera of squid were also consumed. Brodeur, *et al.* (1987) examined the diet of 14 blue sharks (100-333 cm TL) captured off Washington and Oregon. Diet items, in descending order of importance, were Pacific hake, northern anchovy, flatfishes, Pacific herring, and squid. (Flatfishes were taken predominantly in the warm water year of 1983).

In the most comprehensive study conducted to date, Preti (2020) sampled 205 blue sharks from 2002 to 2014 (61 to 249 cm FL) and found that 150 stomachs contained 46 prey taxa with *Gonatus spp.* and jumbo squids representing the most important prey. While *Gonatus* was important in all areas, other prey items shifted in importance regionally. *Argonauta spp.* was significantly more important within the SCB (Preti 2020).

In addition to varying spatially, blue shark diets vary temporally. Preti (2020) found that cephalopods were the most important in general, except for 2002 and 2006 when crustaceans were the most important prey item (pelagic red crab and euphausiids respectively). Jumbo squid was the most important prey item in 2003 and in 2008 through 2010. No jumbo squid was present in the diet in 2011, 2013, and 2014. *Gonatus* spp. was the most important prey in 2005 and 2012. The importance of *Gonatus* spp., jumbo squid, *Argonauta* sp., *Histioteuthis dofleini*, *Octopoteuthis* sp., and unidentified euphausids in the diet varied significantly between different years over the study period.

Diet composition was also found to change with shark size. Preti (2020) found that for blue sharks <109 cm FL Pacific euphausiids were the most important prey item (although this result is biased due to a large number of this prey found in a single stomach) followed by *Gonatus* spp. and *Argonauta* sp. *Gonatus* spp. ranked first in importance for blue shark between 110-149 cm FL, followed by jumbo squid and *Argonauta* sp. Jumbo squid ranked first in importance for blue sharks > 150cm FL, followed by *Gonatus* spp. and *Octopoteuthis* sp. One large specimen fed on an unidentified cetacean. The number of taxa consumed increased with body size, demonstrating an ontogenetic expansion of diet rather than a shift in prey types. Sciarrotta and Nelson (1977) noted that the blue shark fed around the clock but was more active at night, with highest activity in the early evening. These authors observed a twilight movement from offshore to shallower waters around Santa Catalina Island, California, during March and June, but a shift to offshore waters during late June to October, suggesting a response to a change in prey availability.

2.3.4   Migrations, Movements, and Stock Structure

The International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) Shark Working Group recognizes two stocks in the Pacific Ocean, north and south, based on biological and fishery data. Relatively few blue sharks are encountered in the tropical equatorial waters that separate the two stocks. Tagging data demonstrate long distance movements and a high degree of mixing of blue sharks across the North Pacific Ocean (ISC 2022a).

Blue shark is highly migratory with movement patterns associated with reproduction and prey distribution (Nakano and Stevens 2008). They exhibit seasonal movements both on the high seas and in coastal waters.

In coastal waters, mature females are thought to start their northward journey in early spring as warm water moves northward, while juveniles of both sexes follow closely; large males start later and tend to stay further offshore (Hanan, *et al.* 1993). Nakano (1994) has proposed a migration model for blue shark in the North Pacific on the high seas where birth occurs in early summer in nursery areas located at 35-45° N, then 1-5 year old females move north of these latitudes, while 2-4 year old males move south. In coastal waters, observer data examined from the California DGN fishery from 1990-2017 show that YOY- juvenile blue sharks are commonly encountered north of Point Conception, California (34.4° N) well into waters off Oregon and Washington (Nosal, *et al.* 2019). Electronic tagging studies conducted on blue sharks tagged off southern California, Canada, and Hawaii, showed that late juveniles/subadults utilized the entire U.S. West Coast EEZ from the Mexico border to the Canada border, while adults utilized the region south of approximately 37° N seasonally, with mature males traveling offshore west towards Hawaii and mature females traveling south to the Equatorial Counter Current region (Nasby-Lucas, *et al.* 2023).

2.3.5   Reproduction

Blue sharks are viviparous with young nourished first by a yolk sac, then by a maternal placental connection. Litters average about 35.5, with maximum litter size reported at 135; gestation period is estimated to be 11 months (Fujinami, *et al.* 2017; Nakano and Stevens 2008; Strasburg 1958). Reproduction has been reported as seasonal in most areas, with birth often in spring or summer (Nakano 1994; Pratt 1979; Stevens 1983), although periods of ovulation and parturition may be extended (Hazin, *et al.* 1994; Strasburg 1958). Off California, parturition reportedly occurs in early spring, and mating occurs during late spring to early winter (Hanan, *et al.* 1993). Although Hanan, *et al.* (1993) suggest that the SCB is a major pupping and nursery area for this species, the pattern of young pups in the observed DGN catch suggest the nursery habitat may also extend northward to off the Columbia River mouth, and primarily offshore of the 100 fathom isobath (Nosal, *et al.* 2019).

2.3.6   Essential Fish Habitat for Blue Shark

Blue shark EFH is defined using a combination of data sources provided in the previous sections as well as expert opinion (see Figure 3b). Combining sexes and age classes, blue shark EFH includes the entire U.S. West Coast EEZ seaward of the 12 m depth contour. While blue sharks may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species and habitat along the continental margins make the California Current a suitable habitat for feeding and growth to maturity for blue sharks.

- Neonate and Early Juveniles (< 83 cm FL): YOY blue sharks spend most of their time over the continental margin, but off the continental shelf. Blue shark nursery areas extend along the continental margins of the SCB ecoregion, north through Oregon (approximately 32−46.2° N). Young blue sharks off California have been found to feed heavily on pelagic cephalopods, with *Gonatus* spp. and paper nautiluses (*Argonauta* spp.) being the most important.
- Late Juveniles and Subadults (males > 82 cm FL and < 175 cm FL; females > 82 cm FL and < 170 cm FL): Epipelagic, oceanic waters from the U.S. - Canada border to the U.S. – Mexico border. Within the U.S. West Coast EEZ they are known to feed on northern anchovy, Pacific hake, squid, spiny dogfish, Pacific herring, flatfishes, and opportunistically on surface-swarms of euphausiids, and inshore spawning aggregations of market squid. A study showed *Gonatus* spp. ranked first in importance followed by jumbo squid and *Argonauta* spp.
- Adults (males > 175 cm FL; females > 170 cm FL): Epipelagic, oceanic waters in the region from northern California to the U.S. – Mexico border. A study showed jumbo squid ranked first in importance followed by *Gonatus* spp. and *Octopoteuthis* spp. Larger specimens may feed on marine mammals, including pinnipeds and cetaceans. The relatively warmer and productive waters off California make this a suitable feeding habitat for adult blue sharks.

3   Tunas

Tunas are members of the tribe Thunnini in the family Scombridae. Overall, they are both important predators and prey and through much of their range support recreational and commercial fisheries. Tunas are unique in possessing a high metabolic rate and vascular heat exchanger systems that allow them to elevate body temperature above water temperature. The five tunas included in the FMP fall into two categories, the tropical tunas (bigeye, skipjack, and yellowfin tuna) and temperate tunas (Pacific bluefin and albacore tuna). Tuna abundance, as inferred from landings, varies over time and space.

3.1   Albacore Tuna (*Thunnus alalunga*)

3.1.1   General Distribution

Albacore tuna (*Thunnus alalunga*) are a highly migratory, epipelagic, and mesopelagic species found in tropical and temperate waters of all the oceans (Figure 4a). In the Western Pacific, their distribution extends in a broad band between 40° N and 40° S, whereas in the Eastern Pacific catch is rare in equatorial waters. Their range in the Northeastern Pacific extends from the tip of Baja California to British Columbia (Collette and Graves 2019). The areas of highest abundance in the California Current have historically been in the SCB and the waters off Oregon and Washington, although there is high variability in the abundance and distribution of albacore in the California Current-related to changes in environmental variables and flexibility in foraging strategies (Muhling*, et al.* 2019). There are two known stocks with the northern stock occurring in the North Pacific (ISC Albacore Working Group 2020).

For the North Pacific stock, spawning occurs in tropical and subtropical waters in the Central and Western Pacific Ocean (Foreman 1980; Nishikawa*, et al.* 1985). Miller (1979) found a relatively high concentration of albacore larvae around the Hawaiian Islands. Similarly, Leis*, et al.* (1991) found high concentrations of tuna larvae, including albacore, at sample sites near coral reefs on three islands in French Polynesia. It may be that island features provide important habitat for larval albacore. Small juvenile albacore have also been found in coastal waters from several areas in the Western Pacific including the Mariana Islands, Japanese coastal waters, Fiji, waters east of Australia, and Tuvalu, and from Hawaiian waters. Juvenile albacore recruit to the California Current region starting around two years of age and return to forage each summer until they move to spawning grounds in the Central Tropical Pacific at approximately five years of age (Childers*, et al.* 2011; Wells*, et al.* 2013b) (Figure 4a).

The distribution of albacore is influenced by oceanography with the largest studies being conducted with juveniles. Juveniles are often found near oceanic fronts or temperature discontinuities. Laurs and Lynn (1991) describe the distribution of juveniles in terms of the North Pacific Transition Zone that lies between the cold, low-salinity waters north of the sub-arctic front and the warm, high salinity waters south of the subtropical front (between 40° and 20-35° N). More recent archival tagging studies show that in addition to the North Pacific Transition Zone, the offshore waters from Canada through the Baja Peninsula are also important in the Eastern Pacific Ocean (Muhling*, et al.* 2019). For juvenile albacore tagged in the Eastern Pacific Ocean, 99% of SST was between 12 and 21 °C.

Archival study by Childers*, et al.* (2011) found that albacore had a broad range of vertical behaviors. In southern portions of the California Current, juvenile albacore made frequent dives to depths exceeding 200 m during the day and remained in the surface mixed layer at night, whereas off Oregon and Washington they remained near the surface both day and night. Water temperatures encountered ranged from 3.3 to 22.7 °C.

3.1.2   Growth and Development

North Pacific albacore mature at approximately five years of age, with size at 50% maturity in females estimated to be 87.5 cm FL, and maximum longevity is believed to be around 21 years (Ashida*, et al.* 2020; Wells*, et al.* 2013b). According to Bartoo and Foreman (1994) albacore in the North Pacific have the

following size at age: 1 yr-35 cm, 2- 52 cm, 3- 65 cm, 4-76 cm, 5- 85 cm, 6- 93 cm FL.

Using the von Bertalanffy equation where a is age, k is the growth coefficient, t_0 is the theoretical age when size is zero, and L∞ is asymptotic size.

$$L(a) = L\infty(1 - e^{-k(a - t0)})$$

Xu, *et al.* (2016) estimated the following parameters for albacore: L∞ = 111.6 cm, K = .241 yr^{-1}, and t_0 = 0.047 yr.

3.1.3   Trophic Interactions

Albacore are considered to feed opportunistically, with fish, squid, and crustaceans as the dominant prey. There have been multiple studies that have examined stomach contents demonstrating that while small schooling fish are overall dominant in diets, there is high variability in time and space. The most recent study by Nickels, *et al.* (2023) is the most comprehensive and compiled data from 3 regions across 13 years.

Nickels, *et al.* (2023) found that important prey include northern anchovy, rockfishes (Sebastes spp.), boreal clubhook squid (*Onychoteuthis borealijaponica*), euphausiids (Order: Euphausiidae), and Amphipods (Order: Amphipoda), each contributing > 5% mean proportional abundance. Over time, diet variability mostly reflected changes in the relative importance of common prey species rather than the inclusion of novel prey. They found that albacore switch between generalist and specialist foraging strategies under different environmental conditions. Regional averages of the Biologically Effective Upwelling Transport Index (BEUTI), surface chlorophyll-a, and SST over the first six months of the year best explained diet variation. Low BEUTI was associated with specialization on northern anchovy, while higher BEUTI diets varied with region and SST.

Muhling, *et al.* (2019) used catch logbook data and trawl survey records to investigate how juvenile albacore in the California Current use their oceanographic environment, and how their distributions overlap with the habitats of four key forage species. They showed that northern anchovy and Pacific hake habitat are associated with productive coastal waters found more inshore of core juvenile albacore habitat, whereas Pacific sardine and boreal clubhook squid habitat overlaps more consistently with that of albacore. The prey consumed impacts the availability to fishers.

3.1.4   Migrations, Movements, and Stock Structure

There are two populations of albacore in the Pacific, one in the Northern Hemisphere and one in the Southern Hemisphere. The albacore in the North Pacific are managed as one population (ISC 2020).

Albacore have complex migration patterns based on life history stage. From the spawning grounds in the Central and Western Pacific, albacore recruit to the California Current region starting around two years of age. They return to forage each summer until they return to the spawning grounds in the Central Tropical Pacific at approximately five years of age. The largest migrations are undertaken by pre-adults, two to four years old.

Juvenile albacore found along the North America coast in summer and fall months move offshore in the winter and spring. Childers, *et al.* (2011) showed five patterns of movement away from the northern California Current. Albacore migrated 1) far offshore between 150 and 180° W during the winter and returned to the northern region off Oregon and Washington the following summer; 2) west and south during the winter then into the southern California Current the following summer; 3) into the central North Pacific during the winter then into the Western Pacific the following spring, presumably to spawn; 4) west to offshore areas between 130 and 140° W during the winter and returning to the southern California Current the following summer; 5) overwintered along the Baja peninsula and returned to the SCB the following summer.

Vertical habitat use varies with region (Childers, *et al.* 2011). Tagged juvenile albacore were found to exploit deeper waters off Baja California, Mexico, making frequent dives to depths exceeding 200 m during the day and remaining in the surface mixed layer at night. Off Oregon and Washington, where mixed layer depths are shallow and chlorophyll-a concentrations are high, they remained near the surface both day and night. As albacore moved offshore to the west, the vertical habitat use deepened, corresponding with the increased depth of the deep scattering layer.

3.1.5   Reproduction

Like all tunas, albacore are broadcast spawners. Spawning occurs in the tropical and subtropical waters in the Central and Western Pacific. Foreman's (1980) map shows a spawning area that is centered on 20° N and 160° E and does not extend east of about 150° W. Ashida, *et al.* (2020) examined the reproductive traits of albacore tuna in the western North Pacific. Sex ratios shift with size, in juvenile and subadult size classes the ratio is 1:1 whereas at larger size classes (above 95 cm FL) males dominate. They found evidence of active spawning in all months except for January with most spawning occurring in April through September. The estimated batch fecundity and relative batch fecundity (mean ± SD) were 1.16 ± 0.67 million oocytes and 59.1 ± 31.5 oocytes/g, respectively (FL range: 88.6–104.8 cm) with fecundity increasing with FL.

