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Importance of Bahia Sebastian Vizcaino as a nursery area for white sharks (*Carcharodon carcharias*) in the Northeastern Pacific: A fishery dependent analysis

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ABSTRACT

In the Northeastern Pacific, immature white sharks (*Carcharodon carcharias*) have been recorded in the nearshore waters of the Southern California Bight (SCB), USA, along the Mexican coast off Baja California and throughout the Gulf of California, which makes them susceptible to incidental capture by coastal fisheries. While the SCB is considered a nursery area for white sharks, records of young-of-the-year white sharks (YOY) in Bahia Sebastian Vizcaino (BSV) off central Baja California suggest that this region could also be an important white shark nursery area, but a formal evaluation of the region's habitat function is lacking. We analyzed incidental catch records of white sharks from the US-Mexico border to BSV and evaluated whether Heupel et al.'s (2007) criteria for the identification of shark nursery areas were met for BSV. We compiled a total of 390 white shark incidental catch records between 1999 and 2013 and compared incidental catch records from the region north of Bahia Sebastian Vizcaino (NBSV; an area not considered to be a nursery ground) with those for BSV. There was a significantly higher abundance of newborns and YOY in BSV than NBSV. White shark were caught consistently throughout the year within BSV; however, the majority (70.1%) were caught between May and September. Our results are consistent with the shark nursery area criteria proposed by Heupel et al. (2007), and indicate the region between BSV to the SCB may be an important migration corridor for YOY and juvenile white sharks. Future management and conservation efforts ought to consider BSV's nursery habitat function.

1. Introduction

Juvenile shark survivorship is partially dependent upon the availability of suitable nursery areas (Yates et al., 2012; Ward-Paige et al., 2015). Identifying shark nursery areas and documenting the specific geographic areas that are essential for the preservation of threatened or endangered species (critical habitat) are important steps for the conservation and sustainable long-term management of shark populations (Heithaus, 2007). Successful management and conservation of shark populations is dependent upon implementing strategies that are conducive to successful juvenile recruitment and survivorship.

Nearshore habitats such as bays and estuaries are highly productive, have a relatively high abundance and diversity of species, some of them important for fisheries, and support large abundances of juvenile shark species, many of which utilize different habitats than those of adults (Dahlgren et al., 2006; Knip et al., 2010). As a result, these areas are often heavily targeted by fishers, and can often be degraded due to coastal development, storms and other anthropogenic impacts. Potential nursery areas for sharks were first identified based on the presence or absence of young individ-

Abbreviations: BSV, Bahia Sebastian Vizcaino (Mexico); CONAPESCA, National Commission of Fisheries and Aquaculture (translated from Spanish); JWS, juvenile white sharks with sizes ranging from 175 cm to 300 cm in total length; NBSV, North of Bahia Sebastian Vizcaino (region that extends from the Popotla to Punta Canoas fishing camps along the western coast of the Baja California peninsula); NEP, Northeastern Pacific; NWS, newborn white sharks less than 150 cm total length; SCB, Southern California Bight (USA); SDS, selected demersal species that comprise species that are caught with bottom gillnet fishing gear; YOY, young-of-the-year white sharks ranging from neonates to 175 cm total length.

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uals (Springer, 1967). Castro (1993) proposed that for aplacental viviparous sharks, nursery areas could be inferred based on the presence of gravid females, neonates and small juveniles. However, not all species have discrete nursery areas, as some species spend all life stages in the same area while others are more transient (Knip et al., 2010). Hence, the mere presence of gravid females or immature sharks in a particular habitat does not always indicate that the habitat is actually function as a nursery area (Heupel et al., 2007). Bass (1978) suggested that immature sharks might require two distinct types of nursery areas depending on their size and life stage: a primary nursery area is where sharks are born and spend the first part of their lives, and a secondary nursery area is that which is inhabited by the slightly older, but not yet mature individuals. Recently, Heupel et al. (2007) argued that this definition was ambiguous and that nursery types proposed by Bass (1978) were difficult to define geographically, as primary and secondary nurseries can spatially overlap. For example, neonates born in the primary nursery area can move to another region and subsequently return to the same area, which would then function as a secondary nursery. For this reason, Heupel et al. (2007) proposed the elimination of the terms "primary" and "secondary" and suggested that the term "nursery area" should be used to collectively represent these critical habitats. They also proposed the following three criteria for identifying nursery areas for newborns and young-of-the-year sharks: 1) the area must have a higher relative abundance of neonates and young juveniles compared to other areas; 2) immature sharks must show the tendency to remain or return to the area for extended periods; and 3) the area should be consistently used by immature sharks across years. Based on this definition, all three criteria must be met for a particular area to be considered as shark nursery habitat (Heupel et al., 2007).

