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Thesis of
Emma M. Brennan

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science
Marine Science

Nova Southeastern University
Halmos College of Arts and Sciences

November 2020

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HALMOS COLLEGE OF ARTS AND SCIENCES

LIFE HISTORY, BIOLOGY, FISHERIES, AND MANAGEMENT FOR SIX LESSER KNOWN SPECIES OF HAMMERHEAD SHARKS (FAMILY: SPHYRNIDAE)

By:

Emma M. Brennan

Submitted to the Faculty of
Halmos College of Arts and Sciences
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in

Marine Biology

Nova Southeastern University

November 2020

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Abstract

Historically, sharks were not considered to be of high commercial value due to low demand and modest catch rates in comparison to bony fishes. However, with recent heightened demand for shark products, their economic value has increased profoundly, which has led to overharvesting of many species. Sharks are considered as a K-selected species, which includes life history traits such as slow growth, late maturity, few offspring, and slow reproductive rates. Given the slow intrinsic rate of increased characteristic of most species of sharks, few species can support heavy fishing pressure and are vulnerable to drastic population declines as a result of fishing. For many species of sharks, even modest rates of mortality in fisheries (either targeted or as bycatch) may lead to population declines and require decades for recovery from overfishing. Hammerhead sharks (family Sphyrnidae) in particular have experienced large population declines over the past several decades, estimated as high as 86% throughout the world oceans, primarily due to overfishing. The vulnerability of hammerhead sharks to overfishing results from a combination of factors, including relatively slow rates of population growth and low post-release survivorship of for individuals captured and released in fisheries. Research on hammerhead sharks has focused almost exclusively on three large species: scalloped hammerhead (*Sphyrna lewini*), great hammerhead (*Sphyrna mokarran*), and smooth hammerhead (*Sphyrna zygaena*). The other six species of hammerheads – winghead shark (*Eusphyra blochii*), scalloped bonnethead (*Sphyrna corona*), Carolina hammerhead (*Sphyrna gilberti*), scoophead (*Sphyrna media*), bonnethead (*Sphyrna tiburo*), and smalleye hammerhead (*Sphyrna tudes*) – have received much less attention and the biology is poorly understood in comparison to the three large species. Limited information about the biology of the six lesser known species, particularly in regards to life history characteristics, interactions with fisheries, and status of their populations has hindered assessments of the status of their populations and curtailed the ability to enact well-informed policy for management of their populations. This thesis reviews information on the biology of six lesser known species of hammerhead sharks and documents the current knowledge of interactions with fisheries around the world, with the overall goal of collating and summarizing knowledge for these species and contributing information useful for improved management of their populations.

Keywords: Sphyrnidae, hammerhead, *Eusphyra blochii, Sphyrna, corona, media, gilberti, tiburo, tudes*

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Introduction

Historically, shark species were of low economic value in world fishery markets due to low demand (Ferretti et al. 2010). Beginning in the 1940s, shark liver oil increased in demand during World War II as a source of vitamin A (Castillo-Geniz et al. 1998). Shark fisheries developed as the demand for shark liver oil increased and led to the targeting of several large shark species, particularly in the Gulf of California (Osorio-Tafall 1943). In addition to liver oil, sharks are captured in a wide variety of recreational and commercial fisheries for their meat, fins, liver, gill rakers, and skin for leather (Rose 1996; Stevens et al. 2005). Since the 1950s, there has been a significant expansion in commercial shark fisheries due to advances in technology (e.g., nylon netting, sonar, and fish freezing (Zerbe 2013)). Although sharks are targeted in some commercial fishery efforts, a substantial portion of sharks occur in fisheries as bycatch. Additionally, public support of shark fisheries as an underutilized fishery resource resulted in substantial increases in directed fisheries for sharks (Shiffman and Hammerschlag 2016). A steady growth of 6% per year in demand for shark fins, mainly driven by Asia's growing economy, has further intensified shark fisheries in numerous locations around the world (Rose 1996; Clarke 2004; Clarke et al. 2006; Lack and Sant 2011). Most shark fisheries are highly unregulated, this coupled with unchecked bycatch, have resulted in overexploitation and unsustainable fishing practices (Olsen 1959; Graham et al. 2001; Clarke et al. 2006).

Many elasmobranch populations are subjected to rapid decrease when targeted or captured as bycatch (Ripley 1946; Devine et al. 2006). With the high rate of exploitation, shark populations have been drastically affected, with shark stocks thought to have decreased by 90% over the past 68 years (World Wildlife Fund). Data from those few species that have long term catch records indicate that several shark species have suffered severe population declines of more than 50% (Baum et al. 2003). According to the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species, ten species of sharks in the order Carcharhiniformes are considered critically endangered, 12 species are endangered, and 22 species are vulnerable (IUCN 2019). Some of the species that are listed as endangered by the IUCN include smoothback angelshark (*Squatina oculata*), winghead (*Eusphyra blochii*), whale (*Rhincodon typus*), great hammerhead (*Sphyrna mokarran*), and zebra sharks (*Stegostoma fasciatum*) (IUCN 2019).

Most shark species are vulnerable to overexploitation due to their predominately K-selected life history traits and they are unable to tolerate high levels of fishing pressure or recover easily when overfishing occurs (MacArthur and Wilson 1967; Frisk et al. 2001; Cortés 2002; Gallucci et al. 2006). K-selected life history patterns are characterized by slow growth rates, low fecundity, delayed sexual maturity, large adult sizes, long lifespans, and long gestation periods (Holden 1972; Holden 1977; Compagno 1990). While K-selected traits such as late sexual maturity tend to favor growth and increased fecundity, which contribute to higher juvenile survivorship, they can also have disadvantages (Stearns 1992; Smith et al. 1998). Shark species with slow rates of reproduction and low fecundity cannot withstand heavy exploitation and typically experience population declines when they are captured in even moderate numbers in commercial fisheries (Cortés 2000). Once a shark stock has been affected by unsustainable fishing, recovery can be very lengthy, with the threat of extinction if harvesting is left unregulated (Hoenig and Gruber 1990).

As many as 100 million sharks may be killed annually with estimates as high as 273 million sharks killed per year (Bonfil 1994; Worm et al. 2013). About 26 million and possibly up to 76 million of these sharks are killed for their fins alone (Clarke et al. 2006). The number of sharks caught annually in artisanal and recreational shark fisheries are still uncertain (Worm et al. 2013). Fifty-seven percent of all sharks are caught as bycatch in commercial fisheries targeting other marine life (Ferretti et al. 2010). Shark landings increased notably by 227% between 1950, when landings were first recorded and 2003. Between 2003 and 2011 shark landings declined by 15% (FAO 2013). This decrease in shark landings is thought to reflect not a decrease in fishing pressures but changes in ecosystem dynamics, mainly resulting from unsustainable fishing practices (Davidson et al. 2016). The average annual shark catch rate is between 6.4% and 7.9% of the overall population, whereas the rebound rate, calculated from 62 shark species life history traits, is on average 4.9% per year. Therefore, the exploitation rate of shark fisheries surpasses their rebound rate by 1.5% – 3.0% annually (Worm et al. 2013). These practices have generated insurmountable fishing pressure for a majority of shark populations (Bonfil 1994; Rose 1996; Clarke et al. 2006). Estimates as high as 96% of all elasmobranch species are threatened by fishing efforts, of which 31.7% are directly targeted in commercial fisheries (Ferretti et al. 2010; IUCN 2010).

Although many species of elasmobranchs have been adversely affected by fishing, some groups that have small population, limited distribution, and slow growth are particularly

susceptible to fishing pressure. One of the most overexploited shark groups is the hammerhead sharks (family Sphyrnidae). The family Sphyrnidae is comprised of two genera and nine species, five of which are considered small bodied (Quattro et al. 2006; Cavalcanti 2007; Quattro et al. 2013; Gallagher et al. 2014). Sphyrnids are among the more morphologically recognizable families, with a cephalofoil that expands laterally to form a unique hammer or shovel shape. These cranial morphologies can range from wide and slender to curved and spade-like, distinguishing these species from the rest in the order (Gilbert 1967, Compagno 1984, Castro 2011). Sphyrnids are exploited in a multitude of fisheries. Shark fins are the most expensive seafood items in the world and can cost upwards of $700 per kg in Hong Kong’s fin trade depending on the species (Clarke 2004). The fins from large bodied hammerhead species could fetch up to $100-120 per kg at the market because of their large fin size and high elastin fiber content within the fin (Tsuchiya and Nomura 1953; Abercrombie et al. 2005). Larger bodied hammerheads such as, *Sphyrna gilberti*, are harvested for their fins in Asia’s shark fin trade (Abercrombie et al. 2005; Clarke et al. 2006; Hareide et al. 2007). Smaller bodied hammerheads are not targeted for their fins because of their small size, however they have been increasingly sought after for their meat (Castro et al. 1999; Clarke et al. 2006; Hareide et al. 2007; Cortés et al. 2016).

Hammerhead populations have been in decline for many years due to overexploitation (Perez-Jimenez 2014). The global hammerhead population has declined by an estimated 89% since 1986 (Baum et al. 2003) and since 1952, their populations have declined by as much as 76% to upwards of 99% (Myer et al. 2007; Baum and Blanchard 2010; Ferretti et al. 2010). Not surprisingly considering this level of population decline, the majority of hammerhead species are either listed as either endangered or data deficient on the IUCN Red List and several are included in CITES Appendix II (CITES 2014; IUCN 2018)

The family Sphyrnidae is one of the most vulnerable shark species to be overexploited because of their low recovery capabilities (Smith et al. 1998). They have a long reproductive life, slow growth rate, small litter size, and delayed maturity, which increases their susceptibility to overfishing (Pratt and Casey 1990; Stearns 1992; Smith et al. 1998). These species have a long reproductive life which allows for a longer life span and larger adult sizes. With the increase adult sizes, this makes it possible for females to produce larger and more fit offspring. These offspring will be harder to prey upon and in return increase the likelihood of maturing to a reproductive age (Stearns 1992). Regrettably, this delayed maturity lowers the chance for the juveniles to reproduce

and assist in potential population growth (Stearns 1992; Smith et al. 1998). They are susceptible not only because of their life history patterns but also their complex migration patterns and preferred distribution (Heupel and Simpfendorfer 2005). Hammerheads typically inhabit tropical and subtropical inshore continental shelf regions where they are heavily fished (Robbins et al. 2006; Hayes et al. 2009; Bornatowski et al. 2011). When caught, targeted or accidental, hammerheads have a high rate of at-vessel and post-release mortality, which further amplifies their population decline (Butcher et al. 2015; Gallagher et al. 2014). Their habitats are also severely affected by pollution and habitat degradation (Silva Junior et al. 2012; Moura et al. 2013). Though some hammerhead populations are listed as endangered and other species exhibit declining populations, inclusion in national and international management or trade agreements i.e. CITES is largely limited to the three large species of hammerheads (Chapman et al. 2009). Management and conservation efforts skewed towards the three large species of hammerheads illustrates the paucity of information available on lesser hammerhead species and application of data on the status of their populations towards management.

Given concern over declining shark populations, there has been increased interest in managing their populations sustainability. Sustainable management of shark populations requires information on their biology to evaluate the status of stocks and provide recommendations for acceptable levels of exploitation, as well as specific management measures for each stock. Accurate stock assessment of a stock requires knowledge of the biology (particularly life history traits) and occurrence in fisheries for the species being evaluated. With the exception of the three large species of hammerheads, understanding of the biology and interactions with fisheries for hammerhead sharks is poorly understood.

Attempts to manage and conserve declining populations of sharks have been impeded due to the lack of overall data for those species that are integral in commercial and recreational fisheries (Castro et al. 1999). Data is deficient not just in life history knowledge, but also in species-specific catch data (Castro et al. 1999). Most fisheries target multiple species where landings are combined, and species are not reported correctly (Graham et al. 2001). Historically, when fishermen would land sharks, they would not report these numbers but, recently shark landings have begun to be documented (Bonfil 1994; Barker and Schluessel 2005; Lack and Sant 2006; Ferretti et al. 2010). Catches, if reported, are not to a species-specific level due to the difficulties of identification between species. Furthermore, most fishermen fail to differentiate between small shark species

and juveniles of larger species that are likely to be more susceptible to overexploitation (Moore et al. 2012). Alternatively, shark catches are combined into either a generic "shark" category, a broad elasmobranch class, or into family groups (Shotton 1999, Clarke et al. 2004; Abercrombie et al. 2005). Only 15% of shark landings have included species-specific data rather than being classified to a higher taxonomic level (Clarke et al. 2006; Lack and Sant 2006; Dulvy et al.2008). Reporting species-specific catches is even more difficult when sharks are landed either finless or headless. The body-part removal have become commonplace in commercial fisheries and make identification of carcasses, detached fins, meats, and cartilage near impossible (Castro 1993; Smith and Benson 2001; Shivji et al. 2002). This lack of documentation of shark catches has resulted in a data deficiency for assessment of many populations of sharks throughout the world. (Stevens et al. 2000; Graham et al. 2001; Myers &Worm 2005; Dulvy et al. 2008; Ferretti et al. 2008).