3.1.6   Essential Fish Habitat for Albacore Tuna

Albacore tuna EFH is defined using a combination of data sources provided in the sections above as well as expert opinion (see Figure 4b). Combining all age classes, albacore tuna EFH includes the entire U.S. West Coast EEZ seaward of the 12 m depth contour. While albacore tuna may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species make the California Current a suitable habitat for feeding and growth to maturity for juvenile albacore tuna.

- Eggs and Larvae: No habitat within the U.S. West Coast EEZ.
- Juvenile (~50 to < 85 cm FL): Oceanic, epipelagic waters from the U.S.-Mexico border north to the U.S.-Canada border. Albacore feed on small fishes (northern anchovy, rockfish species, boreal clubhook squid, and crustaceans (amphipods, euphausiids).
- Adult (>85 cm FL): Adulthood is defined by the ability to reproduce rather than size. Thus, while some fish >85 cm are landed in the EEZ these fish are not reproductively mature and thus, not adults. Following this logic, adult albacore are not found in the EEZ and consequently adult albacore EFH is not found within the U.S. West Coast EEZ.

3.2   Bigeye Tuna (*Thunnus obesus*)

3.2.1   General Distribution

Bigeye tuna (*Thunnus obesus*) are circumglobal in tropical and warm-temperate seas, occupying epi- and mesopelagic waters (Figure 5a). In the Western Pacific their distribution stretches between northern Japan and the north island of New Zealand and in the Eastern Pacific from 40° N to 30° S (Calkins 1980; Miyabe and Bayliff. 1998). There is limited information on the occurrence of bigeye tuna in the West Coast U.S EEZ. While these datasets do not show the complete picture and species misidentification is a concern (small yellowfin and bigeye look very similar) data reveals limited landings in the commercial passenger fishing vessel (CPVF) logbooks and even less length data. A search of both the DGN observer database and the RecFIN database shows only one bigeye tuna record for a 61 cm fish in 2004. In 2022, fishermen off northern California reported landing bigeye tuna ~140-180 cm FL. While landings occur, bigeye tuna are rare in the U.S. West Coast EEZ.

Bigeye tuna spawn in tropical waters across the equatorial Pacific (Calkins 1980; Collette and Graves 2019; Nishikawa, *et al.* 1978) although larvae are most common in warm surface waters between 30° N and 20°

S and are relatively more abundant in the Western and Eastern Pacific (Reglero, *et al.* 2014). Bigeye larvae appear to be restricted to the mixed layer well above the thermocline and at depths less than 50 to 60 m (Matsumoto 1961). The distribution of juvenile bigeye tuna less than 35 cm FL is not well known but is assumed to be similar to that of larvae (i.e., occupying warm surface waters).

The distribution of juveniles greater than 35 cm FL is better understood than smaller fish, as they begin to enter catch statistics.

Juvenile and subadult bigeye of 35 cm to 100 cm are regularly taken in the Eastern and Western Pacific purse seine fisheries, usually on sets made in association with floating objects (Hampton and Bailey. 1993). Adults also aggregate around drifting flotsam and anchored buoys, though to a lesser degree than juvenile fish. Juvenile bigeye form mono-specific schools of similar-sized fish at or near the surface, or they may be mixed with skipjack and/or juvenile yellowfin tuna (Calkins 1980). Larger juvenile and subadult bigeye appear in higher latitude fisheries. Fish taken in the northern longline fishing grounds around 30° N are immature adults or spent spawners (Calkins 1980). Adult bigeye are distributed across the tropical and temperate waters of the Pacific.

SST in which the species has been found range from 13 to 29 °C (Collette and Nauen. 1983). In a 2019 report, Lopez, *et al.* (2019) examined observer data for tropical purse seine fisheries. They found that for small, medium, and juvenile size classes the most important predictor of elevated bigeye catch was temperature at 100 m (20-28 °C) and that for these size classes, SST did not account for >5% variability. In contrast, for adult bigeye (>15kg) while temp at 100 m was also important, it ranked second behind salinity, the range was lower (15-28 °C), and SST accounted for 8.6% of the variability with the peak in catch at 21 °C.

Data from electronic tags provide insight into vertical habitat use. Schaefer, *et al.* (2015) analyzed the vertical behavior of 65 bigeye tuna (estimated size range 48–130 cm FL) in the equatorial Pacific Ocean and the Coral Sea. They found that vertical movements became progressively deeper from east to west. In addition, depths were deeper at larger body size and when the thermocline depth increased in the Eastern Pacific Ocean during El Niño events. Overall, bigeye tuna have been shown to dive to more than 1,000 m where temperatures were less than 3 °C. These fish have been shown to exhibit diel vertical migrations with depths of less than 50 m at night, and during the day diving to depths associated with the deep scattering layer during the day (Schaefer, *et al.* 2015; Schaefer, *et al.* 2011).

3.2.2 Growth and Development

Bigeye tuna are relatively fast growing and have a maximum FL of about 200 cm (Aires-da-Silva, *et al.* 2015; Farley, *et al.* 2017).

Available data indicate that bigeye tuna in the Western and Central Pacific Ocean (WCPO) become reproductively active from about 80 cm FL, and nearly all individuals >120 cm FL are reproductively mature (Farley, *et al.* 2017). For the Central and Eastern Pacific, Zhu, *et al.* (2010) reported the onset of maturity at 94 cm FL with a size at 50% maturity of 108 cm. Maximum age has been estimated at around 16 years (Farley, *et al.* 2017).

Farley, *et al.* (2017) looked at the standard von Bertalanffy and Richards growth models and found that the Richards model was preferred based on statistical tests and residuals analysis. The Richards growth model is defined as

$$L_t = L_\infty (1 - 1/b * e^{-k(t-t0)})^b$$

where all parameters are defined as for the von Bertalanffy model except t_0 now determines the point of inflection and *b* governs the shape of the curve. The resulting Richards model parameter estimates using only high readability age determinations were $L = 161.1$ cm FL, $k = 0.24$ yr^{-1}, $b = 0.58$ and $t_0 = 2.26$ yr.

3.2.3   Trophic Interactions

Bigeye tuna are considered opportunistic feeders, and their forage base is made up of a variety of fish, crustaceans, squid, and gelatinous creatures (Bertrand*, et al.* 2002; Duffy*, et al.* 2017; Josse*, et al.* 1998; Sund*, et al.* 1981). Larvae consume epi- or mesopelagic prey including zooplankton before shifting to fish larvae at the late larval and early juvenile stages. Young juvenile bigeye feed opportunistically during day and night (Collette and Nauen. 1983), on fish, crustaceans, and cephalopods. Large juveniles and adults exploit the deep scattering layer, consuming mesopelagic fishes, cephalopods, and crustaceans at depths to 300–500 m during the day, and in surface waters at night (Dagorn*, et al.* 2000; Schaefer and Fuller 2010; Vaske Jr.*, et al.* 2012) with time-at-depth and foraging depth increasing with body size. Duffy*, et al.* (2017) reported that while small bigeye in the Eastern Pacific Ocean fed mostly on ommastrephid squids, larger bigeye tuna showed high diet diversity consuming a mix of squid, crustaceans, and fishes, including deep-dwelling or vertically migrating micronekton (e.g., ommastrephid squids, alepisaurid, myctophid, and paralepidid fishes). Bigeye are opportunistic feeders, foraging broadly across a range of habitats and taxa.

3.2.4   Movements and Stock Structure

A range of approaches have been used to examine stock structure of bigeye tuna in the Pacific including genetics, otolith microchemistry, differences in growth rates, and tagging studies. There is currently no clear evidence for population structure in the Pacific Ocean although authors agree more work is needed. (McKechnie*, et al.* 2015; Moore*, et al.* 2020). Given their largely continuous distribution across the tropical Pacific and capacity to make large-scale movement, it is considered unlikely that multiple discrete populations exist. What is considered most likely is separation by distance, with locations farther apart having the greatest divergence (Moore*, et al.* 2020). The most recent stock assessment concluded that conducting separate assessments in the Western and Central Pacific Ocean and Eastern Pacific Ocean was appropriate (McKechnie*, et al.* 2015).

Studies examining seasonal migrations show a range of patterns. Tagging studies using both archival and conventional tags show that the majority of tagged bigeye are recaptured in the general regions of their release (i.e., within 1,500 nm) although they are capable of larger-scale movements (i.e., >4,000 nm) (Moore*, et al.* 2020; Schaefer*, et al.* 2015). While longitudinal (N-S) movements are common and occur seasonally, latitudinal movements (E-W) are thought to be less extensive (Moore*, et al.* 2020; Schaefer*, et al.* 2015). The species appears to move freely within broad regions of favorable water temperature and dissolved oxygen values.

3.2.5   Reproduction

Bigeye tuna are serial spawners, capable of repeated spawning at near daily intervals with batch fecundities of millions of ova per spawning event (Nikaido*, et al.* 1991). Spawning spans broad areas of the Pacific and occurs throughout the year in tropical waters and seasonally at higher latitudes at water temperatures above 23 or 24 °C (Kume 1967). Spawning takes place during the afternoon or evening hours at or near the surface (McPherson 1991). Eggs are epipelagic, buoyed at the surface by a single oil droplet until hatching occurs. The early larval stages of bigeye and yellowfin are difficult or impossible to differentiate without allozyme or mitochondrial DNA analyses (Graves*, et al.* 1988).

Zhu*, et al.* (2010) studied the reproductive biology of bigeye tuna in the Eastern and Central Tropical Pacific. There the main spawning period of bigeye tuna was between March and November although statistically female and male bigeye tuna had no significant reproductive seasonality.

3.2.6   Essential Fish Habitat for Bigeye Tuna

Bigeye tuna EFH is defined using a combination of data sources provided in the sections above as well as expert opinion (see Figure 5b). The occurrence of bigeye tuna in the U.S. West Coast EEZ is not common, and typically occurs in warm water years. Bigeye tuna EFH includes oceanic, epipelagic, and mesopelagic

waters of the U.S. West Coast EEZ from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N), seaward of the 12 m depth contour. Habitat is concentrated in the SCB primarily south of 34° N latitude. While bigeye tuna may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species make the California Current a suitable feeding habitat for juvenile and adult bigeye tuna.

- Eggs and Larvae: No habitat within the U.S. West Coast EEZ.
- Juvenile (< 108 cm FL): Oceanic, epipelagic, and mesopelagic waters from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N). Feeding appears to be opportunistic at all life stages, with prey items consisting primarily of crustaceans, cephalopods, and fishes. Sternoptychids, gempylids, paralepidids, and myctophids are important prey items.
- Adult (>108 cm FL): Oceanic, epipelagic, and mesopelagic waters from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N). Feeding appears to be opportunistic at all life stages, with prey items consisting primarily of crustaceans, cephalopods, and fishes. Sternoptychids, gempylids, paralepidids, and myctophids are important prey items.

3.3   Pacific Bluefin Tuna (*Thunnus orientalis*)

3.3.1   General Distribution

The Pacific bluefin tuna (*Thunnus orientalis*) (referred to as bluefin tuna below) is a highly migratory, epipelagic, and mesopelagic species found in tropical and temperate waters. It is present throughout much of the Pacific Ocean and enters the eastern Indian Ocean (Figure 6a). In the Western Pacific, especially west of 180°, the distribution extends southward to off New Zealand, eastern Australia, and New Guinea; and westward to Japan, the East China Sea, and the Philippines (Bayliff 2001; Tomlinson 1996). Bluefin are known to spawn only in the Sea of Japan, the East China Sea, and off the Pacific coast of Japan (Bayliff 1994; Dewar, *et al.* 2022; Schaefer 2001; Tanaka, *et al.* 2020), with most larvae collected where SST ranges between 24° and 28 °C (Ohshimo, *et al.* 2017). Some portion of juvenile fish migrate from spawning grounds in the Western Pacific at ages zero to three years to forage in the California Current System before returning west at ages 3-7+ years (Boustany, *et al.* 2010; Madigan, *et al.* 2017). The general range of the species in the eastern North Pacific is from as far south as the tip of the Baja Peninsula, Mexico. To the north, Pacific bluefin tuna have occurred as incidental catch in the DGN fishery off the U.S. West Coast north to near 47° N latitude off Grays Harbor, Washington, with occasional records off Vancouver, B.C., and to Shelikoff Strait in Alaska, but only during extreme warm water years (Radovich 1961; Squire 1983).

In the Western Pacific off Japan, optimal SST for juveniles are reported as between 14 and 20 °C (Inagake, *et al.* 2001; Itoh, *et al.* 2003; Kitagawa, *et al.* 2007), but small juvenile fish (15-31 cm FL) have been caught by Japanese coastal fishers in warmer water, as high as 29 °C. In the Eastern Pacific, Boustany, *et al.* (2010) found that SST experienced by tagged fish ranged from 11-26 °C, but that the mean daily SST for this study was 14-21 °C. Bayliff (1994) provides maps of the areas of the North Pacific bounded by the 17 and 23 °C isotherms by season; in winter this band is centered on 30° N latitude and in summer on 40° N.

Runcie, *et al.* (2019) examined the effects of local oceanic conditions (SST, surface chlorophyll, sea surface height, eddy kinetic energy), as well as large-scale oceanographic phenomena, such as El Niño, on Pacific bluefin tuna availability to commercial and recreational fishing fleets. Results from generalized additive models showed that warmer temperatures of around 17–21 °C with low surface chlorophyll concentrations (<0.5 mg/m3) increased probability of occurrence of Pacific bluefin tuna in the California passenger fishing vessel and purse seine fisheries.

Bluefin tuna off the U.S. West Coast have been caught during every month of the year, but most fish are taken spring through fall (Bayliff 2001; James, *et al.* 2021). Across years most landings in the Eastern Pacific Ocean have been for fish under three years of age and less; 90% of landings are for fish that are 130 cm FL or less, corresponding to age three. There are, however, periods where larger fish are landed. Larger

fish occurred more regularly earlier in the 20th century, judging from early accounts from the historic Catalina Tuna Club (e.g., Collins 1892; Holder 1914). Catches of exceptionally large-sized Pacific bluefin were made by purse seiners in the Eastern Pacific during November and December of 1988 (Foreman and Ishizuka 1990). More recently, larger fish were landed with increased frequency starting in 2016 and continuing through 2022 (James, *et al.* 2021, NOAA unpublished data).