The white shark (*Carcharodon carcharias*) is an apex predator with size-at-birth between 120 and 150 cm total length (TL) (Francis, 1996), and grows to a maximum length of 610 cm TL (Castro, 2012). Four different life stages have been proposed based on size and reproductive stage: 1) young-of-the-year (YOY) sharks ranging from newborn size (120 cm–150 cm TL) to 175 cm TL; 2) juvenile (JWS) sharks ranging from 175 cm to 300 cm TL; 3) sub-adult sharks that include individuals >300 cm to maturity; and 4) adult, mature sharks that are >360 cm TL in the case of males and >480 cm TL for females (Cailliet et al., 1985; Francis, 1996; Pratt, 1996; Wintner and Cliff, 1999; Malcolm et al., 2001; Martin et al., 2005). White sharks are mainly found in tropical and temperate oceans at relatively natural low population densities and their distribution varies based on their size (Compagno et al., 2005). Adult white sharks aggregate around oceanic islands that typically harbor pinniped colonies, while YOY and JWS are primarily distributed close to shore (at depths <200 m) (Weng et al., 2007; Domeier, 2012; Lowe et al., 2012; Ebert et al., 2013).

In the Northeastern Pacific (NEP), YOY, JWS and sub-adults primarily inhabit nearshore waters off California and the Baja California peninsula (Cailliet et al., 1985; Klimley, 1985; Malcolm et al., 2001; Weng et al., 2007; Santana-Morales et al., 2012; Lyons et al., 2013). Based on electronic tagging studies, it has been shown that some immature white sharks (>165 cm TL) move along the coast from the Southern California Bight (SCB), US, to Mexican waters off Baja California and sometimes into the Gulf of California (Weng et al., 2007; Weng et al., 2012). However, given the short retention of most satellite tagging deployments to date (less than 3 months), only one YOY returned to the SCB following its southern migration (Weng et al., 2007; J. O'Sullivan, *pers comm*). Using acoustic tags, five juvenile white shark tagged at SCB were detected inside Laguna Ojo de Liebre (Mexico) in the acoustic receivers array and sometime after they were detected at SCB (Lowe and Sosa-Nishizaki, *pers obs*). Mitochondrial DNA analyses, which provide information on maternally inherited genetic traits, have indicated the existence of genetic differences between immature sharks sampled in the SCB and Bahia Sebastian Vizcaino (BSV), Mexico, located in the Pacific off the central Baja California peninsula (Oñate-González et al., 2015). Given the limited number (<100) of individuals sampled by Oñate-González et al. (2015), and the present-day lack of nuclear DNA data that provides information on bi-parental inheritance, the level of population connectivity between sharks found in the SCB and Mexican waters has not been well established.

The white shark is recognized as a species vulnerable to overexploitation by the International Union for Conservation of Nature (IUCN) Red List (Hilton-Taylor, 2000), and it has been included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 2004. In Mexico, the white shark has been designated as a "threatened species" through official regulations NOM-059-SEMARNAT-2001 (DOF, 2002, 2010) and NOM-029-PESC-2006. The latter established the prohibition of intentional catch, retention and commercialization of any body part of this species (DOF, 2007). Since 2012, a shark and ray fishing closure has been established in Mexican waters between May 1st and July 31th to protect a fraction of the reproductive stock of commercially important elasmobranch species (DOF, 2012). Although the protection of white sharks was not the specific purpose of this regulation, the timing of this closure likely aids in the protection of this species since it coincides with the time of year during which JWS are found close to shore along the western coast of Baja California (Santana-Morales et al., 2012). Since February 2014, a complete fishing ban for white sharks and the mandatory release of incidental catches has been established in Mexican waters (DOF, 2014). Despite the protective regulations that have been implemented internationally and by Mexico, the incidental catch of this species still occurs in commercial and recreational fisheries (Malcolm et al., 2001; Dudley and Simpfendorfer, 2006; Lowe et al., 2012; Santana-Morales et al., 2012; Dicken and Booth, 2013; Lyons et al., 2013; Curtis et al., 2014). This continued pressure supports the need to assess their population status, fishery interaction rates, and identify critical habitats, including nursery areas.

Based on the size distribution and seasonality in catch records, Klimley (1985) proposed that the SCB was a parturition and nursery area for white sharks, and reported that adult white sharks were most frequently seen and caught in central and northern California during September to December, and that YOY were only caught south of Point Conception during the summer. More recently, JWS have been well documented in nearshore waters between Point Conception, California, and BSV in Baja California (Weng et al., 2007; Domeier, 2012; Lowe et al., 2012; Santana-Morales et al., 2012). Artisanal and industrial fisheries on the west coast of Baja California target coastal and pelagic elasmobranchs, bony fishes and invertebrates using a variety of fishing gears (Sosa-Nishizaki et al., 2008; Cartamil et al., 2011). Santana-Morales et al. (2012) documented the incidental catch of YOY and juvenile white sharks along the Pacific coast of Baja California during 1999 and 2010. Eighty-three white sharks (74.7% of the total) were caught by artisanal bottom-gillnets, leading them to suggest that the continental shelf is an important habitat for YOY and JWS, and that BSV could serve as an important nursery area.

In this study, we use a robust conceptual framework with specific criteria to identify nursery habitats as defined by Heupel et al. (2007) in order to evaluate the function of BSV as white shark nursery area. We compiled all artisanal fishery-dependent catch data to date of immature white shark catches off the western coast of northern Baja California for 1999–2013, leading to the most complete YOY and JWS data set compiled for northwestern Mexico. Information about white shark nursery habitat could be used to improve protection and reduce mortalities associated with commercial fisheries.