As with most sharks, sphyrnids when caught are typically not reported or categorized incorrectly. For example, shark finning is illegal within USA waters though it is suspected that some fishermen fin hammerheads and keep the fins because of the high socio-economic value but do not report the catch as landed or bycatch (Abercrombie et al. 2005). If reported, hammerhead shark due to their distinctive head shape are recorded to genus level, but rarely species-specific (Abercrombie et al. 2005). While hammerhead species can be easily distinguishable from other shark orders, they can be difficult to tell apart within the Sphyrnidae family (Gilbert 1967). Hammerhead sharks display a wide variety of cranial morphology, including eye positions, presence of nares, and general shape of the cephalofoil (Mara et al. 2015). Most distinguishable traits are minuscule and can make species-specific identifications in the fisheries unfeasible. This incorrect reporting can cause skews in population data which in turn makes it more difficult to measure the fisheries expansion and bycatch rates (Clarke 2004; Abercrombie et al. 2005).

As hammerhead shark populations continue to decline, the need for information on their biology, particularly aspects of their life history that are applicable to supervision of populations, is critical for effective management. Such information is required to sustainably manage shark populations and to evaluate catch rates with respect to reproductive potential and population growth. However, long term biological data necessary for assessment of populations is scarce for many species of sharks (Baum et al. 2003). Most hammerhead research has revolved around the three larger hammerhead species: scalloped hammerhead (*Sphyrna lewini*), great hammerhead (*Sphyrna mokarran*), and smooth hammerhead (*Sphyrna zygaena*). Understanding where data is

inconclusive is imperative to the future and survival of the lesser known six species of hammerhead sharks.

The goals for this thesis are to compile an encyclopedic set of information on the biology and interaction with fisheries for six lesser known species of hammerhead sharks. Summaries for these six species of hammerheads will provide a source of information for advancement and enhancement of management of their populations and will also include a list of what information on their biology is lacking as a resource for future directions of study for these species.

Methodology

Study species

There are nine species of hammerhead sharks (Gilbert 1967; Compagno 1984; Quattro et al. 2013; Gallagher et al. 2014), including three well-studied species (scalloped *Sphyrna lewini*, great *Sphyrna mokarran*, and smooth *Sphyrna zygaena*) and six lesser species of hammerhead sharks; the winghead shark (*Eusphyra blochii*), scalloped bonnethead (*Sphyrna corona*), Carolina hammerhead (*Sphyrna gilberti*), scoophead (*Sphyrna media*), bonnethead (*Sphyrna tiburo*), and smalleye hammerhead (*Sphyrna tudes*); were reviewed in order to understand where data is deficient (Figure 1).

Eusphyra blochii and *S. tiburo* are both easily recognizable hammerhead species with their very distinctive cephalofoils. As can be inferred by the name winghead, *E. blochii* has lateral blades that are very narrow, broad, and wing-like, while *S. tiburo* has a unique and narrow shovel shaped head (Gilbert 1967; Compagno 1984). *Sphyrna corona*, *S. media*, and *S. tudes* are morphologically similar and share common features (Gilbert 1967) making them almost indistinguishable from one another. Ichthyologist Carter R. Gilbert was the first to speculate that *S. gilberti* was different from *S. lewini* (Gilbert 1967). However, there are no external diagnostic features that could be helpful in distinguishing between *S. lewini* and from *S. gilberti* (Quattro et al. 2013). All six species are extremely different and have a wide range of data available for each individual. Focusing on where data is deficient can aid with management plans and conservation methods.

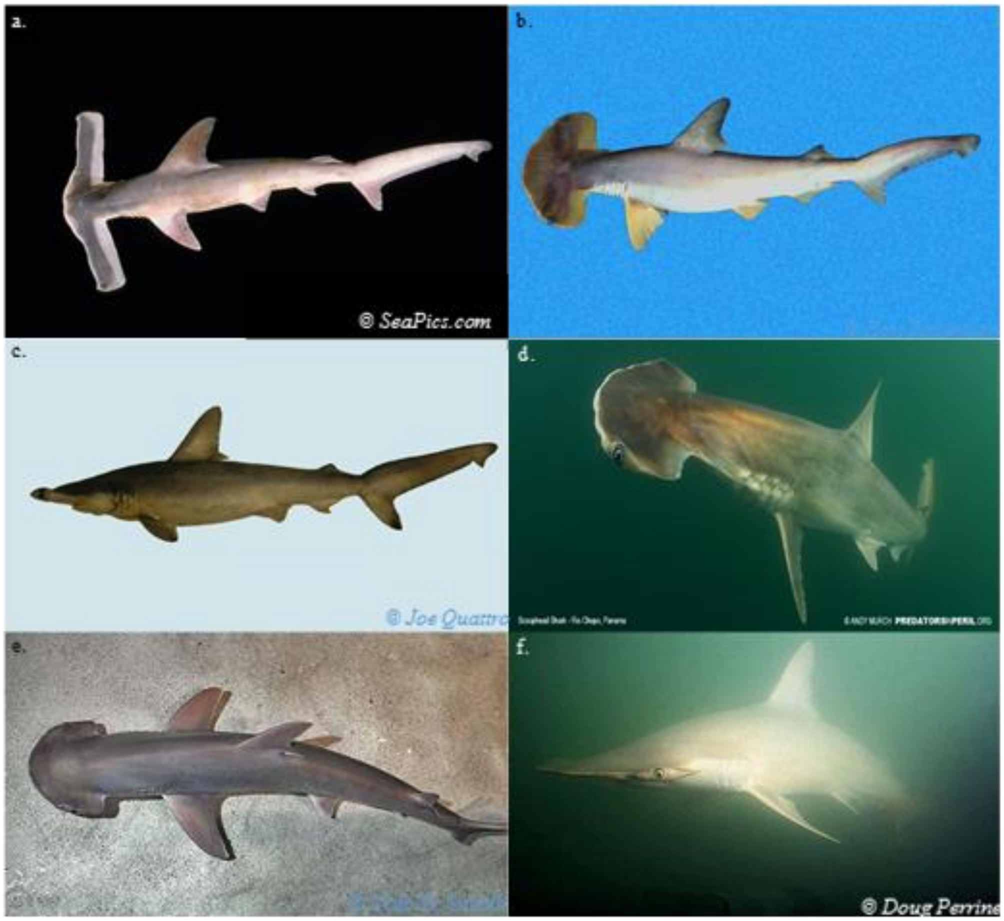


Figure 1. Study species (a) *Eusphyra blochii* (b) *Sphyrna corona* (c) *Sphyrna gilbert* (d) *Sphyrna media* (e) *Sphyrna tiburo* (f) *Sphyrna tudes*

Data Collection

An extensive scientific literature search for species-specific background and fisheries information on six species of sphyrnids was completed. Population data for all six species were collected from open sources. Documented species distribution coordinates were collected from Fishbase, Global Biodiversity Information Facility (GBIF), and from Ocean Biogeographic Information Systems (OBIS). These platforms are global open access databases containing marine biodiversity information that has been published by museums and institutions for science conservation and sustainable development. Each species except *S. gilberti* had known occurrence coordinates which was corroborate with the literature findings (Table 1).

Table 1. Known occurrence data collected from open sources with environmental predictors and geographical coordinates.

	E. blochii	*S. corona*	*S. gilberti*	*S. media*	*S. tiburo*	*S. tudes*
GBIF	51	37	0	114	130	26
FishBase	3	0	0	0	145	14
OBIS	39	10	0	16	2	0
Total Occurrences	93	47	0	130	277	40

Distribution probabilities were collected from a generated model-based prediction database, AquaMaps. These generated predictions were determined from the available occurrence data provided by GBIF, FishBase, and OBIS. The models were constructed by estimating known species data such as environmental limitations which include ranges of depth, salinity, temperature, primary production, and association with coastal areas or sea ice. For hammerhead species the association was with distance from coastal areas over the presence of sea ice. Each point was then assigned a probability based on how well the local environmental and habitat parameters suited the known species preference. Probability range was from 0 to 1, with 1 being highest probably of occurrence and 0 meaning low probability of occurrence. In total, there was a range of predictor data for each species; *E. blochii*: 3543, *S. corona*: 359, *S. media*: 1689, *S. tiburo*: 1872, and *S. tudes*: 923 predictions. As for *S. gilberti* predictions were taken from *S. lewini* predicted distribution in their proposed distribution range (Abercrombie et al. 2005; Quattro et al. 2006; Chapman et al. 2009; Quattro et al. 2013).

Global Capture Production data was taken from the Food and Agriculture Organization of the United Nations (FAO) Fisheries and Aquaculture Department. This database contains shark landing statistics by regions and species/group dating back to 1950 and continues through 2017. Regions were selected based on where each species could potentially inhabit. Once the regions were designated per species, reported catch data from the FAO Global Capture Production database were selected. When countries report catch data to FAO, there are a number of categories they can report within. The first path is a general overall grouping that can range from aquatic plants, whales, or even miscellaneous aquatic animals. For the purpose of this study, marine fishes data was utilized. Within in this group, there are numerous subcategories which include marine fishes not identified - cods, and sharks/rays/chimaeras. From this point, within the subcategories

of species-specific catch data available, it will be presented within the subcategory folder. Five of the hammerhead species higher taxonomic level categories were chosen because species-specific data was not available. The best match FAO categories were "Sharks, rays, and Chimaeras" and "Hammerhead sharks, etc. nei". For most of the species the data categories were vague and only one species, *S. tiburo*, had species-specific catch data was available. While FAO is the most utilized database for fisheries data (Friedman et al. 2018), it has been noted that China revised their 2006 production statistics to reduce their reported catch by 13% based on its Second National Agriculture census conducted in 2007. China also subsequently revised and reduced their capture data going back to 1997 (FAO 2019).

Mapping data

QGIS Desktop version 3.4.12 was used to model known species distribution, probability distribution, population density, predicted population density, fishing pressure, and marine protected areas coverage maps. To ensure consistency, an identical world map was used for all species colored with grey #7d8b8f. A base world map was inserted by entering "world" in QGIS coordinate box at the beginning of each new project. The coordinates for all maps were the standard global projection of EPSG: 4326 – WGS 84. Each map was made once per species.

The first series of maps were species distributions both known and predicted. The data collected from Aquamaps, FishBase, GBIF, and OBIS species were utilized to construct population maps. For the population point data, comma separated values (CSV) files were imported as a new delimited text layer with the encoding UTF-8. The X field was defined as the center longitude and the Y field was defined as the center latitude. The geoprocessing tool was then used to find the symmetrical differences and eliminate any erroneous data points. The input layer was the population point data and overlay was the world map. Using the map as the overlay removed any points that were located on land. For the known population distribution map, points symbology was changed to a vibrant green #16ff01. The predicted population point data symbology was also changed but from single symbols to categorized. In order for the correct information to become categorized, the column 'overall probability' was chosen to be classify from the predicted population point data attribute table. The color ramp blue was used to classify the probabilities. Different shades of blue were assigned to the probabilities with the darker blue

shade designating the areas with higher probability of the species occurring and the lighter blue shade denoting that there would be a less likely presence.

The next set of maps were the population density maps, known and predicted. To create heat maps, a kernel density estimation program within QGIS was utilized. For the actual species population density map the known occurrence point data was used as the designated points required to run the kernel density plot. A radius of a two degree buffer was used for all density maps. Once populated, the heat map's symbology was changed from single band gray to single band pseudo color. The color ramp chosen was magma, where population hot spots were in a bright white and less populated areas tapered off to black. The same steps were repeated for predicted population density maps except with the modified predicted population point data. The symbology was a little different as well. Since there were more data points to work with, a more distinct color ramp was applied. The inverted spectral color ramp was applied, showing high density areas in red and less dense areas in light blues.

The following was to generate fishing pressure maps per species. To start, exclusive economic zones (EEZs) were used to designate fishing areas. World EEZs volume 10, updated 2/21/2018, were utilized from Marine Regions open source. The shapefile was added in QGIS as a vector layer with the standardized UTF – 8 encoding. EEZs that were going to be evaluated were chosen based on the predicted population density maps per species not just the known population density. If the species had a potential of being found within that zone, fishing pressures were assessed (Table 2).

Table 2. Regions evaluated for each species of lesser known hammerhead sharks.