3.3.2   Growth and Development

Pacific bluefin tuna grow rapidly and reach a maximum size of around 3 m (Colette 1995). The current stock assessment (ISC 2022b) considers that 100% of Pacific bluefin are mature at age five. Although Pacific bluefin older than five are caught in the Eastern Pacific Ocean, there is no evidence of spawning within the U.S. West Coast EEZ (Dewar, *et al.* 2022).

Estimates of length and growth have been complicated for several reasons including differences in birth dates and seasonal variability in growth. The ISC used a simple von Bertalanffy growth function to estimate Pacific bluefin age from length for the 2022 stock assessment. Bluefin tuna grow rapidly to age five (approximately 160 cm FL), after which growth slows down. At age 12, the fish reach 226 cm FL, corresponding to 90% of the maximum FL of this species (ISC 2022b). The potential life span of Pacific bluefin tuna is at least 20 years old.

Using the von Bertalanffy equation where L_1 and L_2 are the length (cm) associated with ages (year) near the first (A_1) and second (A_2) ages, L_∞ is the asymptotic average length-at-age, and K is the growth coefficient (y^{-1}).

$$L_2 = L_\infty + (L_1 - L_\infty)e^{-K(A_2 - A_1)}$$

Fukuda, *et al.* (2015) estimated the following parameters for Pacific bluefin: K at 0.188 yr^{-1} and L_1 and L_2 at 19.05 cm and 118.57 cm for age 0 and age 3, respectively.

3.3.3   Trophic Interactions

Bluefin tuna are considered to feed opportunistically, with fish, squid, and crustaceans as the dominant prey. There have been multiple studies that have examined stomach contents, demonstrating that while small schooling fish are overall dominant in diets, there is high variability in time and space. Pinkas, *et al.* (1971) examined purse seine-caught Pacific bluefin off California and Baja California, Mexico in 1968 and 1969 and found that the northern anchovy was the primary food, overshadowing all other ingested species followed by pelagic red crab, and Pacific saury. Madigan, *et al.* (2015) found that in stomach samples taken in the SCB, the most important prey items were Pacific sardine, Jack mackerel, jumbo squid, and midwater eelpout (*Melanostigma pammelas*). In contrast, in a more comprehensive study covering nine years, (Portner, *et al.* 2022) reported that Pacific bluefin forage on a broad diversity of fishes, squids, and crustaceans in the SCB, including high energy epipelagic prey such as anchovies and sardines, as well as large numbers of mesopelagic prey such as myctophids, hyperiid amphipods, and enoploteuthid squids. Bluefin tuna is an opportunistic predator that can exhibit distinct foraging behaviors to exploit diverse forage communities across habitats.

3.3.4   Migrations, Movements, and Stock Structure

Pacific bluefin tuna are considered a single stock throughout the Pacific, although their migratory patterns within this region are complex. Several archival tag studies have shown that Pacific bluefin tuna migrate from the Western Pacific Ocean along the North Pacific Transition Zone at ages zero to three years to forage in the California Current System before returning west at ages 3-7+ years (Bayliff 1994; Bayliff 2001; Boustany, *et al.* 2010; Madigan, *et al.* 2017). Archival tagging data successfully downloaded from 15 tagged Pacific bluefin tuna have shown that the journey from the Western to the Eastern Pacific takes an average of 2.5 months (ranging from 1.2 to 5.5 months) (Fujioka, *et al.* 2018).

Within the California Current, electronic tagging studies showed repeatable seasonal movements along the west coast of North America. Pacific bluefin tuna were found farthest south in the spring when they were located off southern Baja California, Mexico, and farthest north in the fall when fish were found predominantly off central and northern California. Fish showed latitudinal movement patterns that were correlated with peaks in coastal upwelling-induced primary productivity. Interannual variation in the locality of these productivity peaks was linked with a corresponding movement in the distribution of tagged fish. Prey availability can alter the timing and location of Pacific bluefin migrations (Boustany, *et al.* 2010; Domeier, *et al.* 2005). Conventional (Bayliff 1994) and electronic (Block, *et al.* 2011) tagging programs have shown that once Pacific bluefin tuna are in the Eastern Pacific Ocean, they are typically residential for one to four years, prior to returning to the Western Pacific Ocean, presumably to spawn (Block, *et al.* 2011; Boustany, *et al.* 2010; Kitagawa, *et al.* 2007) although starting in 2016 older fish have been more prevalent in landings off the West Coast (James, *et al.* 2021). When leaving the California Current to return to the Western Pacific, fish also use the North Pacific Transition Zone.

3.3.5 Reproduction

Bluefin tuna are known to spawn only in the Sea of Japan, the East China Sea, and off the Pacific coast of Japan (Bayliff 1994; Schaefer 2001; Tanaka, *et al.* 2020), with most larvae collected where SST are 24–28 °C (Ohshimo, *et al.* 2017). Fish spawning in the Sea of Japan are 3–8 years old, while in the East China Sea they are typically 8 years of age or older (Okochi, *et al.* 2016; Shimose, *et al.* 2009). Batch fecundity increased with FL; and preliminary estimates of spawning frequency between batches ranged from 2 to 4.5 days based on analysis of postovulatory follicles (Chen, *et al.* 2006).

3.3.6 Essential Fish Habitat for Pacific Bluefin Tuna

Pacific bluefin tuna EFH is defined using a combination of data sources provided in the previous sections as well as expert opinion (Figure 6b). Pacific bluefin tuna EFH includes the entire U.S. West Coast EEZ seaward of the 12 m depth contour. While Pacific bluefin tuna may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species make the California Current a suitable habitat for feeding and growth to maturity for juvenile Pacific bluefin tuna.

- Eggs and Larvae: No habitat within the U.S. West Coast EEZ.
- Juvenile and Adult (>50 cm FL): Oceanic, epipelagic waters from the U.S.-Mexico border north to the U.S.-Canada border, and westward to the 200 nm EEZ boundary. Major prey of Pacific bluefin across sizes in our region are the northern anchovy, Pacific sardine, Pacific mackerel, jumbo squid, midwater eelpout, Pacific saury, squid, and pelagic red crab. Overall, this is a highly opportunistic predator that can exploit a broad range of available prey species across habitats. In a study in the Eastern Pacific Ocean using gonad histology none of the females were mature although a few males were considered mature (Dewar, *et al.* 2022). Thus, males would be considered adults whereas the females of the same size would not. Regardless, from the perspective of EFH, they share the same habitat, and separation by life history stage is not useful.

3.4   Skipjack Tuna (*Katsuwonus pelamis*)

3.4.1 General Distribution

Skipjack (*Katsuwonus pelamis*) occur in epipelagic and oceanic regions from tropical to warm temperate waters of all oceans (Figure 7a). In the Western Pacific, its habitat is bounded by the 15 °C isotherm or roughly between 45° N and S. In the Eastern Pacific, this range is more restricted due to the basin-wide current regime, which brings cooler water closer to the equator. In the Eastern Pacific Ocean, east of about 145 ° W, their range extends to around 30° N and 25° S seasonally. The bulk of skipjack tuna biomass, however, occurs within 10° of latitude from the equator (Moore, *et al.* 2020). While during El Niño events, skipjack have been found as far north as 50° N along the U.S. West Coast (IATTC 2001; PFMC 1999) they

are more commonly landed in the SCB where fish between 40-60 cm FL dominate landings (92%).

Larval distribution is concentrated in, though not exclusively restricted to, tropical equatorial waters across the Pacific. The distribution was documented in the entire Pacific Ocean by Japanese research vessel net tows (Nishikawa, *et al.* 1985; Nishikawa, *et al.* 1978; Ueyanagi 1969) and summarized more recently by Buenafe, *et al.* (2022). Like adults, larvae have a wider latitudinal distribution in the Western than in the Eastern Pacific. The few areas north of 20° N with relatively high larval abundance include the Hawaiian Islands. Matsumoto, *et al.* (1984) noted that the distribution of juveniles in the Pacific is generally from 35° N to 35° S in the west and between 10° N and 5° S in the east.

Skipjack habitat over their distribution has been described in terms of oceanography. Matsumoto, *et al.* (1984) reported the habitat characteristics in terms of temperature and oxygen saturation: a lower temperature limit around 18 °C; a lower dissolved oxygen level of around 3.5%; and a speculative upper temperature limit, ranging from 33 °C for the smallest skipjack tuna caught. A more recent study in the Eastern Pacific Ocean reported a range of ~20-30 °C and concluded that skipjack in the Eastern Pacific Ocean prefer intermediate sea surface temperatures around 25-26 °C (Mildenberger, *et al.* 2022).

Data on the vertical movements of skipjack are available from archival tags where fish were observed both on and off fish aggregating devices (FADs). While away from FADs skipjack exhibited bounce dives during the day to between 225 and 400 m, (well below the thermocline) with limited dives at night. During the day fish spent 37% of their time below the thermocline in comparison to 1% at night. In contrast, fish associated with FADs did not dive and spent both day and night above the thermocline (Schaefer, *et al.* 2009).

3.4.2   Growth and Development

Skipjack grow rapidly and mature early. (Matsumoto, *et al.* 1984) have summarized larval growth, development, and growth to maturity. Once fertilized, eggs hatch in about one day, depending on temperature. They can reach sexual maturity by approximately 40-50 cm FL (as early as six months of age) (Ashida, *et al.* 2017; Ohashi, *et al.* 2019). Schaefer and Fuller (2019) reported for the Eastern Pacific Ocean that while there was spatial variability, the size at 50% reproduction north of 15° N was ~ 56 cm FL. Maximum size recorded is 111 cm FL and 34.5 kg (Bayliff 1988; Collette 2010; Collette and Graves 2019) and the maximum age is thought to be around 8-12 years. Most fish captured by the industrial purse seine and pole-and-line fisheries are thought to be less than four years old.

A reliable means for establishing an age-length relationship does not exist for skipjack. Matsumoto, *et al.* (1984) and Maunder, *et al.* (2022) both provide an extensive review of growth estimates. Maunder, *et al.* (2022) compile and compare results from tagging and length frequency data from fisheries. Given the limits of the available data they do not estimate von Bertalanffy growth equation (Maunder, *et al.* 2022).

3.4.3   Trophic Interactions

Skipjack are opportunistic feeders, exploiting a range of fish, crustaceans and squid with diets varying across size, time, and space. Matsumoto, *et al.* (1984) reported that smaller skipjack tuna rely mainly on crustaceans for food, presumably zooplankton, and identified 11 invertebrate orders and more than 80 fish families in stomach contents. Off Baja California, Mexico, and southern California, pelagic red crab and northern anchovy were reported as the most important constituents of the skipjack's diet, with euphausiids, Pacific saury, and squid also taken (Alverson 1963, sampling in 1957-1959). In a recent study in the tropical and subtropical Eastern Pacific Ocean by Fuller, *et al.* (2021), anchovies dominated diets in both the California and Humboldt currents where upwelling was prominent. In the other regions both coastal and offshore, various epipelagic and mesopelagic fishes were important in diets. At 55 cm FL, skipjack transitioned from eating anchovies, Humboldt squid, and krill to consuming epipelagic fishes and pelagic red crabs. Across size classes mesopelagic fish were important.

3.4.4   Migrations, Movements, and Stock Structure

In the Pacific Ocean, while skipjack tuna have a continuous east-west distribution; there is evidence from genetic and tagging studies for broad stock separation between the Western and Central Pacific Ocean and the Eastern Pacific Ocean (Grewe, *et al.* 2019; Moore, *et al.* 2020).

Skipjack movement is highly variable and has been shown to be influenced by large-scale oceanographic variability (Lehodey, *et al.* 1997; Senina, *et al.* 2008) and is described as both seasonally and temporally complex (Moore, *et al.* 2020). Pre-recruits are thought to disperse from the Central Pacific, arriving in the Eastern Pacific at 1 to 1 ½ years old and returning to the Central Pacific at 2 to 2 ½ years old (Hunter, *et al.* 1986; Wild 1994). Overall, skipjack exhibit north-south movements in the Eastern Pacific Ocean between ~20° N and 30° N, coincident with the seasonal movement of the 20 °C surface water isotherm (Fink and Bayliff 1970). They move north in the spring and return south the following autumn and winter with evidence of regional site fidelity (Moore, *et al.* 2020).

3.4.5   Reproduction

Based on observations of the gonad state of mature individuals and the distribution of larvae, spawning in skipjack tuna is considered to occur across the Pacific where SST generally exceed 24 °C. Skipjack tuna have been found to spawn throughout the year in tropical regions, and seasonally in subtropical regions, in all major oceans (Ashida and Horie 2015; Ashida, *et al.* 2007; Matsumoto, *et al.* 1984; Nishikawa, *et al.* 1985; Schaefer 2001). The greatest proportion of spawning occurs in waters between 26 and 29 °C (Ashida and Horie 2015; Nishikawa, *et al.* 1985; Schaefer 2001; Schaefer and Fuller 2019; Servidad-Bacordo, *et al.* 2012).

The estimated average batch fecundity from 129 fish was 296,475 oocytes, and the estimated mean relative fecundity was 54.9 oocytes per gram of body weight. The estimated fraction of mature females in the population spawning per day was 0.21, equivalent to a spawning frequency of 4.76 days, whereas for actively spawning females, the fraction spawning per day was 0.85, equivalent to a mean spawning interval of 1.18 days (Schaefer and Fuller 2019).

3.4.6   Essential Fish Habitat for Skipjack Tuna

Skipjack tuna EFH is defined using a combination of data sources provided in sections above as well as expert opinion (Figure 7b). Skipjack tuna EFH includes the oceanic, epipelagic waters of the U.S. West Coast EEZ from the U.S.- Mexico border to just north of Point Conception, California (34° 34' N), seaward of the 12 m depth contour. While skipjack tuna may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species make the SCB during warm years a suitable feeding habitat for adult skipjack tuna.

- Eggs and Larvae: No habitat within the U.S. West Coast EEZ.
- Juvenile: No habitat within the U.S. West Coast EEZ.
- Adult (~56 cm FL): Oceanic, epipelagic waters from the U.S. - Mexico border to just north of Point Conception, California (34° 34' N) to the 200 nm U.S. EEZ boundary. Pelagic red crab, northern anchovy, Euphausiids, Pacific saury, and squid are important components of their diets.

3.5   Yellowfin Tuna (*Thunnus albacares*)

3.5.1   General Distribution

Yellowfin tuna (*Thunnus albacares*) are circumglobal in distribution, in tropical and subtropical seas (Figure 8a). They primarily occur between 20° N to 20° S but have been caught at higher latitudes during summer months. In the Eastern Pacific, they range from Point Conception, California (34.4° N) south to

Peru, including the oceanic islands. While during El Niño events yellowfin occur as far north as Oregon and Washington (Pearcy 2002), they are more commonly landed in the SCB where fish between 50-90 cm FL dominate landings (91%).