Species:	Regions:
Eusphyra blochii	<u>African:</u> Comoros, Madagascar, Mauritius, Mayotte, Reunion, Seychelles, and Somalia <u>Asian</u>: Andaman and Nicobar, Cambodia, China, India, Indonesia, Japan, Malaysia, Maldives, Myanmar, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam <u>Middle East</u>: Bahrain, Iran, Kuwait, Oman, Yemen, Qatar, and United Arab Emirates <u>Oceania:</u> Australia, Christmas Island, Cocos island, Micronesia New Guinea, Palau, and Guam
Sphyrna corona	<u>Central American</u>: Costa Rica, El Salvador, Guatemala, Mexico, Nicaragua, and Panama <u>South American</u>: Colombia, Ecuador, Galapagos, and Peru
Sphyrna gilberti	<u>North American</u>: United States of America <u>South American</u>: Brazil
Sphyrna media* and *Sphyrna tiburo	<u>Central America</u>: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, and Panama <u>North American</u>: Bermuda and United States of America <u>South American</u>: Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, Uruguay, and Venezuela <u>Caribbean:</u> Anguilla, Antigua, Aruba, Bahamas, Barbados, Bonaire, British Virgin Island, Caymans, Cuba, Curaçao, Dominica, Dominica Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Saba, Saint Barthelemy, Saint Martin, Sint Eustatius, Saint Kitts, Saint Lucia, Saint Maarten, Saint Vincent, Trinidad and Tobago, Turks and Caicos, and US Virgin Island
Sphyrna tudes	<u>Middle East</u>: Israel, Lebanon, Syria, and Turkey <u>European</u>: Albania, Bulgaria, Croatia, Cyprus, France, Greece, Italy, Malta, and Montenegro <u>African</u>: Algeria, Egypt, Libya, and Tunisian <u>North American</u>: Bermuda <u>South American</u>: Argentina, Brazil, Colombia, French Guiana, Guyana, Suriname, Uruguay, and Venezuela <u>Caribbean</u>: Anguilla, Antigua, Aruba, Barbados, Bonaire, British Virgin Island, Curaçao, Dominica, Dominica Republic, Grenada, Guadeloupe, Haiti, Martinique, Montserrat, Saba, Saint Barthelemy, Saint Martin, Sint Eustatius, Saint Kitts, Saint Lucia, Saint Maarten, Saint Vincent, Trinidad and Tobago, Turks and Caicos, and US Virgin Island

EEZs that overlapped with species possible range were then exported as their own vector layer. This made it possible for each individual zone to be manipulated. Each zone was then named based on which territory owned it. Once EEZs were separated and named, each zone was researched individually to see what types of fisheries occurred within that zone. Fishery data collected from FAO Fisheries and Resources Monitoring Systems, FAO Fisheries and Aquaculture database, and literature determined which specific regions were assigned which colors. The colors were based on the following categories; shark sanctuaries (green: #4daf4a), sharks fished but species not targeted (orange: #ff7f00), species specifically targeted and/or noted that the species is landed frequently as bycatch (red: #e41a1c), and data deficient (yellow: #fffb01). All of these colors were replicated for each species to ensure consistency.

The final map set was MPA coverage and protection level. MPA data was pulled from MPAtlas which is a product of the Marine Conservation Institute. MPAs shapefile, last updated October 2019, was imported as a vector layer with the standardized UTF – 8 encoding. MPAs were selected based on their proximity to probability population density range and exported to their own species-specific vector layer. The symbology was changed to categories and the 'IUCN categories' column for attributes table was selected. Each MPA was sorted based on the protection category IUCN has assigned them (Table 3).

Table 3. IUCN marine protected area categories definitions.

MPA Categories	Definition
Ia: Strict Nature Reserve	Strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphical features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring
Ib: Wilderness Area	Protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
II: National Park	Protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.
III: Natural Monument or Feature	Protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.
IV: Habitat/Species Management Area	Protected areas aim to protect particular species or habitats and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
V: Protected Landscape/ Seascape	Protected area where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI: Protected area with sustainable use of natural resources	Protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area

Most of the MPAs had been assigned into an IUCN category or are established World Heritages Sites, if not, they were designated as ‘not reported’. The color ramp selected was the invert purple. This classified the more actively protected MPAs as a dark purple and the areas not defined by the IUCN as the lighter shades.

Fisheries over years

RStudio version 1.2.1335 was utilized to plot reported catch data collected from FAO Fisheries and Aquaculture database. Some regions had fishing data going back from 1950 until 2017 but, some started reported in later years. There were certain countries for each species that did not have fishery capture data available and can be seen in Table 4.

Table 4. Regions not evaluated for each species of lesser known hammerhead sharks because no catch data was available.

Species:	**Regions not evaluated:**
Eusphyra blochii	Somalia, Cambodia, Myanmar, Sri Lanka, Vietnam, Kuwait, Qatar, Christmas Island, and Cocos island
Sphyrna corona	Galapagos
Sphyrna gilberti	NA
Sphyrna media **and** ***Sphyrna tiburo***	Anguilla, Aruba, Bonaire, Caymans, Curaçao, Dominica Guadeloupe, Haiti, Jamaica, Montserrat, Saba, Saint Barthelemy, Saint Martin, Sint Eustatius, Saint Kitts, Saint Maarten, Turks and Caicos, US Virgin Island
Sphyrna tudes	Anguilla, Aruba, Bonaire, curacao, Dominica, Guadeloupe, Haiti, Montserrat, Saba, Saint Barthelemy, Saint Martin, Sint Eustatius, Saint Kitts, Saint Maarten, Turks and Caicos, US Virgin Island

Temporal variation in shark fisheries were created to compare all shark catches by region, hammerhead shark catch by region, and shark catch vs. hammerhead catch by region. The targeted data provided for *S. gilberti* was based off *S lewini* species-specific targeted catches because they both are indistinguishable except for vertebrae count.

Results

Eusphyra blochii

Biology

Common name: Winghead and Slender hammerhead

Eusphyra blochii is one of the most divergent species within the Sphyrnidae family (Lim et al. 2010). They are sister species with the *Sphyrna* genus but are morphologically different enough to be classified as their own genus, *Eusphyra* (Feutry et al. 2016). The main taxonomical difference between these two genera is the amount of vertebrae that each species possesses. *Eusphyra blochii* have less vertebrae, (i.e. ranging from 51 to 54) than *Sphyrna*, and the vertebrae are located largely posterior to the body cavity (Gilbert 1967).

Eusphyra blochii has one of the most unique cranial morphologies of all the sphyrnids. Their hammer has immensely board and narrow lateral blades that are nearly half of its total length (Compagno 1984). The function of this broad hammer is still unknown, but it is thought to potentially increase the species sense organs (Compagno 1984; Mara et al. 2015). Other cranial morphological feature include the small eyes of *E. blochii* being anteriorly positioned on the blades, a presence of outer narial grooves, and their upper jaw has about 30 – 31 teeth while the lower jaw has 29 teeth. The first dorsal fin is further forward on the body than all other sphyrnids and their second dorsal fin is relatively tall. Furthermore, the upper precaudal pit is not crescent shaped because it is longitudinal (Gilbert 1967; Last 1994). Lastly, *E. blochii* has a coloration of grey to brown on the dorsal side, white on the ventral side, and has no distinguishing dark fin marking (Compagno 1984; Last 1994).

Life history

Eusphyra blochii is slow growing, small bodied species that can reach an average size of 169 cm total length with males reaching a maximum size 186 cm and females 176 cm (Stevens and Lyle 1989; Smart and Simpfendorfer 2016). Based on vertebral analysis, these species can live to a maximum age of 21 years with a generation length of 14 years (Smart et al. 2013, Smart and Simpfendorfer 2016). It was originally hypothesized that both male and female *E. blochii* were sexually mature at 100 cm (Setna and Sarangdhar 1949; Compagno 1984), but in the most recent studies researchers found that females measured at 100 cm were not sexually mature. However, males based on clasper calcification, are sexually mature around those sizes, 108 cm with the

smallest sexually matured male at 102 cm (Stevens and Lyle 1989; Castro et al. 1999). According to ovarian and genital conditions, females become sexually mature at 120 cm (Castro et al. 1999). It will take *E. blochii* males 5.5 years and females 7.2 years to reach sexual maturity and contribute to the population (Stevens and Lyle 1989).

Once mature, the mating season varies with location. Within Indian waters mating typically occurs during July through August. Early gestation transpires during India's monsoon seasons of September and October and parturition is from March to May (Setna and Sarangdhar 1949; Appukuttan 1978). Gestation has been estimated to be eight or nine months for the species in Indian and surrounding waters (Compagno 1984). It has been suggested that mating occurs from December to February in Australian waters. These months were proposed due to the monthly changes in male *E. blochii* gonad conditions which could be directly linked to seasonal reproduction cycles. Based on these changes it was determined that mating occurs in December through February, females ovulate in March and April, and parturition occurs in February and March. *Eusphyra blochii* individuals in Australia are thought to have a gestation lasting about 10 to 11 months (Stevens and Lyle 1989) and during this period the pregnant females are known to fight each other (Last 2002).

Eusphyra blochii are a viviparous species and when gravid females give birth, their litter size ranges from 6 – 25 pups with a mean of 11.8 pups per litter (Compagno 1984; Castro et al. 1999). This range varies because as females grow larger they will produce more offspring (Stevens and Lyle 1989; Cortés 2000). When born, the young are about 45 cm in total length (Setna and Sarangdhar 1949, Appukuttan 1978) with some pups as small as 32cm (Last 2002). Little is known about the post-partum and general sex ratio on a regional basis. In northern Australia, a study found that there was an embryonic sex ratio of 1:1 but, the post-partum ratio was significantly different. The post-partum sex ratio was 41.1% females and the rest males, insinuating the males were dominant post-partum. This study continues with sex ratios of inshore environments with results demonstrating that 35.3% of females were inshore while 63.4% were offshore. This suggests that females populate more offshore areas than inshore areas (Stevens and Lyle 1989).

Before 1989, there were no studies conducted on the diet of *E. blochii*. Compagno (1984) suggested that this species prey upon small fishes, cephalopods, and crustaceans based on their distribution. As well as what other smaller shark species fed on in those area. It was found that *E. blochii* prey on demersal fish species, crustaceans particularly clupeids and penaeids, and

cephalopods. This was deduced from a study on 287 specimens that found stomach content comprising of 92.7% contained fish, 14.3% crustaceans, and 4.5% cephalopods. These prey items suggest that this species prefers to feed at or near the seafloor (Stevens and Lyle 1989).

Distribution

There has not been much research conducted on the distribution of *E. blochii*. Most information is based on local knowledge since population surveys are rarely completed (Stevens et al. 2000). *Eusphyra blochii* are known to inhabit tropical shallow waters over the continental and insular shelf (Gilbert 1967; Steven and Lyle 1989; Last and Stevens 2009). Their distribution is typically described as an Indo-west pacific with dispersal ranging from the Persian Gulf through India, Indonesia, and south to north and western Australia (Sainsbury et al. 1984; White et al. 2008; Harry et al. 2011; Moore et al. 2012). Though the distribution information is insufficient, some environmental preferences were predicted based on their known recorded geographic locations. *Eusphyra blochii* prefer depths of 5 – 28 m, temperatures of 25.78 – 29.18 Cº, salinity of 25. 78 – 33.35 psu, and distance from land 11 – 111 km (Kaschner et al. 2019).

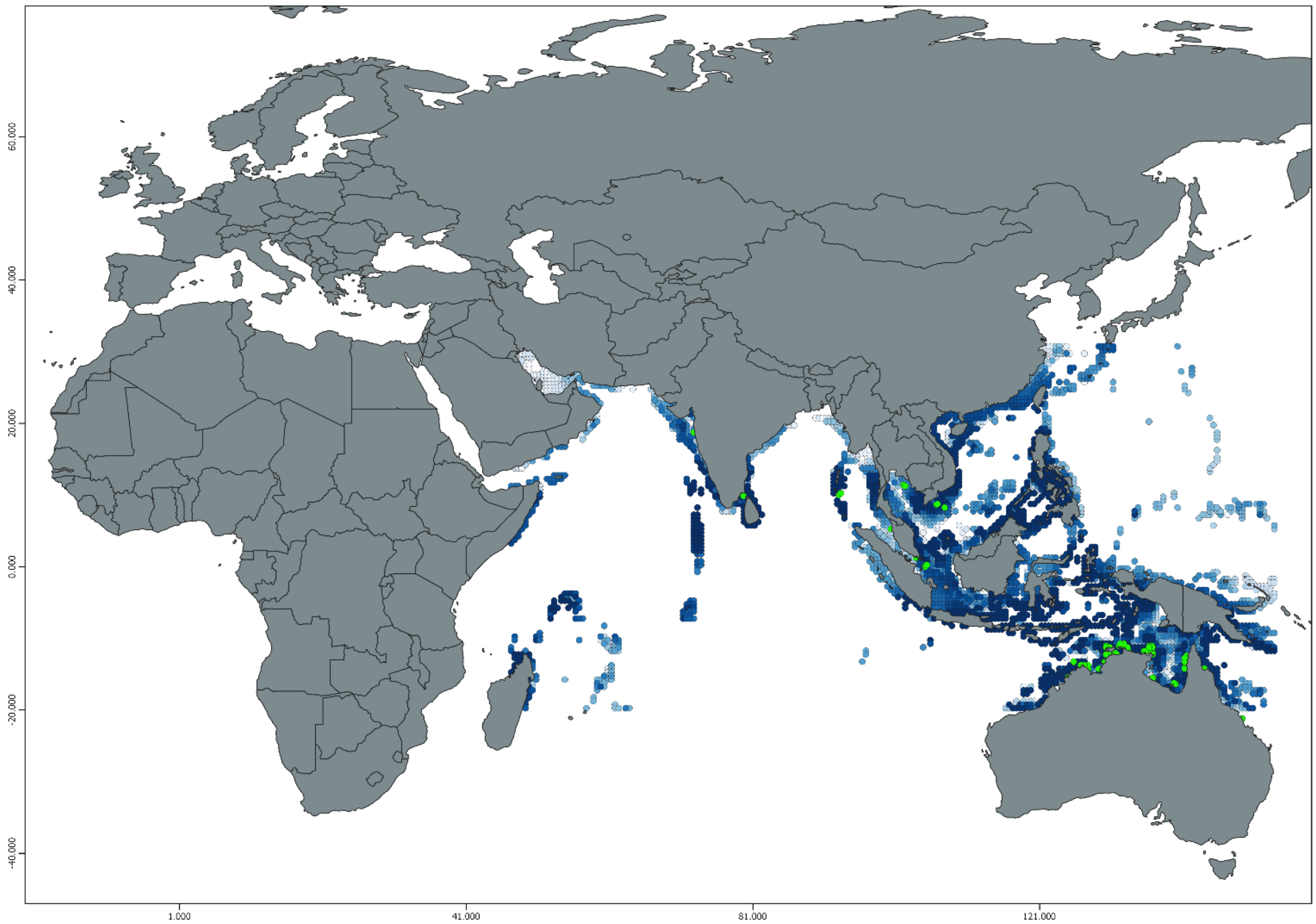


Figure 2. *E. blochii* known distribution and probability distribution. (Green) actual known recordings of species and (blue) probability distribution based on habitat preference. Dark blues indicate a high probability of occurrence lighter blues are less probable.

Eusphyra blochii could potentially have a wider distribution than originally hypothesized (Figure 2). There are numerous highly probable habitats that were not included in the historically used distribution data. These areas that *E. blochii* might be present include the Philippines, China, Japan, Somalia, the Maldives, and even Madagascar. The other commonly cited distribution areas are supported with this generated probability map. The one area of uncertainty is the Persian Gulf. Even though *E. blochii* is assumed to be present in the Persian Gulf, probability and lack of catch data suggest that this species might not inhabit this area any longer.

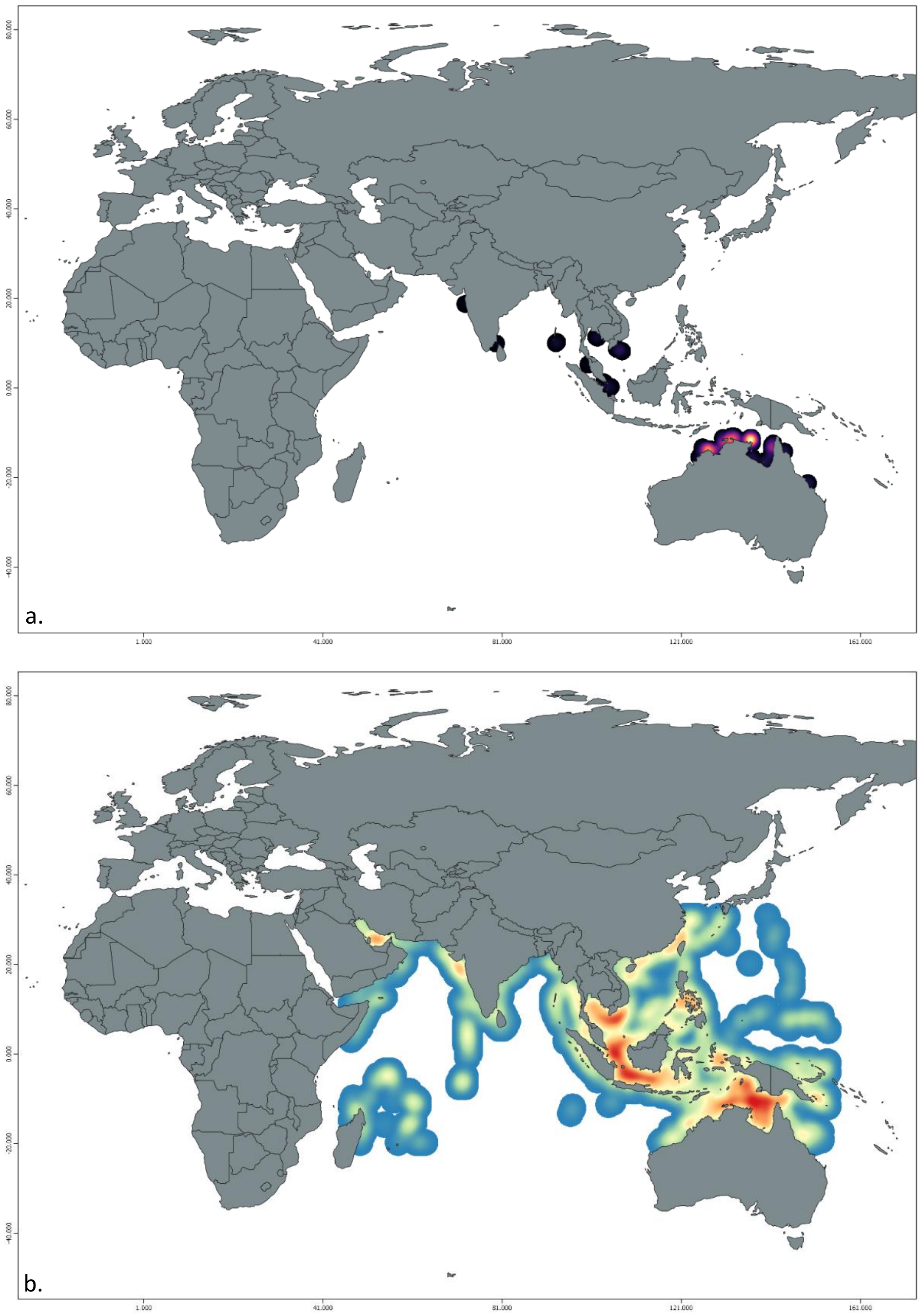


Figure 3. *E. blochii* (a) known population density and (b) probability population density.

Figure 3a. shows the known population density map. There are noticeable population hotspots in the Timor Sea surrounding north Australia and another smaller cluster outside of Vietnam. The probability population density map further confirms that the Timor Sea region of Australia and Vietnam are hotspots but also anticipate significant hotspots in the Gulf of Thailand and waters between Indonesia, Malaysia, and Papua New Guinea (Figure 3b). From the Gujarat India region to east China, Philippines, and Bismarck Sea, there could be a potential for moderate population densities. There is also a potential for a medium hotspot in the Persian Gulf even though the probability distribution map suggests that there might be a lower likelihood for *E. blochii* to occur there. If this species were to reside in this Gulf the predicted density could be substantial. Despite predicted populations of *E. blochii* in the Maldives and Madagascar, their population density would be less than other regions.

Fishing Pressure

This distinctive Indo-Pacific inshore species, *E. blochii*, is subjected to fishing pressures throughout its entire distribution range both known and predicted. This species is sought after primarily for their meat and fins in fisheries utilizing gillnets (Stevens and Lyle 1989; Harry et al. 2011; Smart and Simpfendorfer 2016). *Eusphyra blochii* is particularly susceptible to depletion because of their life history patterns, morphology, and patchy localized distribution (Smart and Simperfendorfer 2016). Life history studies have shown that *E. blochii* females can take over seven years and males five and a half years to reach sexual maturity (Stevens and Lyle 1989). Once they are sexually mature, females could contribute on average 11.8 pups or as little as six pups annually (Compagno 1984; Castro et al. 1999). Their unique head morphology, both size and shape, make them more vulnerable to entanglement in a wide variety of fishing gears. Finally, their limited distribution range, inshore coastal area preference, and habitat restrictions makes this species more susceptible to overexploitation (Smart and Simpfendorfer 2016).

Eusphyra blochii found throughout the Asian region are extremely exploited because of Asia's highly unregulated fishing efforts concentrated around coastal and inshore areas (Smart and Simpfendorfer 2016). Within the Asian region, Indonesia has one of the highest reported elasmobranch catch rates annually. Their net worth of exported shark products is over $13 million dollars per year (Blaber et al. 2009). Therefore, a majority of Indonesian artisanal fishers rely financially on targeted elasmobranch catches including *E. blochii* (Blaber et al. 2009). Other

countries such as India, Pakistan, Malaysia, and Thailand commonly target *E. blochii* but do not record catch data (Compagno 1984; Castro et al. 1999; Smart and Simpfendorfer 2016).

In the Middle East, the countries surrounding the Persian Gulf operate extensive gillnet fisheries and can be presumed to catch shark to some extent (Bishop 2002). Most of the documented shark landings for the Gulf of Persia countries are as bycatch except Kuwait, Qatar, and United Arab Emirates which frequently target most species (Moore 2011; Moore et al. 2012). Of the Gulf states, Oman is the only known and documented country to specifically target *E. blochii* according to FAO Fisheries and Resources Monitoring System (FIRMS). Oman has a total of six fisheries that target *E. blochii* out of 24 fisheries in total (FIRMS 2012).

Australia has the lowest average exploitation rate compared to the other four regions evaluated (Smart and Simpfendorfer 2016). *Eusphyra blochii* though targeted in the Oceanic region, only constitute a small portion of catches in Australia's gillnet fisheries (Harry et al. 2011). The majority of *E. blochii* catch occur in the Northern Territory, while lower quantities are caught near Queensland and in the Gulf of Carpentaria (Stobutzki et al. 2002; Harry et al. 2011). Not much is known about shark fisheries in the African region. The states around the Western Indian Ocean are members of the Nairobi Convention and all participate in shark-directed fisheries or fisheries that take sharks as bycatch.

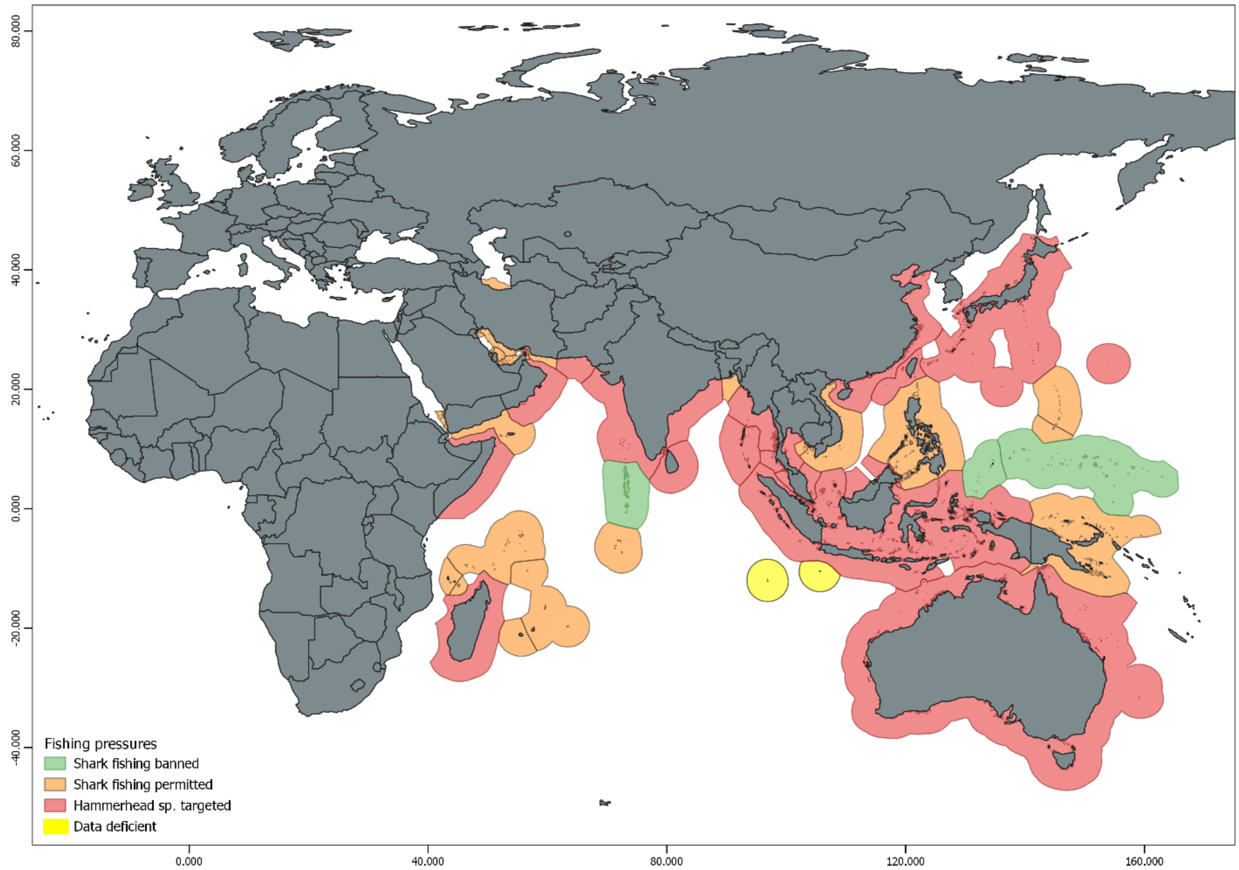


Figure 4. Assessment of fishing pressure throughout both known and predicted *E. blochii* distribution.

There are only two small island regions that are data deficient which are Christmas and Cocos Island (Figure 4). Other than these two data deficient regions, most have some sort of fisheries data available. There are three recognized shark sanctuaries that have completely banned any and all shark fisheries; Maldives, Micronesia, and Palau. Palau was the first shark sanctuary established in 2009 it covers 604.289 sq. km, Maldives was then established in 2010 and is 916, 189 sq. km, and Micronesia was later established in 2015 with 2,992,597 sq. km protected (Ward-Paige 2017). There are 19 regions where shark fishing is permitted and 11 regions where *E. blochii* is specifically targeted. Regions that specifically target this species are Australia, China, Indonesia, Japan, Indonesia, Madagascar, Myanmar, Oman, Somalia, Sri Lanka, and Taiwan.