Yellowfin distribution varies with age class. Yellowfin tuna larvae are trans-Pacific in distribution and found throughout the year in tropical waters (Buenafe, *et al.* 2022). Larvae are common at SST above 26 °C but may occur in some regions with SST down to 24 °C (Harada and Murata 1980). The distribution of early juveniles less than 35 cm FL has not been well documented but is assumed to be similar to that of larvae.

Juvenile fish (> 35 cm FL) are distributed in warm oceanic surface waters and are found throughout the year in tropical waters. Juveniles have been reported in the Western Pacific between 23° S to 31° N and from 23° N near the Hawaiian Islands to 23° S to 23° N in the Central Pacific (Higgins 1970).

Adult and juvenile yellowfin 35 cm FL and greater, are known to aggregate to drifting flotsam, FADs, anchored buoys, dolphin, and other large marine animals (Hampton and Bailey. 1993). They also aggregate in regions of elevated productivity and high zooplankton density, such as near seamounts and regions of upwelling and convergence of surface waters of different densities, presumably because of more abundant forage (Blackburn 1969; Cole 1980).

Archival tagging data provide insight into vertical habitat use of yellowfin in the northeastern Pacific Ocean. Schaefer, *et al.* (2011) reported that yellowfin remained primarily in shallow surface waters at night and dove into deeper waters during the day, with one of two general patterns observed. Fish either remained primarily above 100 m or made at least 10 dives into waters greater than 150 m. An examination of the patterns in occurrence of the two dive types revealed that larger fish were more likely to dive into deeper cooler waters and the shallower dive pattern was more prevalent in coastal waters and near islands. Results also revealed that the yellowfin were more vulnerable to purse seine fisheries from May to September due to increased time in surface waters.

3.5.2   Growth and Development

The species is characterized by rapid growth and development to maturity with high natural mortality. Growth of the juvenile stage is particularly fast, and they can reach a FL of around 20-30 cm by three months of age and approximately 50 cm by one year (Farley, *et al.* 2020). Age and size at maturity varies regionally. Length at 50% maturity in the Western and Central Pacific is at around 100-110 cm (Itano 2000). Schaefer and Fuller (2022b) found high variability in length at 50% maturity in the Central and Eastern Pacific ranging from 71 to 91 cm FL, with a value of 83 cm off Baja California, Mexico. Age at maturity is around two years of age. Yellowfin tuna can reach a maximum FL of around 180 cm and live for up to 15 years, although most fish aged to date have been less than 10 years old (Farley, *et al.* 2020; Itano 2000).

Farley, *et al.* (2020) looked at the standard von Bertalanffy and Richards growth models and found that the Richards model was preferred based on statistical tests and residuals analysis. The Richards growth model is defined as

$L_t = L_\infty(1-1/b * e^{-k(t-t0)})^b$

where all parameters are defined as for the von Bertalanffy model except t_0 now determines the point of inflection and *b* governs the shape of the curve. The resulting Richards model parameter estimates using only high readability age determinations were L_∞= 152.0 cm FL, k = 0.40 yr^{-1}, b = 0.58 and t_0 = -0.55 yr.

3.5.3   Trophic Interactions

Across age classes, yellowfin feeding is opportunistic and occurs largely during the day, with prey items

consisting primarily of crustaceans, cephalopods, and fish (Cole 1980; Duffy, *et al.* 2017; Reintjes and King 1953; Watanabe 1958). As larvae, yellowfin reportedly feed in the upper mixed layer initially on crustacean zooplankton after which they shift to larval fish (Uotani, *et al.* 1981). Juvenile prey items are epipelagic or mesopelagic or pelagic post-larval or pre-juvenile stages of island-, reef-, or benthic-associated organisms. Graham, *et al.* (2007) found that yellowfin tuna diets shifted at approximately 45 cm FL from planktonic organisms inhabiting the shallow mixed layer (e.g., larval stomatopod and decapod crustaceans) to teleosts and adult *Oplophorus gracilirostris*, a vertically migrating mesopelagic species of shrimp. They hypothesized that this transition to deeper prey was linked to the ontogenetic development of their endothermic abilities.

The diets of juveniles and adults vary both temporally and spatially. Off the west coast of Baja California, Mexico, and southern California, in the early 1960's, pelagic red crab and northern anchovy were reported as the dominant prey (Alverson 1963). Cephalopods became more important in the Gulf of California during a period associated with an El Niño regime. In the Eastern Tropical Pacific, Moteki, *et al.* (2001) identified at least 22 species of fish in 18 families. Based on numbers of individuals consumed, sternoptychids (*Sternoptyx obscura)* dominated (61.3%) diets, followed by exocoetids and bramids. Madigan, *et al.* (2015) found that in stomach samples taken in the SCB, the most important prey items were Pacific sardine, jack mackerel, market squid, and jumbo squid. Yellowfin are opportunistic predators and consume a range of fish, squid, and crustaceans across epipelagic and mesopelagic habitats.

3.5.4 Migrations, Movements and Stock Structure

Analyses of single-nucleotide polymorphisms suggest the occurrence of at least three stocks broadly associated with the Western, Central, and Eastern Pacific Ocean (Grewe, *et al.* 2015). The results of genetic studies are broadly consistent with tag/recapture data in suggesting that mixing between the far western and far eastern Pacific Ocean regions is limited (Moore, *et al.* 2020).

While yellowfin are clearly capable of large-scale movements, most tagging data (conventional and electronic) reveal more limited movement (Hunter, *et al.* 1986; Okamoto and Bayliff 2003; Schaefer and Fuller 2022a; Schaefer, *et al.* 2009; Wild 1994). A large archival tagging study provides the best insight into movements in the Eastern Pacific Ocean. Schaefer and Fuller (2022a) archivally tagged 1,522 yellowfin tuna in six areas of the Eastern and Central Pacific Ocean (2002-2019) of which 483 were recovered after 32 to 1,846 days at liberty. Of the recovered tags 99% remained within 1,000 m of their release locations. Fish moved north-south seasonally in association with the ~18 °C isotherm. The northern extent of movements for fish tagged off Baja included the SCB. The full SST range experienced was from ~16-29 °C for fish tagged off Baja (Schaefer, *et al.* 2011). Yellowfin appear to move freely within broad regions of favorable water temperature and productivity and are known to make seasonal excursions to higher latitudes as water temperatures increase. The nature of yellowfin migration in the Central and Western Pacific is less well studied.

3.5.5 Reproduction

Yellowfin are broadcast spawners that have a high spawning frequency and fecundity. Spawning occurs across the Pacific in tropical and subtropical waters. In a large study in the Eastern Pacific, Schaefer and Fuller (2022b) reported that spawning was widespread from about 25° N to 16° S between 78° W and 148° W, occurring throughout the year from 5° N to 15° N. North of 20° N, spawning took place during April–December. Note that the peak spawning season varies across the Pacific. Fecundity in the Eastern Pacific Ocean ranged from about 54 thousand oocytes for an 87 cm female to about 7.2 million oocytes for a 153 cm female and the mean spawning interval was 1.23 days.

Schaefer and Fuller (2022b) also reported that although spawning occurred at SST from 25 °C to 32 °C, 73.0% took place between 27 °C and 29 °C. A positive relationship between spawning activity and areas of high forage abundance has been noted (Itano 1997).

3.5.6 Essential Fish Habitat for Yellowfin Tuna

Yellowfin tuna EFH is defined using a combination of data sources provided in the sections above as well as expert opinion (see Figure 8b). Based on landings data and information on size at maturity for Baja California, Mexico, the majority of fish occurring in the U.S. EEZ are immature although a small percentage may be adults. Yellowfin tuna EFH includes oceanic, epipelagic waters of the U.S. West Coast EEZ from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N), seaward of the 12 m depth contour. While yellowfin tuna may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species make the SCB a suitable feeding habitat for yellowfin tuna.

- Eggs and Larvae: No habitat within the U.S. West Coast EEZ.
- Juvenile and Adults (>35 cm): Oceanic, epipelagic waters from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N) to the 200 nm U.S. EEZ. Pelagic red crab is an important constituent of the diet in southern California (warm water years), as well as northern anchovy, Pacific jack, sardine, and squid species.

4 Billfish/Swordfish

4.1 Striped Marlin (*Tetrapturus audax*)

4.1.1 General Distribution

The striped marlin (*Tetrapturus audax*) is widely distributed in oceanic and epipelagic waters throughout most tropical, sub-tropical and warm temperate waters of the Pacific and Indian Oceans (Nakamura 1974, 1985) (Figure 9a). Based on Japanese longline data, Pacific striped marlin has a sideways, U-shaped distribution, occurring in greatest numbers in two supra-equatorial bands that join at the eastern tropical margin (Nakamura 1974; Squire and Suzuki 1990). Striped marlin are found in greater numbers in the North Pacific with higher catch rates in the north central, Northeast Pacific (Shomura and Williams 1975). In the eastern North Pacific abundance and distribution varies seasonally and with size class. Subadult fish occur in high abundance around the tip of the Baja Peninsula. Off California, primarily adults (>~160 cm EFL) are observed with landings peaking in September in the SCB when SST is greater than 20 °C (Squire Jr. 1974). During the 1997-1998 El Niño, striped marlin were found as far north as the coast around the Oregon-Washington border (47° N) (Pearcy 2002).

Analysis of Japanese longline catches in the Eastern Pacific Ocean by Uosaki and Bayliff (1999) indicate that striped marlin also occur just west of the U.S. EEZ in moderate concentrations from about 22° N to 37° N and west of 125° W. Because of lack of fishing effort in the outer waters of the EEZ, it is not known to what extent the striped marlin distribution is continuous from the SCB westward to the EEZ boundary, although it is likely discontinuous at least in the area influenced by the California Current, which tends to form a barrier of colder, less saline water between the SCB and the warm oceanic waters generally west of 125° W (Lynn*, et al.* 1982; Lynn and J.J.Simpson 1990).

Spawning occurs in tropical and subtropical waters including in the waters off Hawaii, central Mexico, and the mouth of the Gulf of California (Armas*, et al.* 1999; Gonzalez Armas*, et al.* 2006; Hyde*, et al.* 2006). Those that spawn in the Northwest Pacific are thought to migrate eastward as juveniles (Squire and Suzuki 1990), although very little is known about juvenile striped marlin habitat. Holts (2001) estimated that most striped marlin caught in the southern California sport fishery are three-to-six years old and weigh 120 to 200 pounds, and though not reproductively active, appear to be adult-sized.

The most comprehensive characterization of habitat use comes from a study that used the data from 159 pop-up satellite archival tags comparing Australia, New Zealand, Hawaii, Southern California, Baja California, Costa Rica, Panama, and Ecuador (Lam*, et al.* 2015). Overall, the SST range reported was from

15-31 °C. For comparison, an analysis of catch data (Ortega-Garcia, *et al.* 2003; Ortega-Garcia, *et al.* 2008) found that a key determinant of distribution was SST from 23-26 °C.

Electronic tags also provide insight into vertical habitat use. Tracking of adult striped marlin in Hawaiian waters using acoustic telemetry (Brill, *et al.* 1993) indicate that they spend a significant amount of time in the upper 10 m of the water column and 40% of their time between 51-90 m. The authors conclude that depth preference is governed by temperature stratification, with striped marlin preferring to remain in the mixed layer above the thermocline, avoiding waters 8 °C colder than the mixed layer temperature.

The study by Lam, *et al.* (2015) comparing regions across the Pacific reported a similar pattern. Striped marlin spent at least 54% of their time between 0 and 10 m across all regions sampled (Australia, New Zealand, Hawaii, Southern California, Baja California, Costa Rica, Panama, and Ecuador). Lam, *et al.* (2015) found that individuals remained near the surface during the night and were found near the bottom of the mixed layer during daytime. Off California and Mexico, daytime median depth was ~30m. During dives striped marlin exploited cold (<15 °C) or low oxygen (<3.5 ml L−1) environments for short durations (10–40 min).

4.1.2   Growth and Development

Aging of striped marlin has been challenging. The most recent effort by Fitchett (2019) used a combination of tagging data, fin spines, and otoliths to estimate a length at age. Growth in the first few years is rapid. In the Central Pacific, females are reported to reach maturity at 160 cm EFL and two to three years of age (Humphreys and Brodziak 2019). This is approximately 20 cm smaller than estimated for the Western Pacific. While age at maturity for males is not available for the Central or Eastern Pacific, in the Southwest Pacific it is estimated at 144 cm EFL, significantly shorter than females from the same area (Kopf, *et al.* 2012). No von Bertalanffy growth curve is available for striped marlin.

4.1.3   Trophic Interactions

Little is known about the time of first feeding and food preferences. Based on patterns seen in other billfish, juvenile striped marlin larvae are likely to consume copepods and fish larvae (Ueyanagi and Wares 1975). Some data on the foraging ecology of adult striped marlin are available. Nakamura (1974) reports that globally they rely more on epipelagic than mesopelagic organisms, with squid, scombrids, and gempylids dominating the diets. In the Eastern Tropical Pacific, Moteki, *et al.* (2001) found a total of 347 fish of 17 species in 12 families in the stomachs of striped marlin. Based on numbers of individuals found, bramids (*Brama spp*.) were dominant in the stomach contents (60.5%), and scombrids had the second highest value (11.0%). As with other billfish, the broad range of prey indicates that they are opportunistic feeders.

4.1.4   Migrations, Movements, and Stock Structure

In the Pacific, genetic evidence and fisheries data support recognition of three stocks, one south of the equator and two stocks north of the equator 1) the Western and Central North Pacific Ocean west of 140° W longitude and 2) the Eastern Pacific Ocean east of 140° W (Lee, *et al.* 20112; McDowell and Graves 2008; Purcell and Edmands 2011). The two stocks in the North Pacific are assessed and managed separately.

Striped marlin migrate across a range of spatial scales. Seasonal patterns generally conform to water temperature-related changes in range. In Hawaiian waters, striped marlin are more common in the winter months (Ueyanagi and Wares 1975). The smaller fish appear in catches off Hawaii in the winter season and then disappear in the summer when they are presumed to move north, likely to the North Pacific Transition Zone. Off California, striped marlin are most common in summer months.

Despite advancements in tagging studies (Domeier 2006; Domeier, *et al.* 2019; Lam, *et al.* 2022), the annual migration patterns of striped marlin in the Eastern Pacific are poorly understood. While the path or arrival and departure from the SCB is not known, tagging data show the potential for fish to move north from the

Mexican EEZ into the SCB (Domeier 2006; Domeier, *et al.* 2019; Lam, *et al.* 2022) although this was relatively rare. Departure from the SCB is dispersed with fish most either moving south along the coast of Mexico, or towards the spawning grounds in the Central Pacific near Hawaii. Even though striped marlin are capable of migrating long distances, tagging studies indicate that on average they have limited dispersal (Bromhead, *et al.* 2003; Chambers, *et al.* 2013; Domeier 2006; Lam, *et al.* 2015; Ortiz, *et al.* 2003; Sippel, *et al.* 2011; Squire 1987). For example, an archival tagging study with tracks as long as 7.7 years showed that striped marlin remained in the Eastern Pacific throughout the tracked duration (Lam, *et al.* 2022). Results are consistent with the conclusions about stock structure based on genetic analyses.

4.1.5   Reproduction

Striped marlin are broadcast spawners, and spawn multiple times in a season. In the Southwest Pacific, Kopf, *et al.* (2012) estimated a fecundity of at least 3.1 million oocytes in 27–90 spawning events per season. In the Central Pacific, active spawning was documented from May to August (Humphreys and Brodziak 2019). In contrast, in the southern Gulf of California, spawning was more protracted, occurring from May through December and larvae were collected at SST from 27.5 to 31.5 ° C (Gonzalez Armas, *et al.* 2006).

4.1.6   Essential Fish Habitat for Striped Marlin

Striped marlin EFH is defined using a combination of data sources provided in sections above as well as expert opinion (see Figure 9b). Based on catch data the majority of fish landed in the U.S. EEZ are adults. Striped marlin EFH includes oceanic, epipelagic waters of the U.S. West Coast EEZ, from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N), seaward of the 12 m depth contour. While striped marlin may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The relatively warmer temperature, high productivity and presence of diverse fish, squid and crustacean species make the SCB a suitable foraging habitat for adult striped marlin.

- Eggs, Larvae and Juveniles: No EFH within the U.S. West Coast EEZ.
- Subadult (males < 144 cm EFL; females <160 cm EFL): No EFH is identified in the U.S. West Coast EEZ. Based on landings data and the size at first reproduction few subadult striped marlin are expected in the U.S. EEZ.
- Adult (males > 144 cm EFL; females >160 cm EFL): Oceanic, epipelagic waters of the SCB, from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N) and to the 200 nm U.S. EEZ. Diets off California include a range of fish, squid, and crustaceans including Pacific saury, northern anchovy, Pacific sardine, Jack mackerel, squid, and pelagic red crab.

4.2   Swordfish (*Xiphias gladius*)

4.2.1   General Distribution

Swordfish (*Xiphias gladius*) are worldwide in distribution in all tropical, subtropical, and temperate seas, ranging from around 50° N to 50° S (Barrett, *et al.* 1998; Bartoo and Coan Jr 1989; Nakamura 1985) (Figure 10a). Swordfish, also known as broadbill swordfish, are relatively abundant in coastal and oceanic waters in areas of high productivity near current boundaries and frontal zones where forage species are abundant. In oceanic waters of the North Pacific swordfish concentrate in the North Pacific Transition Zone. In coastal waters they are also found along frontal features as well as at sea mounts.

According to Ward and Elscot (2000) citing others, swordfish do not seem to have a discrete spawning ground or spawning season. The geographical distribution of larvae suggests that spawning occurs in waters where SSTs are above 24 °C. Spawning occurs throughout the year in equatorial waters but is progressively restricted to spring-summer at higher latitudes. Larvae and juveniles tend to occur in warmer tropical and subtropical regions – not in the U.S. EEZ. Larval abundance is high along sharp thermal and salinity

gradients. However, this phenomenon may be due to passive collection along boundary areas. Most recently, reproductive habitat for swordfish was visualized in Lu (2014) based on several previous studies documenting where early life history stages have been observed and the occurrence of females with high gonadal indices. In their first year swordfish are thought to remain close to the spawning grounds after which they migrate to foraging grounds around the Pacific. Analyses of otolith microchemistry revealed that while swordfish landed off California recruit from multiple regions, the Central North Pacific Ocean nursery is the dominant contributor (Wells, *et al.* 2021).

Swordfish are found in a broad range of environmental conditions. The SST encountered by swordfish (14 to 30 °C) is regionally and seasonally dependent (Dewar, *et al.* 2011; Sepulveda, *et al.* 2018). Larger fish that tend to be females are more common in cooler waters at higher latitudes. According to Beckett (1974) and Palko, *et al.* (1981) few males occur in waters below 18 °C and the males make up the majority of warm water landings. In the U.S. EEZ both juvenile and adult male and female swordfish are landed in fisheries.

Electronic tags also reveal vertical migrations. Swordfish show a range of vertical movement patterns that are influenced by prey availability and oxygen concentration (Carey and Robison 1981; Dewar, *et al.* 2011; Sepulveda and Aalbers 2018). While their general vertical movement pattern is described as diurnal (deep during the day shallow at night) there is considerable variability, swordfish may not descend during the day, remaining in the mixed layer, or they may come to the surface to bask before returning to depth (Dewar, *et al.* 2011). Off Southern and Central California daytime depths typically range from the surface to depths in excess of 400m. As swordfish move offshore towards tropical spawning grounds the average daytime depth distribution increases to depths closer to 600m (Dewar, *et al.* 2011).

4.2.2 Growth and Development

Swordfish grow in length very rapidly, with both males and the faster-growing females reaching lower jaw-fork lengths (LJFL) of more than a meter during their first year (Cerna 2009; Chong and Aguayo 2009; DeMartini, *et al.* 2007). In the Hawaii-based pelagic longline fishery, males mature at 102 cm Eye Fork Length (EFL) or 118 cm LJFL; females at 144 cm EFL or 163 cm LJFL (DeMartini, *et al.* 2000; Sculley, *et al.* 2018). The maximum reported size is 455 cm FL (IGFA 2001) and the maximum age is estimated at 15 years (Cerna 2009).

Using the von Bertalanffy equation where L_t is the mean EFL (in cm) at age t, L_∞ is asymptotic length, *t* is a specific age, and t_0 is hypothetical age at length zero, and *k* is the growth coefficient.

$$L_t = L_\infty \left(1 - e^{-k(t - t0)}\right)$$

DeMartini, *et al.* (2007) estimated the following parameters for male and female swordfish with *k* at 0.246 yr^{-1} for female with L_∞ at 230.5 cm and t_0 at -1.24 yr, and *k* at .0271 for male with L_∞ at 208.9 t_0 at -1.37 yr^{-1}.

4.2.3 Trophic Interactions

Swordfish are considered voracious and opportunistic feeders at all life stages and their diet generally reflects the presence and abundance of available prey species in any given geographic region. The larval and young swordfish actively feed on zooplankton during the day and are known to swallow prey as long as themselves (Taning 1955). Juveniles and adults feed opportunistically on a wide range of squids, fish, and crustaceans preying heavily on squid. Prey consumed include benthic, epipelagic, and mesopelagic species highlighting their ability for forage across habitats and depths (Stoehr, *et al.* 2017). Their cranial endothermy enhances their ability to forage in deep water.

Many studies have been conducted on swordfish diets in the California Current (Fitch, *et al.* 1971; Markaida and Hochberg 2005; Markaida and Sosa-Nishizaki 1998; Mearns, *et al.* 1981; Moteki, *et al.* 2001). Most recently, Preti (2020; 2023) examined swordfish stomach content from 2007-2014 comparing regions,

years, and small and large size classes. Preti reported that jumbo squid was the most important prey item, and the Boreopacific armhook squid (*Gonatopsis borealis*) was the second most important prey overall. A comparison across size revealed that while both large and small groups fed on similar prey, some differences were apparent. Northern anchovy was found only in the small size group while louvar was eaten only by large swordfish. Additionally, jumbo squid, Gonatus spp., and Pacific hake were significantly more important in larger swordfish (Preti 2020). A comparison by subregion also revealed some differences in diet. Jumbo squid, Gonatus spp. and market squid were significantly more important within the SCB, while *Gonatopsis borealis* and Pacific hake are significantly more important beyond the SCB. Diet comparisons by year showed that jumbo squid was the first ranked prey followed by *Gonatopsis borealis* in 2007, 2008, 2010, 2012, and 2013. In 2009, 2011, and 2014 Pacific hake ranked first followed by *Gonatopsis borealis*. Pacific hake was not present in the diet from 2008 through 2010. In 2018-2021, swordfish fed prominently on northern anchovy, which are now more available in the SCB (Preti, pers. comm.).

4.2.4 Migrations, Movements, and Stock Structure

The stock structure of swordfish in the North Pacific is highly uncertain and multiple hypotheses have been put forth over the years ranging from one to four separate stocks. Determining stock structure for HMS where spawning and foraging grounds are separated by long distances can be challenging. The most recent stock assessment set the stock boundary such that the majority of the North Pacific is included in the North Pacific Stock. Progressing from west to east, the boundary starts at 0° N and, at 165° W, it steps up to 5° N until 150° W where it steps up again to 10° N until it reaches Central America (ISC 2023).

The majority of information on swordfish migrations comes from electronic tagging studies. In the eastern North Pacific juvenile and adult swordfish migrate to the SCB to forage during the summer and fall. During warm water periods (i.e., El Niño) the average size and length frequency distribution of swordfish landed off Southern California may change, with juveniles making up a large component of the commercial catch (Sepulveda 2023a; Sepulveda and Aalbers 2018; Sepulveda, *et al.* 2019). The use of dorsal fin mounted smart position transmitters (SPOT tags) have shown that swordfish off California display some level of seasonal site fidelity, returning to the SCB in subsequent seasons (Griffiths, *et al.* 2020; Sepulveda 2023b; Sepulveda, *et al.* 2019). Movements across the current stock boundary in the Eastern Pacific Ocean are common.

4.2.5 Reproduction

Swordfish are broadcast spawners, spawn multiple times in a given spawning season, and are believed to spawn close to the surface. Spawning occurs year around in tropical waters and during the spring and summer months at higher latitudes (Matsumoto and Kazama 1974; Nishikawa, *et al.* 1978; Nishikawa and Ueyanagi 1974; Palko, *et al.* 1981; Uchiyama and Shomura 1974).

4.2.6 Essential Fish Habitat for Swordfish

Swordfish EFH is defined using a combination of data sources provided in the sections above as well as expert opinion (see Figure 10b). Swordfish EFH, including adults and juveniles, includes the entire U.S. West Coast EEZ seaward of the 12 m depth contour. While swordfish may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The high productivity and presence of diverse fish, squid, and crustacean species make the California Current a suitable habitat for feeding and growth to maturity for swordfish.

- Eggs and Larvae: No habitat within the U.S. West Coast EEZ.
- Juvenile (males <102 EFL or 118 cm LJFL; females <144 cm EFL or <163 LJFL): Oceanic, epipelagic, and mesopelagic waters from the U.S.-Mexico border north to 41° N latitude and to the 200 nm U.S. West Coast EEZ. Diet is thought to be largely opportunistic on suitable-sized prey. In the SCB, swordfish feed on jumbo squid, *Boreopacific gonate,* Barracudinas, market squid, Pacific hake, northern anchovy, and myctophids.

- Adult (males > 102 cm EFL or 118 LJFL; females > 144 cm EFL or 163 JFL): Oceanic, epipelagic, and mesopelagic waters from the U.S.-Mexico border to the U.S. - Canada border and to the 200 nm U.S. West Coast EEZ. Large swordfish feed on similar prey as the smaller size group but jumbo squid, Gonatus spp., Luvar and Pacific hake are significantly more important.

5 Other

5.1 Dolphinfish (Dorado, Mahimahi, *Coryphaena hippurus*)

5.1.1 General Distribution

Dolphinfish (*Coryphaena hippurus*) occur in epipelagic and oceanic regions from tropical to warm temperate waters of all oceans (Ambrose 1996; Norton 1999; Oro 1999; Palko*, et al.* 1982) (Figure 11a). In the Pacific Ocean, greatest concentrations occur closer to the coast in both the east and west although they are also common around oceanic islands, including Hawaii's EEZ. Throughout their range they are often found associated with both natural and manmade floating objects. In the Eastern Pacific, dolphinfish are most abundant off Mexico, Panama, Ecuador, and Peru, and around the Galapagos Islands (Aires-da-Silva*, et al.* 2016) and generally occur at SSTs between 20 and 30 °C (Moltó*, et al.* 2020); (Perle*, et al.* 2020). They move into U.S. waters as far north as Point Conception, California (34.4° N), primarily during warm water years. The largest concentrations of dolphinfish off California have occurred in late summer and early fall when temperatures exceed 20 °C and northern geostrophic flow is greatest (Norton 1999; Norton and Crooke 1994). Of the dolphinfish landed, the majority were between 60-100 cm FL (~95%). During the 1997-1998 El Niño, dolphinfish were found as far north as the coast of Oregon (44° N) (Pearcy 2002).

The most detailed information on vertical habitat use comes from electronic tagging data. A study using acoustic tagging data reported that vertical habitat use varied depending on their association with floating objects. When not associated with FADs, dolphinfish used the upper 75–100 m of the water column during the day and made descents up to 160 m during the night. In contrast, FAD- associated fish generally stayed within the upper 10 m of the water column and tended to make deeper excursions during the day rather than at night (Whitney*, et al.* 2016). A second study using pop-up satellite archival tags, with longer deployments, reported that while dolphinfish were primarily surface oriented and there was a high degree of variability in vertical habitat use. In the warmer waters off Oaxaca, Mexico, fish spent less time in surface waters (61%) than off Baja California (85%) although their mean maximum daily depths were shallower (37m vs 60m). Additionally, they reported a mix of diel and reverse diel movements.

5.1.2 Growth and Development

Dolphinfish are fast-growing and mature relatively early. Maximum size is 200 cm. Fish reach maturity in less than a year (at about 35 cm FL or ~7 months old), and only rarely live beyond three to four years of age (Beardsley Jr 1967; Lasso and Zapata 1999; Palko*, et al.* 1982). Actual growth rates vary among regions and are sensitive to prevailing water temperatures. Kraul (1999) and Uchiyama*, et al.* (1986) estimate fish in the wild have an average growth of about 2 mm per day. Based on the von Bertalanffy growth relationship reported by Lasso and Zapata (1999), for the Eastern Pacific off of Columbia and Panama dolphinfish reach ~110 cm FL by age 1, 170 cm by age 2 and 180 cm FL by age three.