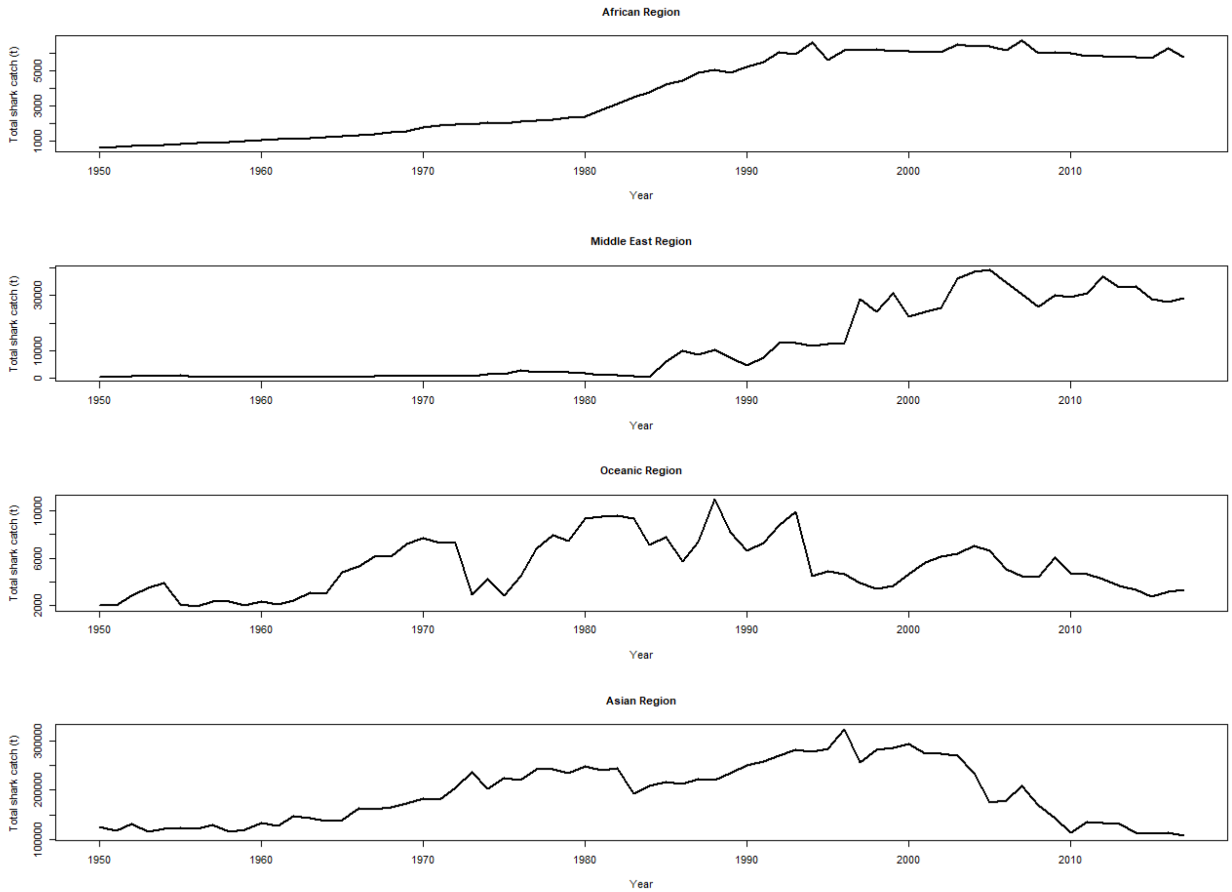
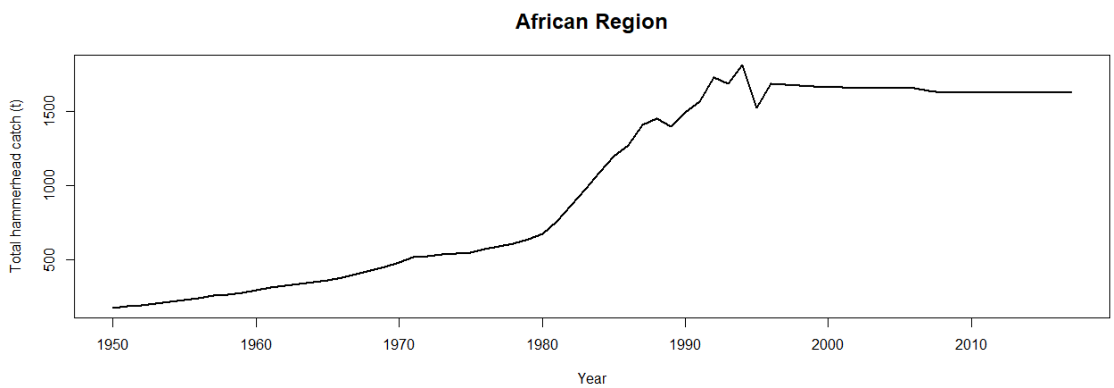


Figure 5. *E. blochii* distribution regional assessment of areas where sharks are caught but species is not specifically targeted based on FAO capture fisheries statistics. Regions of concern and total number of shark catches in tons (t) reported by year.

Though the literature suggests and researchers frequently document shark catches in Somalia, Cambodia, Myanmar, Sri Lanka, Vietnam, Kuwait, and Qatar, these areas do not report their shark landings data to any regional agencies. Out of the four overall regions examined, the African and Middle East region have the most stable shark fishery practices, while the Oceanic and Asian region have experienced an unsustainable shark fishery as can be seen in Figure 5. In the African region data was not originally reported until the late 1950s. Beginning in the late 1990s, countries in the African region had seemingly found a sustainable maximum fishing yield not exceeding 4,000 tons (t) annually. This sustainable fishing has led to stable shark catch rates throughout the published years. In the Middle East region, which demonstrates a less stable but semi sustainable shark fisheries, landings were reported intermittently from 1950 until around 1970 where data became more frequent. Starting in the mid-1980s the reported catch data began

to gradually increase experiencing low variations mid-2000s. This region hit a maximum of 40,000 t during this period and immediately saw a decrease in catch rates. The decrease continued until almost 2010 where fishing numbers remain in the upper 30,000 t.

One of the regions that struggled to maintain sustainable fisheries is the Oceanic region which had landing information starting in the early 1950s. Within a ten year span starting mid-1960s the fisheries has experienced a steady increase up to 8,000 t and then an abrupt rapid decrease. Following the first catch decrease the shark fisheries started increasing take rates in the late 1970s. There were a few peaks and troughs throughout the time until the early 1990s where catches plummeted again. Ever since, catch rates total around 2,000 t when maximum catch used to be 12,000 t. The Asian region has the most severely unsustainable shark fishery of all four regions. With steady high rate of catch maxing out at 350,000 t, this region started to see the first signs of catch rate decrease around 2005 and by 2010 the shark fishery had collapsed to an unsustainable level. There was a miniscule increase in catches around 2012 but since then this region's shark fisheries are completely unsustainable for today's market demands.



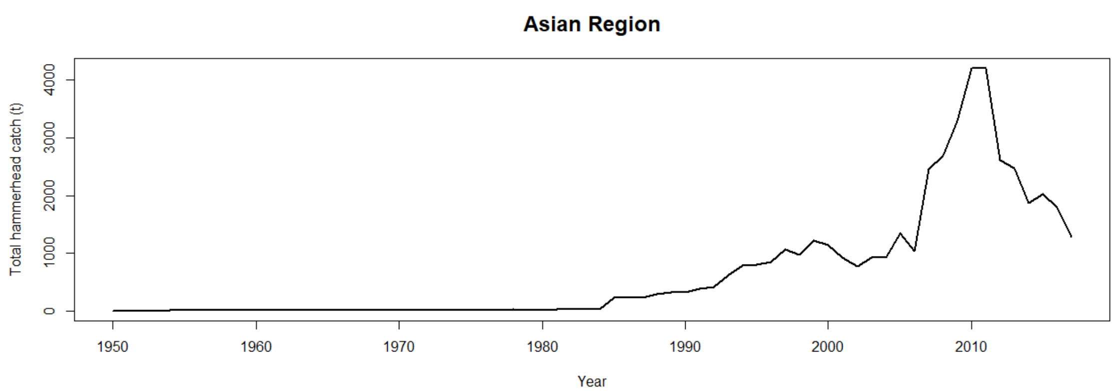


Figure 6. *E. blochii* regional assessment of areas where this species is specifically targeted based on FAO capture fisheries statistics. Regions of concern and total number of hammerhead catches reported (t) by year.

There were two regions that had recorded their shark catches up to the family level, Sphyrnidae (Figure 6). In the examined African region, Madagascar was the only country that reported landings to family specific origins. Madagascar showed a slow and steady rate of increase in hammerhead shark landings beginning in the 1950s. During the 1980s, the increased take became more rapid and in the early 1990s this region reached a catch maximum of about 2,000 tons. Once the maximum yield had been attained there was a slight decline. Around mid-1990s the targeted hammerhead fishery reached a steady plateau of catches, around 1,500 tons and this steady catch rate continued throughout the published years. Asia's region did not report any hammerhead catches until the beginning of the 1980s where there was a steady marginal increase of reported landings. This region did not experience a decline in catches until the early 2000s. In mid-2000s there was a drastic increase in sphyrnid catch reports reaching the maximum yield of over 4,000 tons in the year 2010. This catch rate stayed stable for a year or two and then the decline began. As of 2017 there has not been a complete collapse reported but the trend suggests the steady rate of decline will continue until this fisheries bottoms out from overexploitation.

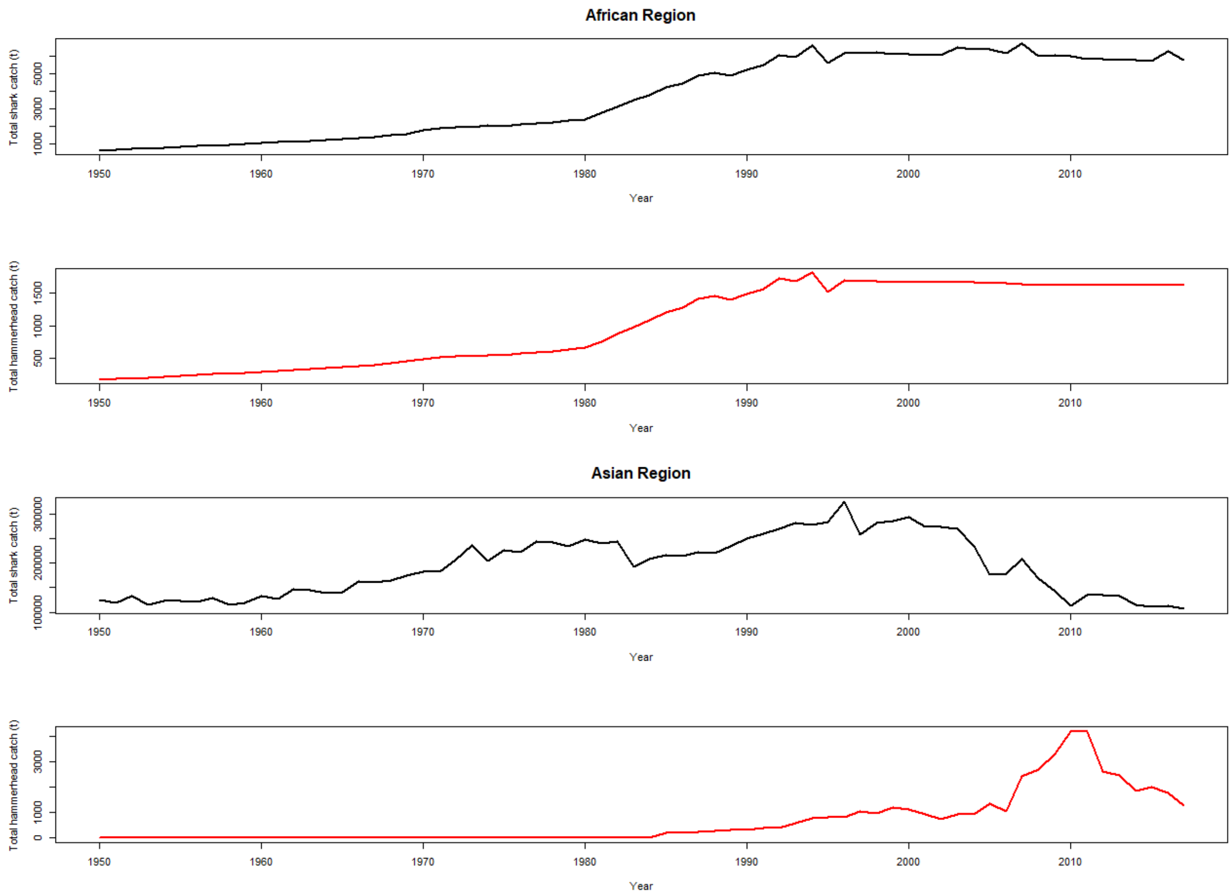


Figure 7. *E. blochii* Both regions of concern that have data for both shark and hammerhead catches based on FAO capture fisheries statistics. African regions and Asian Region with both total number of shark and hammerhead catches reported (t) by year.

Overall, the African region has the most stable fishery systems in both the general shark and hammerhead fisheries (Figure 7). This region has found a stable maximum yield especially in the hammerhead fishery where the catches have been reported as stable for almost 17 years with little to no fluctuation in reported landings. The main difference is the extent of sharks and hammerheads catch quantity in tons. In the African region the catch rates are lower values while the Asian region report catches in the hundreds of thousands. For sharks alone in the African fisheries, catches reach a maximum around 6,000 tons and about 2,000 tons for hammerheads. In the Asian region sharks in general are caught at rates over 300,000 tons and hammerheads 4,000 tons. This vast difference can mean all the difference between a healthy population and collapsing fishery.

Conservation

Eusphyra blochii was last assessed globally by the IUCN Redlist on February 18, 2015 and was subsequently categorized as endangered. Though listed by IUCN as endangered this species does not have an action recovery plan, harvest management, monitoring, nor regional management plan. *Eusphyra blochii* is also not included in any international legislation nor are they part of any international management or trade controls (Smart and Simpfendorfer 2016). There is no long-term species-specific population data available for *E. blochii*, but the evaluation completed in 2015 concluded that the species population had declined by at least 50% and the trend was still in decline due to unchanged fishing practices (Dulvy et al. 2014; Smart and Simpfendorfer 2016).

Most countries attempt to implement national conservation plans and/or follow regulations and guidelines proposed internationally. The African region falls under the Indian Ocean Tuna Commission (IOCT) an international governmental group affiliated with FAO. IOTC is a regional fisheries management organization that promotes and protects, through management, the conservation, optimization of stocks, and sustainable development of fisheries based on such stocks. Of these African regions within *E. blochii* distribution, only one region does not abide by IOTC regulations; Mayotte. On a national basis, a majority of the countries in the African region have little or no legislation for shark fishing. As of 2019, only three regions, Seychelles 2007, Mauritius 2016, and Madagascar 2019, have formal National Plan of Action for the Conservation and Management of Sharks (NPOA – Sharks) (IOTC 2019). Seychelles NPOA was prepared using the guideline set forth by FAO International Plan of Action for the Conservation and Management of Sharks (IPOA – Sharks). There are ten objectives to Seychelles NPOA all of which encompass that if sharks are caught they are caught sustainably, utilized completely, and without waste (Nevill et al. 2007). Mauritius NPOA focuses on actions needed to improve national legislation, skills, and data handling systems available for managing sharks. Finally, Madagascar's plan called for a shark trade surveillance program, more restrictions on illegal fishing, more "no-take" zones, and a more concerted effort to collect catch data. While these three are the only regions for now that have NPOAs established, Somalia as of 2019, is revising their fisheries legislation from 1985 and considering the development of NPOA. As well as Comoros, which has banned shark fishing but there are no laws or regulations in place (IOTC 2019).

For the Middle East region, shark conservation has received little attention and NPOA plans could potentially aid in the protection of over utilized shark stock (Moore 2011; Moore et al.

2012). NPOA – Shark plans are particularly essential in the Persian Gulf area due high catch rates and lack of reporting. Even though there has been no significant movement on NPOA shark plans being established, two regions have loosely formed NPOAs. Oman, which has strived to characterize the areas shark population and biodiversity has also begun drafting a NPOA as of 2019 (Henderson et al. 2009; Henderson and Reeve 2011; IOTC 2019). While Iran has no documented legislation, they claim to have a NPOA in place stating they banned the retention of live sharks. Regionally, only three countries are member of a Regional Fisheries Management Organization (RFMO) IOTC; Iran, Oman, and Yemen (IOTC 2019).

In the Asian region, the population of *E. blochii* is widely acknowledged to be in crisis because extensive data shows a continuing declining trend (Suzuki 2002; Stobutzki et al. 2006). In most Asian countries *E. blochii* used to be caught regularly but now are rarely encountered. For example, in India where *E. blochii* was previously reported, recent catch data from this area and has no mention of this species even as bycatch (Varghese et al. 2013; Smart and Simpfendorfer 2016). On a regional basis some Asian countries are involved members of multiple RFMOs. China and Japan are members of six and seven respectively RFMOs including but not limited to the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), International Commission for the Conservation of Atlantic Tuna (ICCAT), Inter-American Tropical Tuna Commission (IATTC), Northwest Atlantic Fisheries Organization (NAFO), and the General Fisheries Commission for the Mediterranean (GFCM). For the 14 reviews regions, all but Cambodia, Myanmar, Taiwan, and Vietnam are participating members of IOTC. Another commonly participated RFMO is the Western and Central Pacific Fisheries Commission (WCPFC). Within the WCPFC China, Indonesia, Japan, Philippines are members, and Thailand and Vietnam are cooperating non-members. Nationally, nine of the 14 areas have a NPOA – Shark plan including India and their territory Andaman and Nicobar, Indonesia, Japan, Malaysia, Philippines, Sri Lanka, Taiwan, and Thailand. India NPAO seeks to review current shark fisheries, assess management and their effectiveness, and detect any lapses in data collection. Japan has more of a NPOA–Shark assessment than a plan, where they report catches and efforts to the Committee of Fisheries (COFI). Pakistan has a finalized NPOA draft being reviewed but have laws against shark finning. In Pakistan, sharks may be landed with the fins attached and every part of the shark carcass must be utilized. Finally, Philippines has NPOA from 2009 but is currently under periodic review by FAO and IOTC.

Oceania mainly follows the regional guideline dictated by WCPFC. Australia, Micronesia, Papua New Guinea, and Palau all are active member of WCPFC. Those same regions also have documented NPAO – Shark plans. Australia not only works regionally with WCPFC but also IOTC, WCPFC, and CCAMLR as well as with Southern Indian Ocean Fisheries Agreement (SIOFA) and Southern Pacific Regional Fisheries Management Organization (SPRFMO). In Australia, there are two NPOA – Sharks plans. *Eusphyra blochii* is a minor portion of commercial catches in a heavily regulated fishery. After being assessed regionally by IUCN it was determined that the *E. blochii* population in the Oceanic region was relatively stable. Therefore, IUCN classified this species as Least Concern within this region. (Smart and Simpfendorfer 2016). Australia has one of the most regulated and monitored shark fisheries with catch quota, formal risk and stock assessments, and sex differential harvests (Stevens et al. 2000; Harry et al. 2011). These monitoring programs are mainly focused around Northern Australia and areas such as the Eastern coast of Queensland received little attention and are unregularly monitored (Anon 1990; Stobutzki et al. 2002; Salini et al. 2007). Between 1993 and 2004, there was a 200% increase in shark landing along the coast of Eastern Queensland (Bensley et al. 2010). Therefore, this further verifies that protection plans and monitoring need to be extended to all of the Oceanic region.

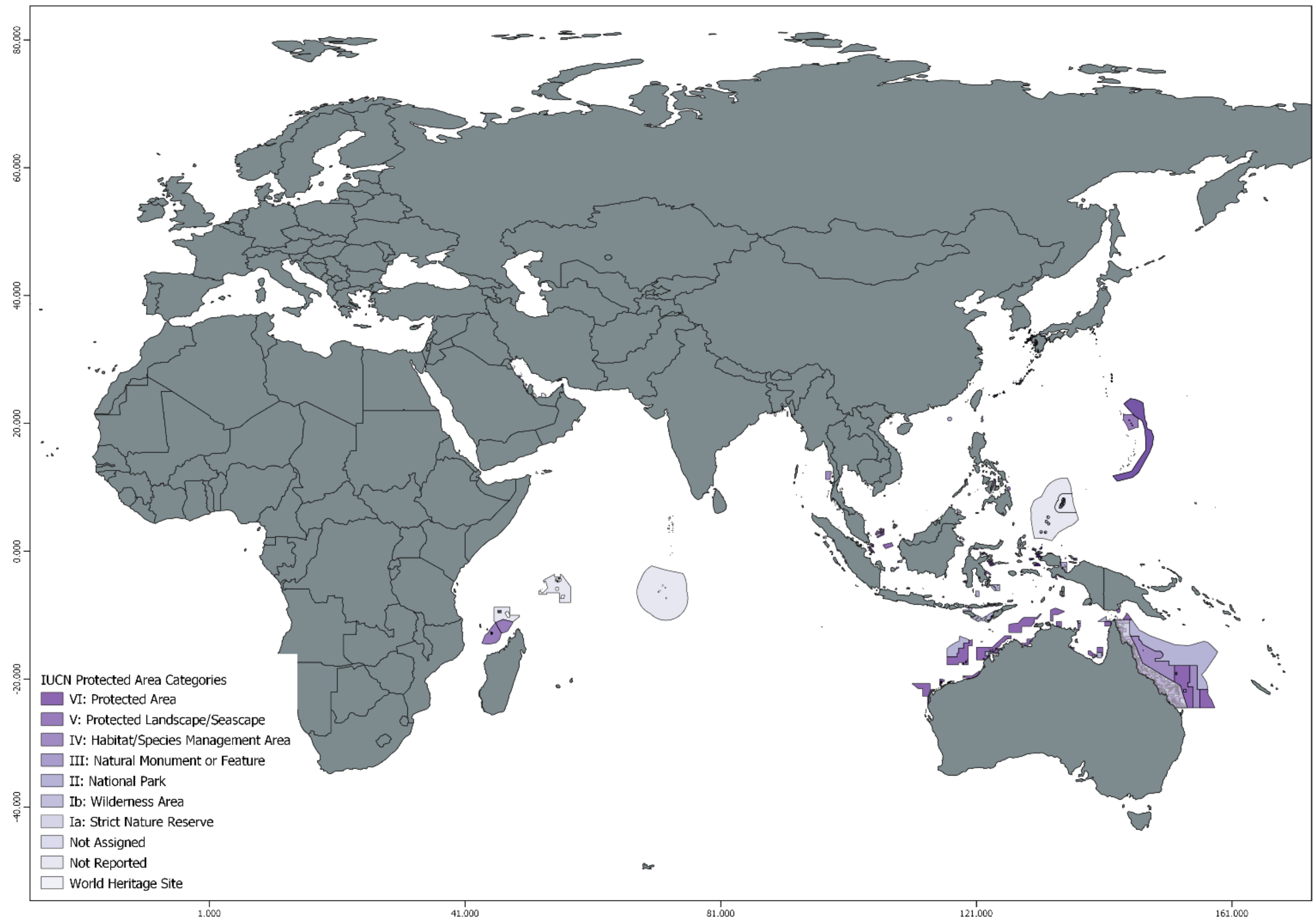


Figure 8. *E. blochii* marine protected area overview where more actively protected MPAs are dark purple shades and the areas not defined by the IUCN are the lighter shades.

Eusphyra blochii occurs in at least one protected area and Figure 8 depicts the MPAs that are located throughout this species distribution both known and predicted. There are a total of 1,477 recognized MPAs with 286 of these sites being no take zones. Theses MPAs can be further broken down into categories; 94 Ia, 12 Ib, 181 II, 18 III, 288 IV, 163 V, 328 VI, and 11 World heritage sites. There are a total of 328 sites that are unknown, of which 32 are unassigned by the IUCN and 350 sites have not reported what their MPA type is and if they have been categorized by the IUCN. Most of these MPAs are centered around Australian waters. Out of the 1,477 total MPAs, 223 of these sites are around the species range of Australia. These 223 sites range from two world heritage sites, the largest and most noticeable being the Great Barrier Reef and the rest are 1a, II, III, few IV, V, and VI zones. Not only does Australia have the highest quantities of MPAs 34% are the highest protection level VI.

Sphyrna corona

Biology

Common names: Scalloped bonnethead, crown shark, and mallethead shark

Sphyrna corona individuals are more uncommon and rarely seen compared to other hammerhead species (Mycock 2004). Therefore, data gaps are present within the scientific literature for *S. corona*. *Sphyrna corona* was first described by Stewart Springer in 1940 from specimens that were taken from Panama and the Gulf of California. This species is presumed to be the smallest of all nine sphyrnids and most morphologically similar to *S. media*. The main difference between these two species is *S. corona* has a substantially longer snout that is about two – fifths the width of its head, the anal fin is concaved, and they have a strongly arched mouth. Other distinctive features for this species include a moderately broad arched mallet shaped cephalofoil that has medial and lateral indentation along the anterior edge and no prenarial grooves present. The width of the blades are about 24 – 29% of its TL (Compagno 1984; Mycock 2004). *Sphyrna corona* has a narrowly arched mouth with about 24 – 37 teeth in the upper jaw and 25 – 37 teeth in the lower jaw (Last 2002). The posterior teeth are mostly, cuspidate not molariforms, while the anterior teeth are long and slender cusps that are not serrated (Compagno 1984). The first dorsal of *S. corona* is falcate with a free rear tip over the pelvic fin insertion, the second dorsal is notably tall, the precaudal pit is crescentic, and the anal fin is a longer straighter fin than the second dorsal (Gilbert 1967; Compagno 1984). The anal fin's base alone is 8.2 – 9.2% of the species TL and is positioned in front of the second dorsal (Compagno 1984). *Sphyrna corona* has a total vertebra count of 135 and a possible maximum of 140. This species exhibits countershading coloration, their dorsal is gray with no noticeable fin markings and fades to a white ventrally. The white coloration extends to the ventral side of the head as well (Last 2002).