Lasso and Zapata (1999) estimated growth using the following von Bertalanffy growth equation (FL in cm): Note that there is considerable variability in parameters across studies and additional work is needed (Chang and Maunder 2012).

$$L_t = L_\infty \left(1 - e^{-k(t - t0)}\right)$$

Where L_∞ = 194 cm, K = 0.91 yr^{-1}, and t_0 = -0.1049 yr5.0.3

5.1.3 Trophic Interactions

Dolphinfish consume a broad range of fish, cephalopods, and crustaceans and are opportunistic feeders (Varela*, et al.* 2016). According to Shcherbachev (1973), the larvae feed mainly on crustaceans, particularly pontellid copepods, with fish larvae appearing in the diet of young juveniles > 20 mm SL. Prey importance varies dramatically across studies and diets vary with fish size, region, and time of day (Moltó*, et al.* 2020). Torres-Rojas*, et al.* (2014) reported that dolphinfish consumed mainly epipelagic prey, with the pelagic red crab as the most abundant prey species. In contrast, Olson and Galván-Magaña (2002) reported that flying fishes, epipelagic cephalopods, tetraodontiform fishes, several mesopelagic fishes, Auxis spp., and gempylid fishes predominated in the diet. In the waters off Oaxaca, Bergés-Tiznado*, et al.* (2019) reported that the five most important species by percent weight were Auxis, dolphinfish, two species of squid (*Histioteuthis dofleini* and *Dosidicus gigas*), and longfin halfbeaks (*Hemiramphus saltator*). All life stages of dolphinfish serve as prey for oceanic fishes, particularly marlin, epipelagic sharks, swordfish, sailfish, and members of their own kind (Bergés-Tiznado*, et al.* 2019; Brock 1984; Palko*, et al.* 1982; Parin 1970; Takahashi and Mori 1973).

5.1.4 Migrations, Movements, and Stock Structure

Stock structure for dolphinfish in the Pacific is still not resolved although there is some genetic evidence for regional separation. Rocha-Olivares*, et al.* (2006) reported significant genetic differences between fish found in the Central Pacific (Hawaii) and the Eastern Pacific Ocean (Mexico). Aires-da-Silva*, et al.* (2016) developed a conceptual model (IATTC 2016) that postulated two sub-stocks, a resident coastal sub-stock and an oceanic sub-stock that migrates seasonally towards the coast. In a more recent study by Ochoa-Zavala*, et al.* (2022) researchers examined samples at nine sites from Magdalena Bay, Mexico, to Peru. They found a clear pattern of genetic structure at the latitudinal limits of the study. More work is needed on dolphinfish stock structure.

Globally, the dolphinfish is known to be capable of making long-distance migrations within ranges generally limited poleward from the equator by the 20 °C isotherm to both the north and south (Hammann*, et al.* 1995; Norton 1999; Oro 1999) Seasonal movements are inferred from limited tagging data and shifts in catch. For example, Marín-Enríquez*, et al.* (2018) modeled 10 years of catch data from the tuna purse seine fleet in the Pacific Ocean off Mexico and concluded that that dolphinfish followed a "corridor" that ran from the Gulf of Tehuantepec along the equatorial upwelling zone; moved around the eastern Pacific warm pool offshore; and ultimately to the Baja Peninsula, Mexico. It should be noted that while catch does increase off Baja in the summer and fall, dolphinfish are landed year around in this region (Ghosh*, et al.* 2022). Note that from catch data direct connections between regions can only be inferred.

5.1.5 Reproduction

Dolphinfish are oviparous broadcast spawners, with pelagic eggs and larvae. Spawning is thought to occur year around in waters > 21 °C (Lasso and Zapata 1999). In a study by Zúñiga-Flores*, et al.* (2011) off Baja California, Mexico, the gonads from 2,839 dolphinfish ranging in size from 42 to 155 cm FL were collected and examined. The gonad histology of 320 individuals revealed that the maximum activity during the summer and fall occurred at SST 28–30 °C. Mean batch fecundity (number of oocytes) estimated for 24 females was 279,383. It was determined that 50% of all individuals reached maturity at an average length of 80 cm FL. In CalCOFI larval fish surveys, larvae have been collected off central and southern Baja California, Mexico, and only occasionally off southern California in warm years, with peak abundance in August and September (Ambrose 1996).

Dolphinfish show clear sex dimorphism. The male head exhibits a well-developed crest (vertical slope) while the female head is rounded. Small-sized males and all sizes of females may spend more time associated with floating objects than large sized males, which tend to spend more time in open water, possibly traveling between female-dominated schools below rafts (Oxenford 1985).

5.1.6 *Essential Fish Habitat for Dolphinfish*

Dolphinfish EFH is defined using a combination of data sources provided in the sections above as well as expert opinion (Figure 11b). Dolphinfish EFH includes the epipelagic and oceanic waters of the U.S. West Coast EEZ from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N), seaward of the 12 m depth contour. While dolphinfish may occur in shallow water <12 m, they occur primarily in deeper waters and these shallow regions including bays and estuaries are not considered essential. The relatively warmer waters, high productivity, and presence of diverse fish, squid, and crustacean species make the SCB a suitable feeding habitat for adult dolphinfish.

- Eggs, Larvae and Small Juveniles (<13.7 cm FL): No EFH within the U.S. West Coast EEZ. Occurrence of larvae is rare.
- Juveniles and Subadults (> 13.6 cm FL and < 35 cm FL): No EFH within the U.S. West Coast EEZ. Based on the size composition of landings data, juveniles and subadults would be rare in the U.S. EEZ.
- Adults (>35 cm FL): Epipelagic and oceanic waters from the U.S.-Mexico border to just north of Point Conception, California (34° 34' N) and to the outer edge of the U.S. EEZ. Flying fishes, epipelagic cephalopods, tetraodontiform fishes, and several mesopelagic fishes are important prey species.
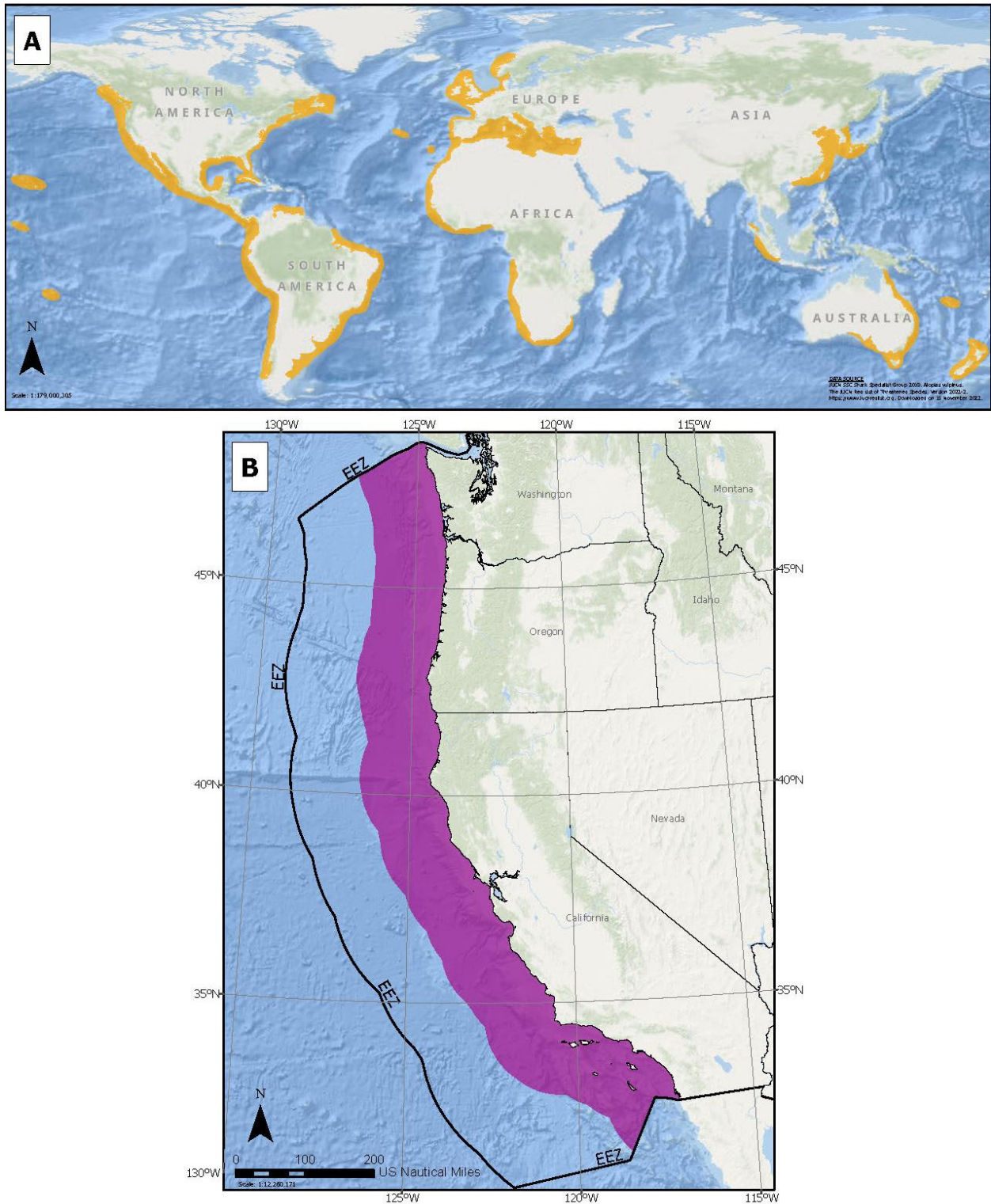
6 Figures

Figure 1. Common thresher shark (a) global range and (b) essential fish habitat. (Global range data source: IUCN SSC Shark Specialist Group 2018. *Alopias vulpinus***. The IUCN Red List of Threatened Species. Version 2022-2.)**
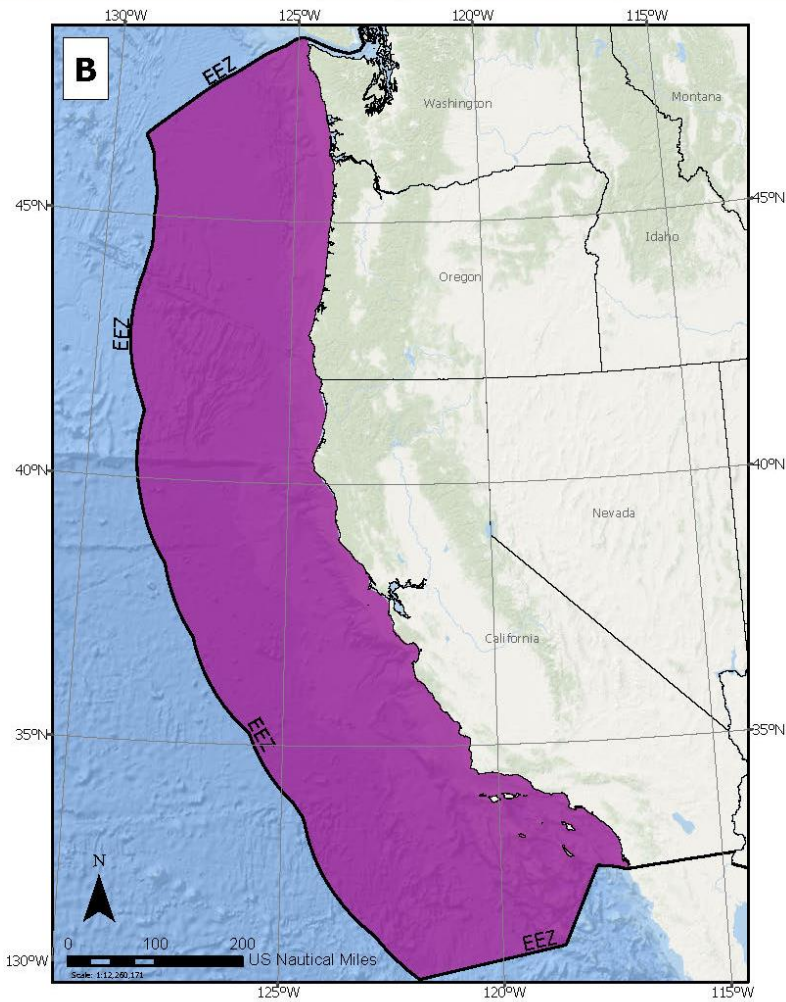
Figure 2. Shortfin mako shark (a) global range and (b) essential fish habitat. (Global range data source: IUCN SSC Shark Specialist Group 2018. *Isurus oxyrinchus*. **The IUCN Red List of Threatened Species. Version 2022-2.)**
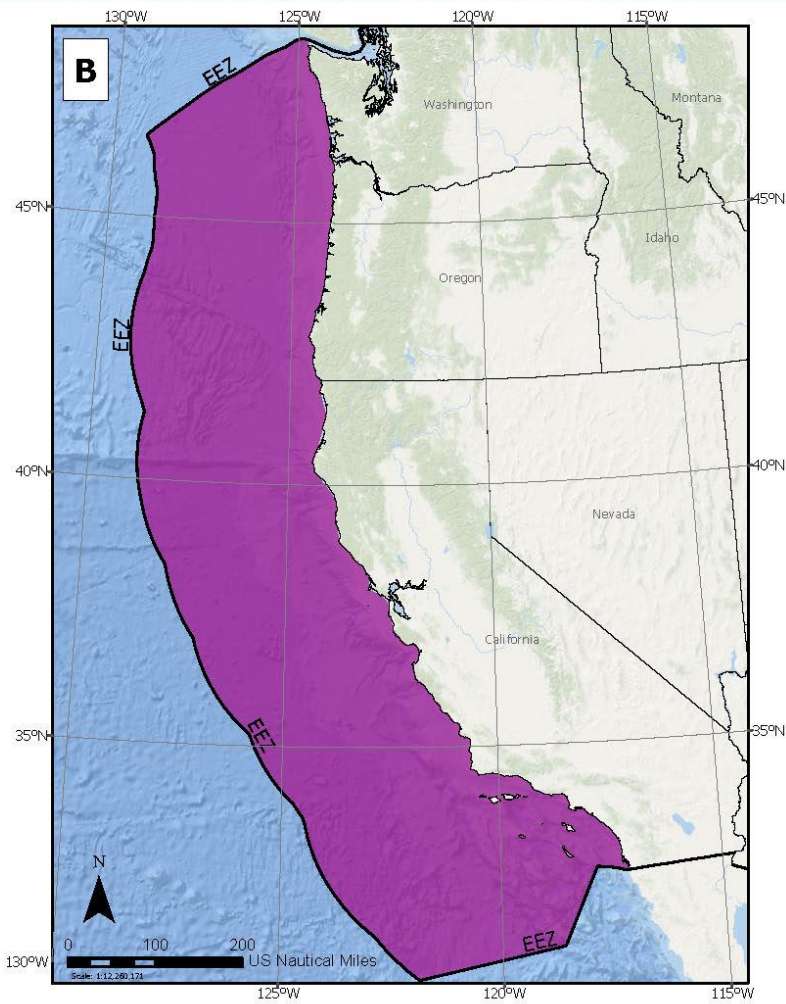
Figure 3. Blue shark (a) global range and (b) essential fish habitat. (Global range data source: IUCN SSC Shark Specialist Group 2018. *Prionace glauca*. The IUCN Red List of Threatened Species. Version 2022-2.)
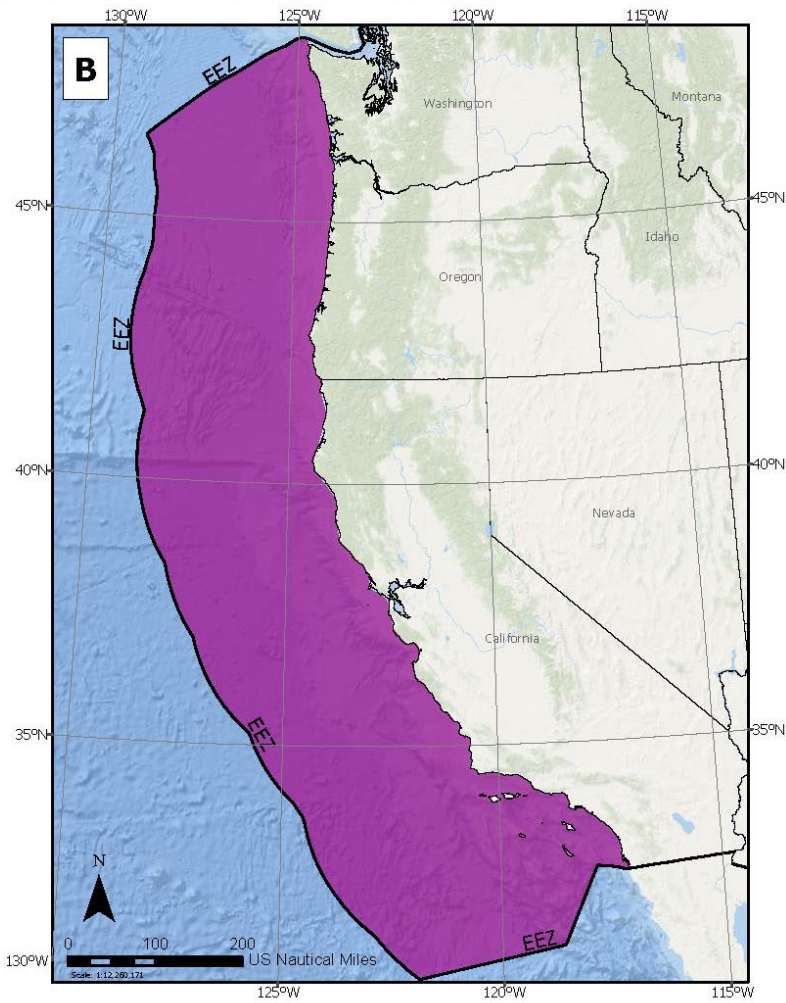
Figure 4. Albacore tuna (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021. *Thunnus alalunga.* **The IUCN Red List of Threatened Species. Version 2022-2.)**