Life history

This small uncommon tropical hammerhead can grow to a maximum size of about 92 cm. Males reach maturity around 67 cm TL but, the length of maturity for females is unknown as well as the age of maturity for both sexes (Mycock 2004). This species is viviparous and presumed to have about two pups per litter (Last 2002). This estimate may be inaccurate but there is no other information available to validate this reproductive output. Pup size is still debated within the

current scientific literature, however, it is widely accepted that *S. corona* has a low fecundity. Size at birth could be 23 cm TL but, this is unknown as well (Last 2002; Mycock 2004).

Distribution

Sphyrna corona is a tropical coastal species that lives over the continental shelf in eastern Pacific Ocean with a range from the Gulf of California to Peru (Compagno 1984; Last 2002; Castro 2011; Rico-Mejia and Rueda 2007). While this species was originally thought to occur in the Gulf of California, central, and southern Mexico Pacific, there has been some debate about whether or not this species has been extirpated from these waters (Bizzarro et al. 2009; Smith et al. 2009; Perez-Jimenez 2014). Some researchers have determined that though this species was previously recorded in both the Gulf of California and Mexican Pacific but, it is now missing from surveys in these areas (Bizzarro et al. 2009; Smith et al. 2009; Perez-Jimenez 2014). The last record of *S. corona* in central and southern Mexico Pacific was back in 1995 in a survey conducted by Balart et al. (1995). Since then there has been no record of this species being present in these waters (Perez-Jimenez 2014). Researchers argue that the absence of this species may be due to sampling data from fisheries where this species is not caught, and not the extirpation of *S. corona* from these areas (Castro 2011). Even though distribution data is uncertain, environmental predictors were estimated based on previously known catch data. *Sphyrna corona* prefer depths ranging 22 – 95 m, temperatures 23.75 – 29.03 Cº, salinity 30.32 – 34.96 psu, and distance from shore 8 – 380 km. (Kaschner et al. 2019).

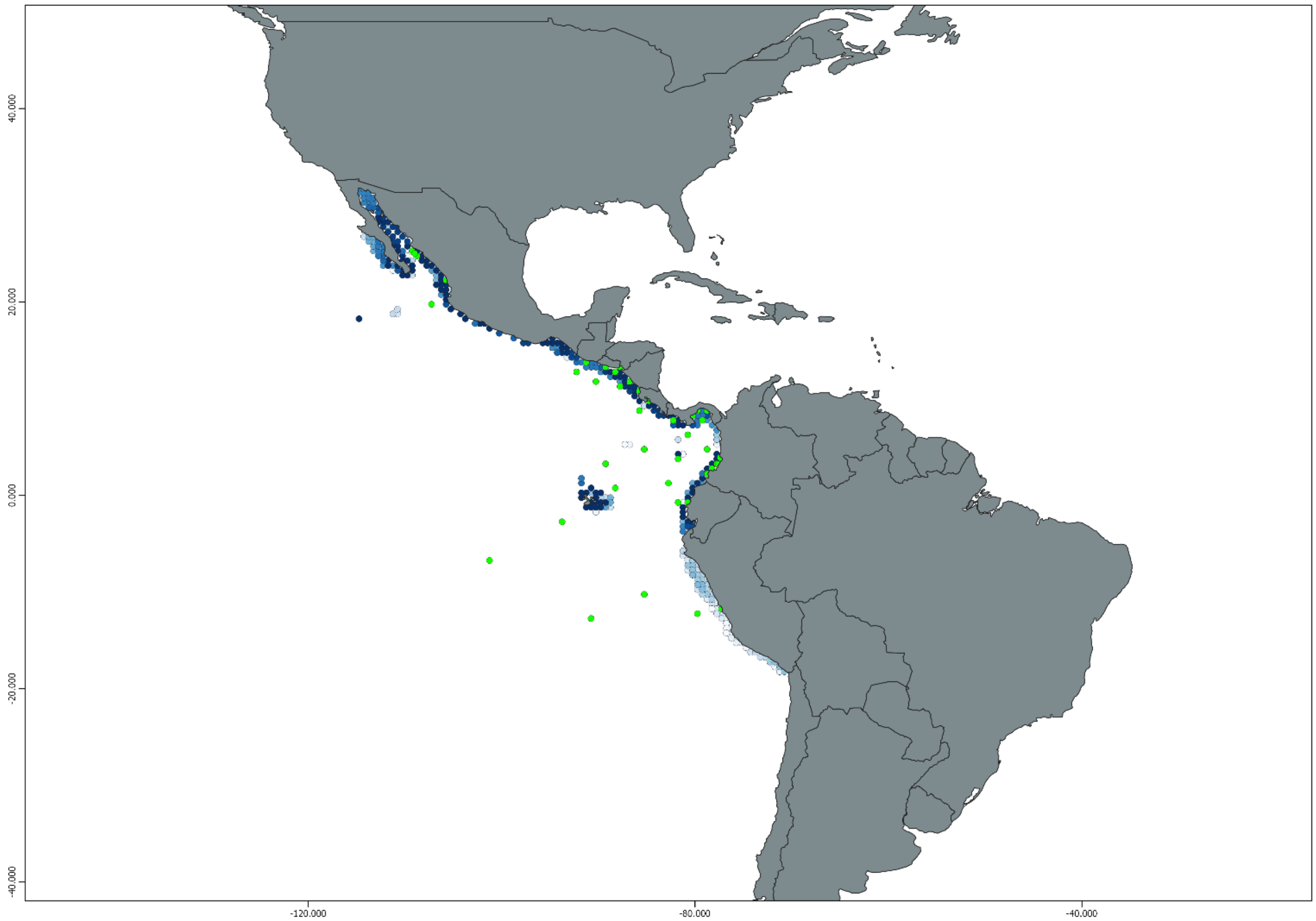


Figure 9. *Sphyrna corona* known distribution and probability distribution. (Green) actual known recordings of species and (blue) probability distribution based on habitat preference. Dark blues indicate a high probability of occurrence lighter blues are less probable.

Constructed from the environmental predictors, Figure 9 demonstrates that *S. corona* should be present in the Gulf of California because of the high probability of presence. This area has quintessential environmental parameters suitable for this species. Another potential habitat area is the Galapagos with significantly high predicted probability. As the distribution continues south, the probability is still relatively high until Peru, where the predicted population probability begins to decrease. Furthermore, the probability decreases even more southwards to Chile. The predicted distribution follows the same basis of the known geographic locations of *S. corona*. The only difference between the known and predicted distribution is that there have been reported catches of *S. corona* as far off the coast of Peru, even though the predicted distribution shows no probability of this species finding a preferred habitat in these waters.

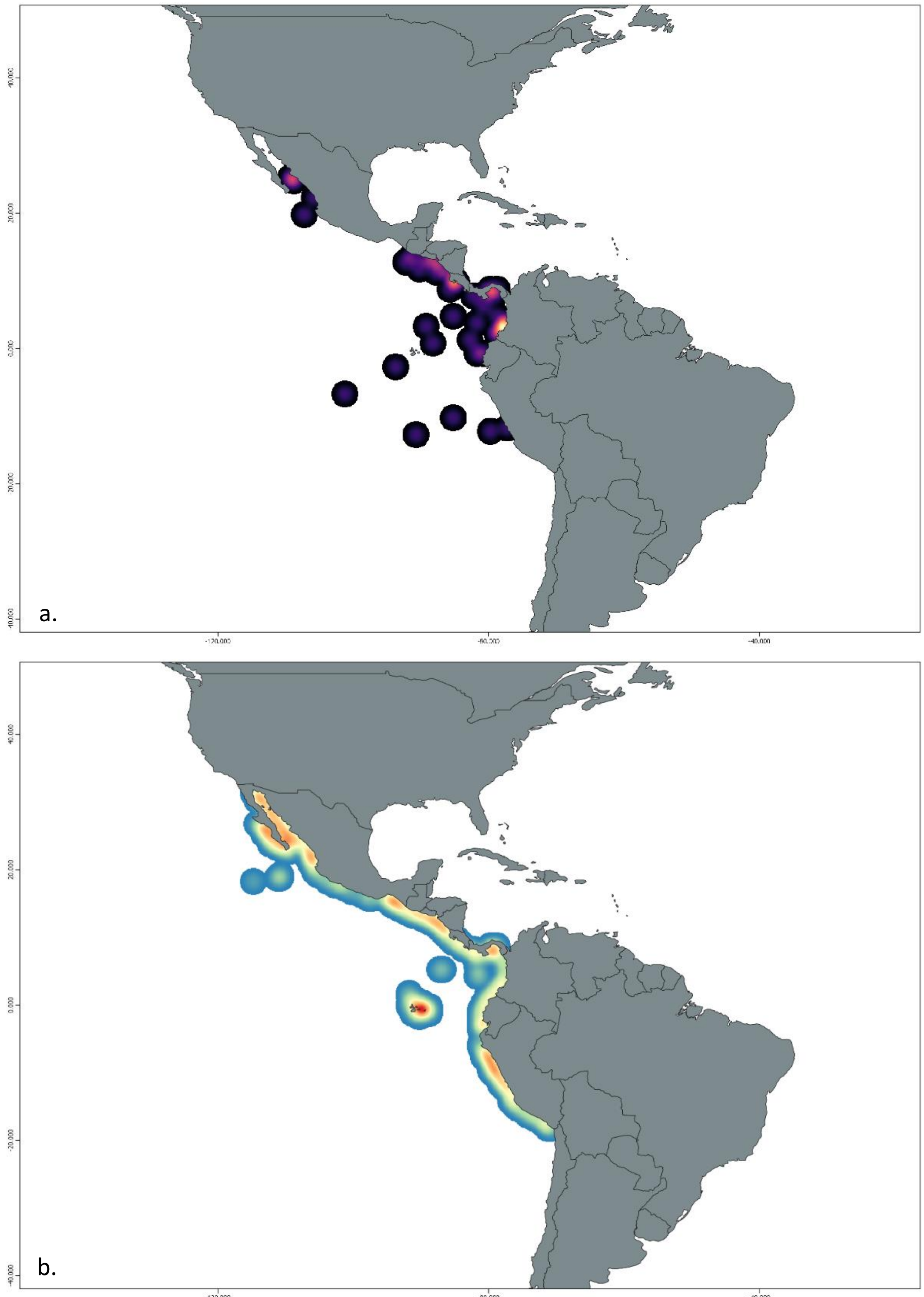


Figure 10. *S. corona* (a) known population density and (b) probability population density.

The known records of *S. corona* show that there is a main population density hotspot in the coastal oceans of central to southern Columbia (Figure 10a). Other regions that have density masses are be Panama, Costa Rica, Nicaragua, Honduras, and a decline in density around Guatemala. Another hotspot is towards the mouth of the Gulf of California. The predicted density map in Figure 10b shows that any inshore coastal waters throughout the *S. corona* range could have a moderately high probable population density, with the exception of southern Mexico Pacific. The highest population density mass is potentially in water around the Galapagos Islands. In Figure 10a, the highest density is in Columbian inshore waters while in Figure 10b the predicted density of Colombia is less than other regions. The predicted density maps corroborate the known population densities and suggests that there could be potentially higher densities than originally concluded in south Mexico and Guatemala.

Fishing Pressure

Sphyrna corona is assumed to be taken in local artisanal inshore fisheries for their meat, however, data is lacking in this area of study (Compagno 1984; Mycock 2004; Perez-Jimenez 2014). In most fishing communities throughout their range, *S. corona* is landed and sold whole (Perez-Jimenez 2014). It is unlikely that this species is caught for their fins because of their small stature, restricted distribution, and demand for their fins is menial in the global fin trade market (Abercrombie et al. 2005).

Regionally, shark fisheries data is deficient. Most regions report that they catch small sized hammerheads but often do not differentiate which catches are juvenile large-bodied hammerheads or adult small-bodied hammerheads. Distinguishing between the small-bodies sphyrnids can be difficult because there are three smaller-bodied hammerhead species that occur within the same distribution range. Three regions specifically target *S. corona* which are Colombia, Mexico and Panama. This species is mostly caught in inshore artisanal fisheries throughout the Mexican Pacific Ocean and Panama (Perez-Jimenez 2014). In Panama, artisanal catches are predominantly sphyrnids with 2.6% of the total catch being *S. corona* (Rodriguez-Arriatti 2011; Harper et al. 2014). In regions such as Colombia and Guatemala, *S. corona* is frequently caught as bycatch. In Colombia, as well as being targeted, this species is caught primarily as bycatch in shrimp fisheries and based on estimated maximum size bycatch is mainly adult *S. corona* (Rico-Mejia and Rueda 2007). In Guatemalan fisheries, *S. corona* is exploited as a product of bycatch in a variety of

artisanal fisheries utilizing gillnets (Ruano and Ixquiac 2007). The remaining regions have fisheries that target hammerhead species but there is no data stating specifically which species are targeted. El Salvador shark fisheries are known to target multiple sphyrnid species using gillnets but only report to the family taxonomic level (Siu and Aires-da-Silva 2016). In both Ecuador and Galapagos, researchers have suggested that since the 1950s hammerhead species have been a targeted in their shark fisheries but there is no species-specific data available (Watts and Wu 2005; Jacquet et al. 2008; Schiller et al. 2014).