Figure 5. Bigeye tuna (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021. *Thunnus obesus*. The IUCN Red List of Threatened Species. Version 2022-2.)

Figure 6. Pacific bluefin tuna (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021. *Thunnus orientalis***. The IUCN Red List of Threatened Species. Version 2022-2.)**
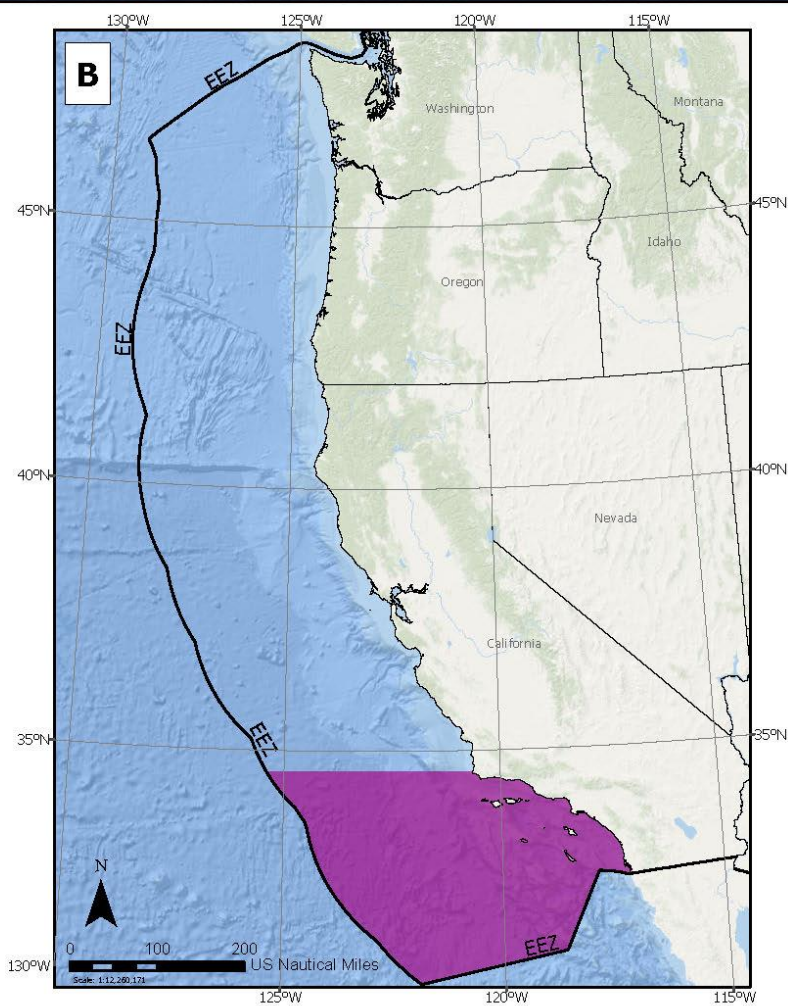
Figure 7. Skipjack tuna (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021. *Katsuwonus pelamis*. The IUCN Red List of Threatened Species. Version 2022-2.)

Figure 8. Yellowfin tuna (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021. *Thunnus albacares*. The IUCN Red List of Threatened Species. Version 2022-2.)
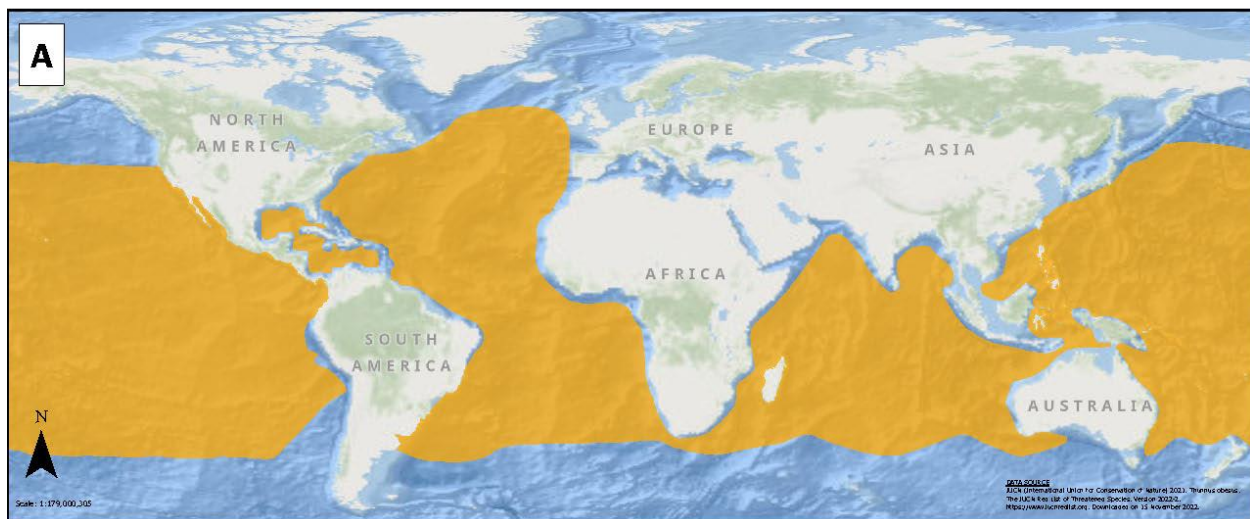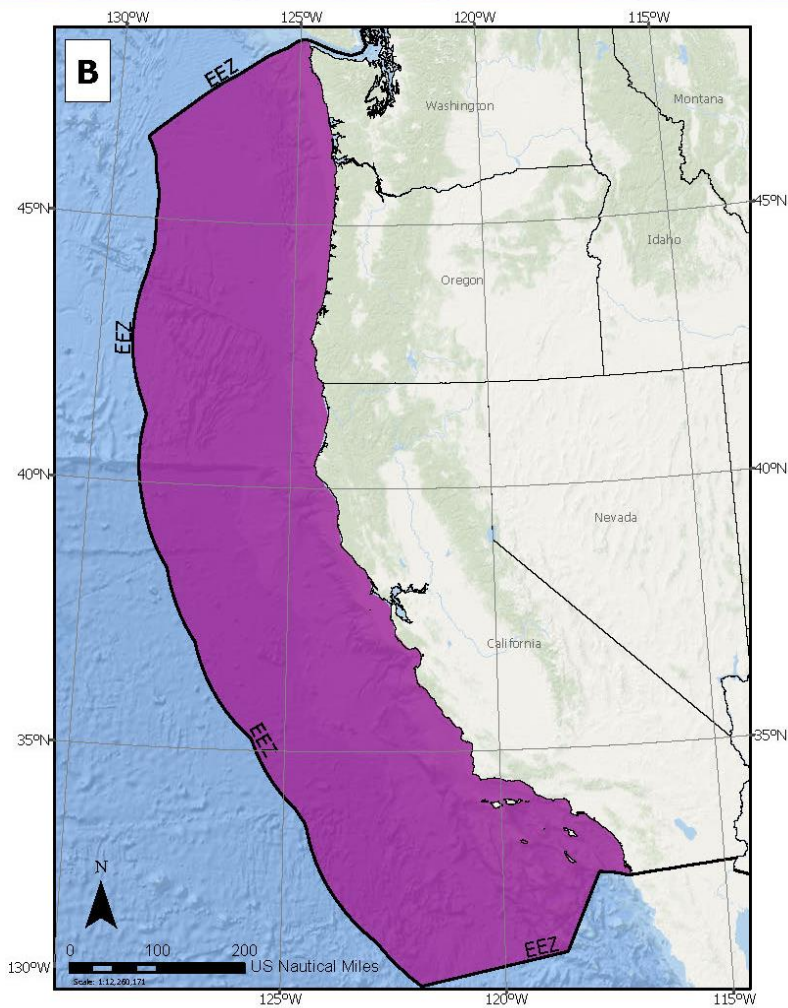
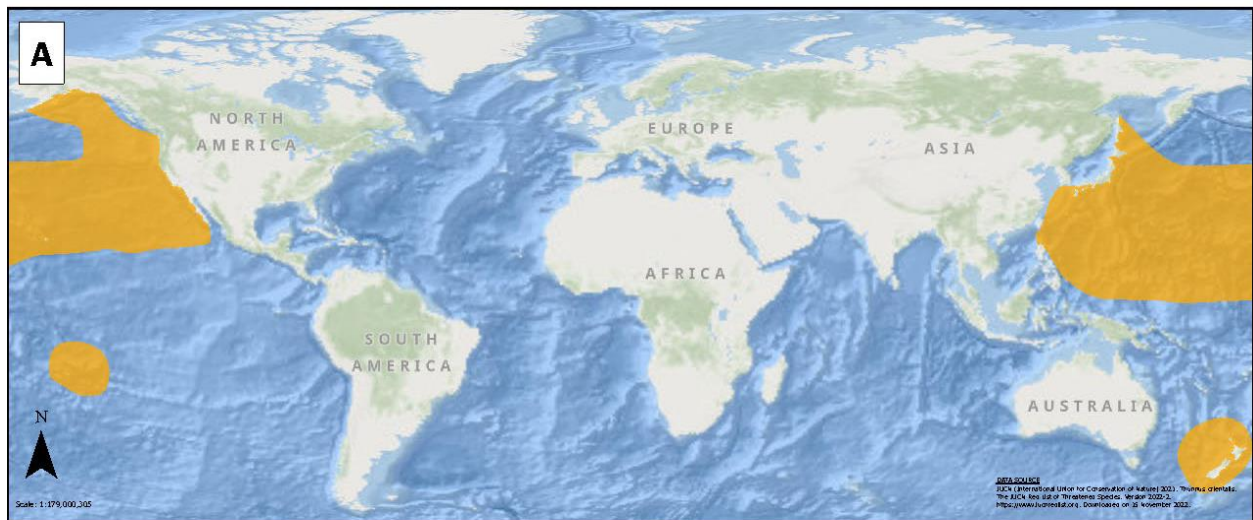**Figure 9. Striped marlin (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021.** *Tetrapturus audax***. The IUCN Red List of Threatened Species. Version 2022-2.)**

Figure 10. Swordfish (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2021. *Xiphias gladius.* **The IUCN Red List of Threatened Species. Version 2022-2.)**
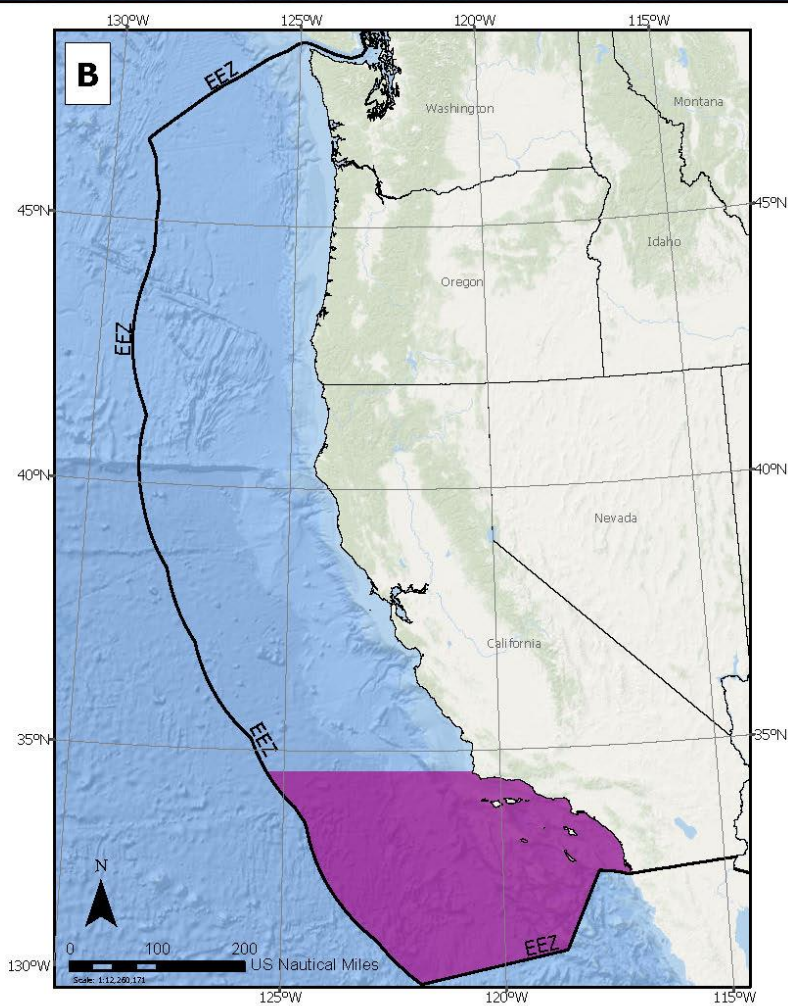
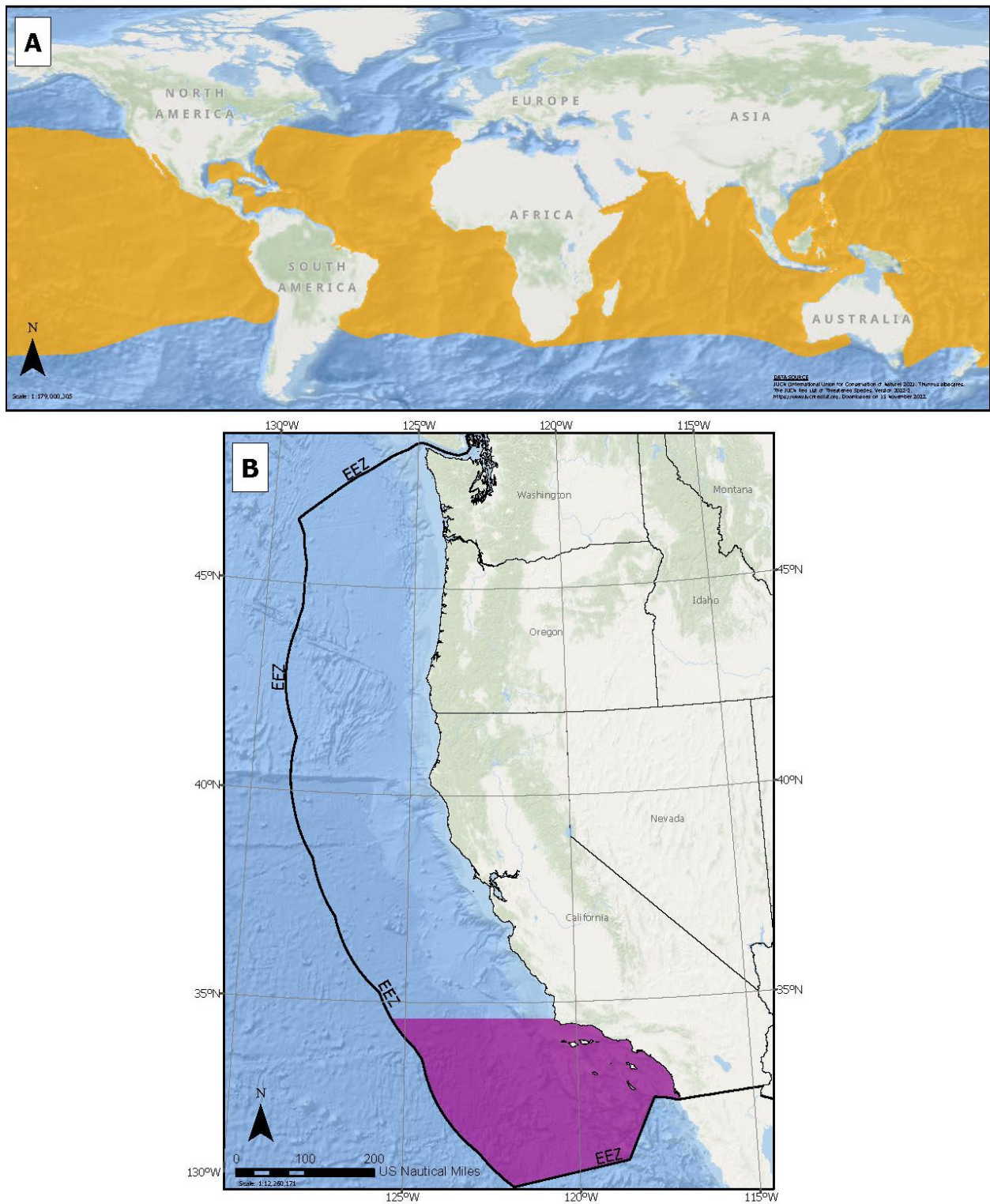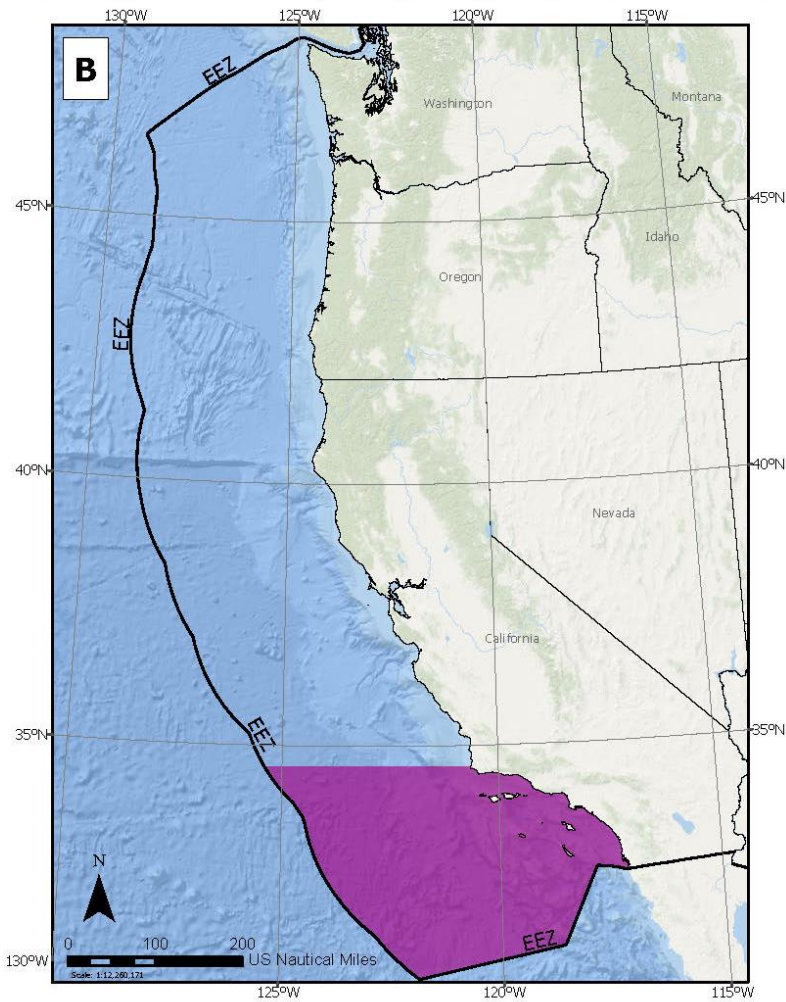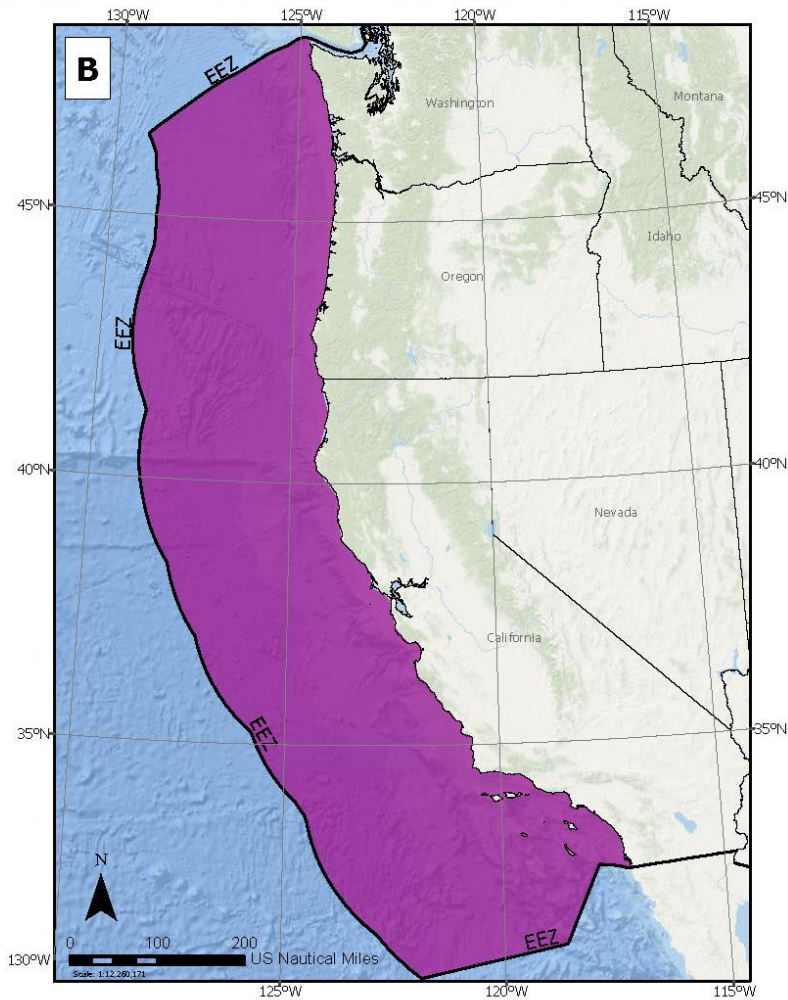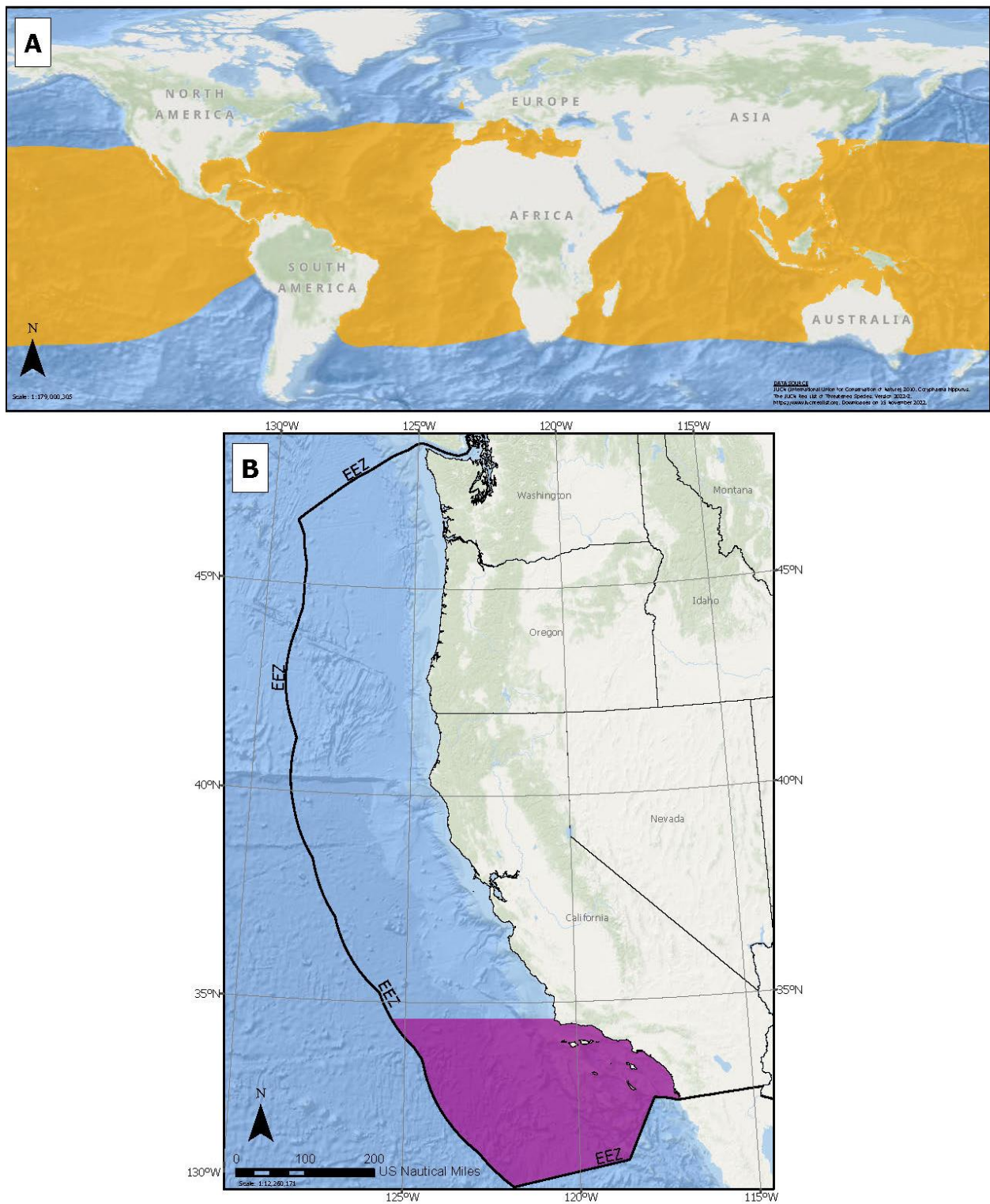**Figure 11. Dolphinfish (dorado, mahimahi) (a) global range and (b) essential fish habitat. (Global range data source: IUCN (International Union for Conservation of Nature) 2010. *Coryphaena hippurus*. The IUCN Red List of Threatened Species. Version 2022-2.)**

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