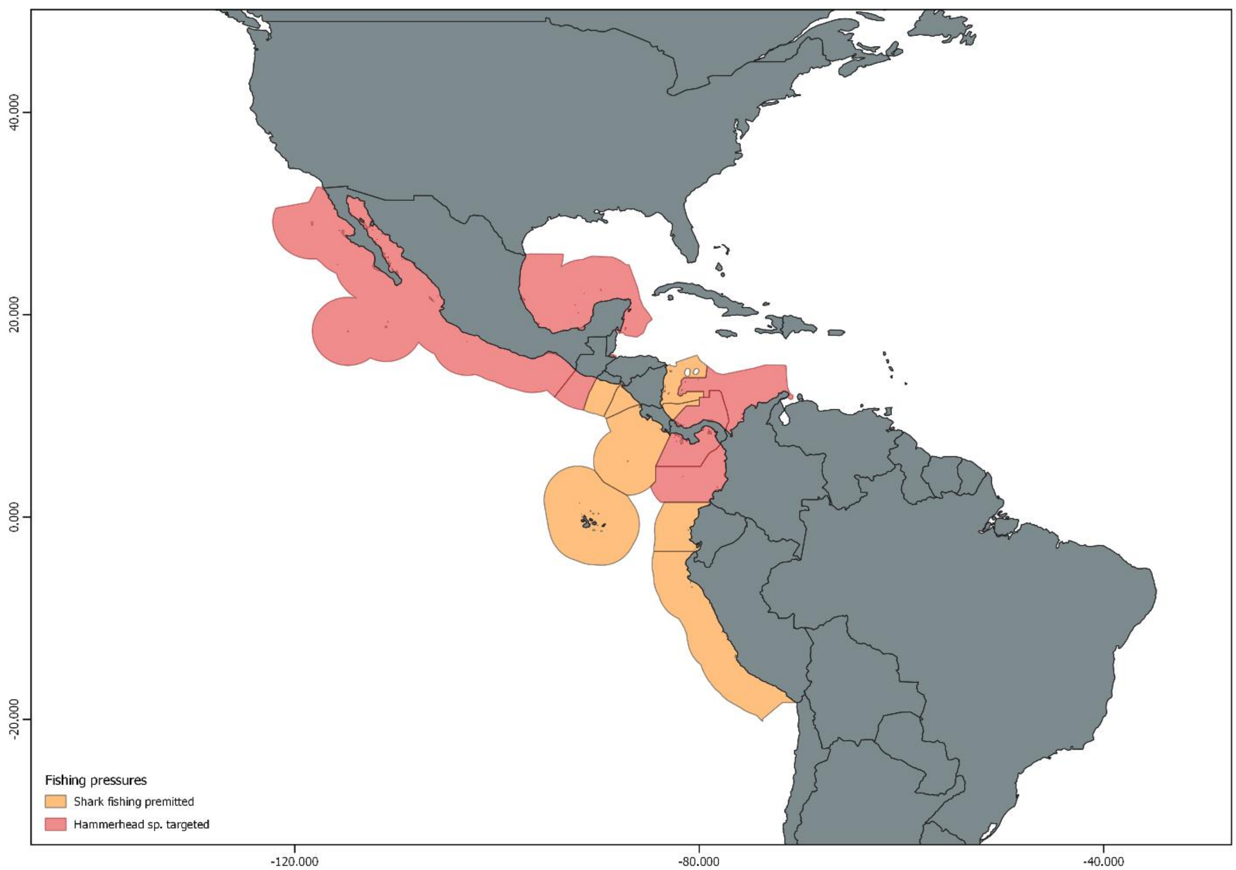


Figure 11. Assessment of fishing pressures throughout both known and predicted distribution of *S. corona*.

In Figure 11, four of the ten regions throughout this species' range are indicated as having targeted or frequently catching *S. corona* as bycatch. The only region that did not have fisheries catch data reported was the Galapagos. Since this is a territory of Ecuador, it is likely that their fishing efforts get reported as one to their RMFOs. Therefore, they are depicted as fishing for

sharks and in particular hammerheads. Most of these regions only reported catch to a higher taxonomic level and did not specify which sphyrnid species they targeted.

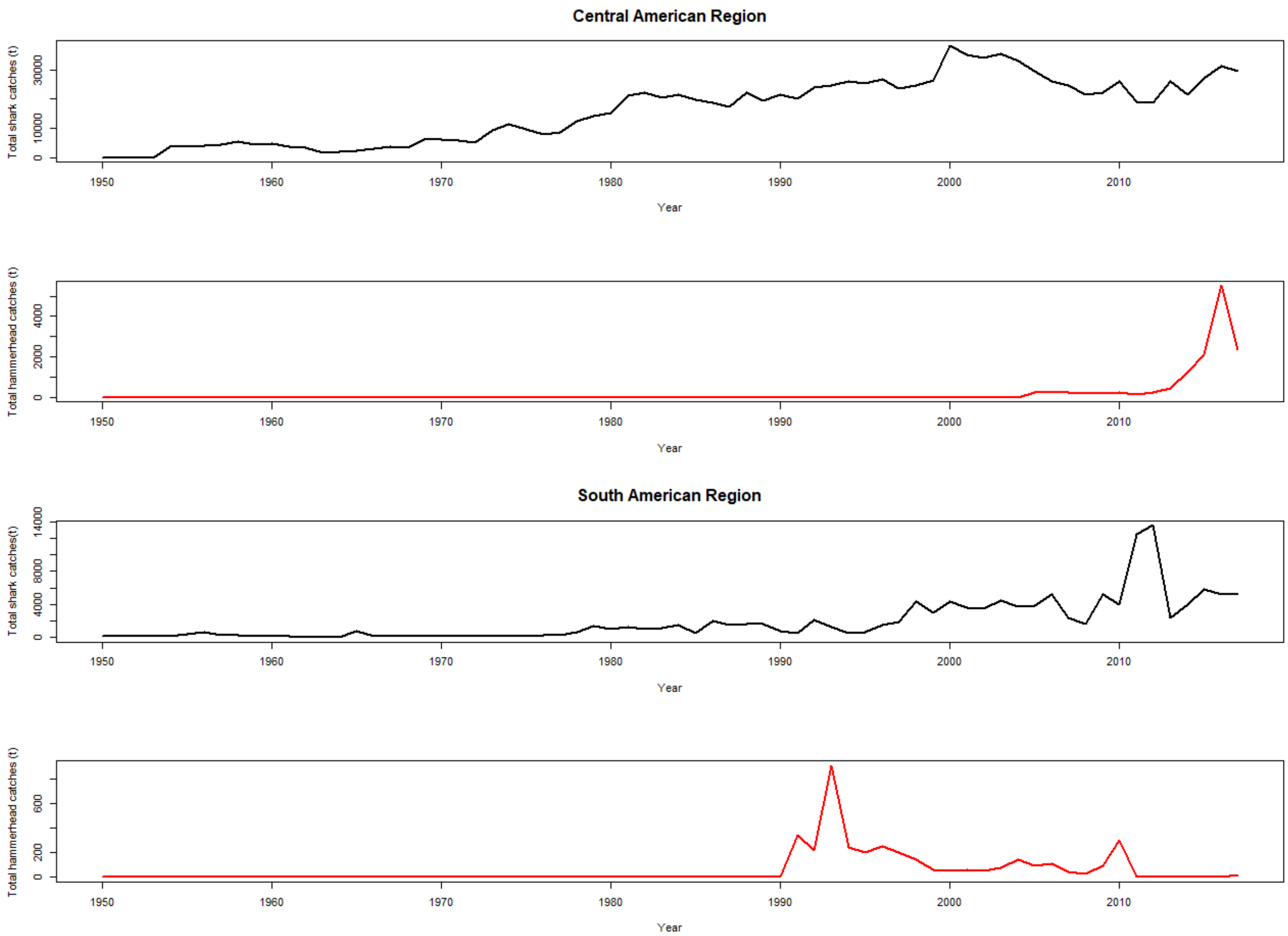


Figure 12. *S. corona* both regions of concern based on FAO capture fisheries statistics. Central American regions and South American region with both total number of shark (black) and hammerhead catches (red) reported in tons (t) by year.

The graphs above (Figure 12) show how fishing pressures might affect the population of this rare species throughout its range. Both in Central and South America, the total shark fishery have been rather sustainable. In Central America, overall shark catches were reported in the early 1950s. There was a slow and steady increase in catch rates for decades until the 2000s. In 2000, there was a steep increase in catches over a two year period reaching a maximum yield rate of 40,000 t. In years since this maximum was hit, total shark catches slowly decreased with few fluctuations. Low catch was around 20,000 t and higher catches at about 30,000 t. In the South American region, the shark fisheries have been a little more volatile. Data reporting began in the

late-1950s and did not exceed catch rates of 4,000 t until the early 2010s. Beginning in 2010, there was a sharp increase in reported shark catches attaining a high of 14,000 t. Shark populations could not handle these exploitation rates and catches plummeted back to 3,000 t in only about a five year span. From there fishing has leveled off to be about 4,000 t which seems to be a more sustainable fishing level.

For Central America, Mexico, and for South America, Colombia and Ecuador, were the only regions to report family specific catch data to their RMFOs. Mexico did not report their total hammerhead catches until mid–2000s. In the mid–2010s there was a spike in catches reaching 6,000 t. This catch rate did not last for more than a year with an immediate decrease in reported catch rates. As of 2017, the trend shows a steady level of decrease in hammerhead catches. In the South American region, hammerhead data was not reported until 1990. Shortly after beginning to report, their catch increased to an unsustainable amount around 800 t. Directly after, there was a decrease in catch rate for about ten years. Take rates were stable around 200 t. In 2010, there was a smaller increase in catch rates reported, promptly followed by a complete collapse where the reported catch was zero for about five years. In 2017 the reported hammerhead catch was under 100 t which is an economically unsustainable fishery.

Conservation

The conservation status of *S. corona* was last reviewed globally in 2004. On April 30, 2004, the IUCN determined that their population status qualified as near threatened because of the lack of available information. Back in 2004, this rare species almost met all the requirements to be categorized as vulnerable. However, since the population trend was unknown and there was no tangible evidence showing population decline, they were ranked one level lower, near threatened. Heavily inshore focused fisheries suggest that all of this species life history stages are susceptible to overexploitation. This in combination with low fecundity, guesstimated litter size of two pups, and small maximum size but no data on maturity age, makes *S. corona* vulnerable to even the smallest amount of fishing pressures (Mycock 2004). There are currently no conservation actions in place for this species. Researchers have tried to encourage Central and northern South American regions to provide species-specific legislation because *S. corona* is thought to be critically endangered in these regions (Mycock 2004; Perez-Jimenez 2014).

In Central America, all six countries follow regulations put forth by at least one RMFO including IATTC, ICCAT, and the Central America Fisheries and Aquaculture Organization (OSPESCA). On the national level all but two countries have NPAO – Sharks plans, Guatemala and Nicaragua (Siu and Aires-da-Silva 2016). Costa Rica's NPOA was established in 2010 and its objective is to avoid further degradation of the shark populations by ensuring optimal sustainable use of the shark fisheries (OSPESCA 2010). In El Salvador, prohibiting shark finning was their first step followed by a restriction on gear types, fishing within nursery habitats, and fishing neonate hammerhead sharks Siu and Aires-da-Silva 2016). Mexico's NPOA established protection for known shark nursery areas, banned shark finning, and prohibited fishing for some select species (Perez-Jimenez 2014; Siu and Aires-da-Silva C 2016). However, *S. corona* is no longer a recognized shark species in Mexican Pacific waters. After extensive surveys it was apparent over a two decade period that the frequency of catches declined drastically. This inferred that a serious declining population trend took place for this species and suggestions have been made that *S. corona* should be regionally reassessed as endangered or critically endangered due to their lack of presence in Mexico and throughout the Eastern Pacific region. Finally, in Panama their NPOA was the last to be established and came into effect in 2016 (Siu and Aires-da-Silva 2016).

In South America all evaluated regions follow the rules and regulations provided by IATTC with Colombia being the only country that also follows OSPESCA guidelines. Both Colombia and Peru have NPOA – Sharks plans while Ecuador and Galapagos are without. This is rather important because records indicate that *S. corona* may only be located in the Colombian Pacific. A once thought restricted distribution has been dwindled down to an even more confining range (Rico-Mejia and Rueda 2007; Perez-Jimenez 2014). As of 2010 their NPOA had a three part plan of action which focused mainly on research, management/control, and inspections/monitoring programs (Caldas et al. 2010). The other two regions without national plans, Ecuador and Galapagos, follow a Regional Plan of Action (RPOA) for the region of South America (CMS 2015). While in the Galapagos, this region is a marine reserve that tried to prohibit all shark fisheries but, these regulations are well known for being ineffective. It is widely accepted that this is an unmanaged and unregulated ban which led to sharks being targeted by illegal fisheries (Fowler 2005).

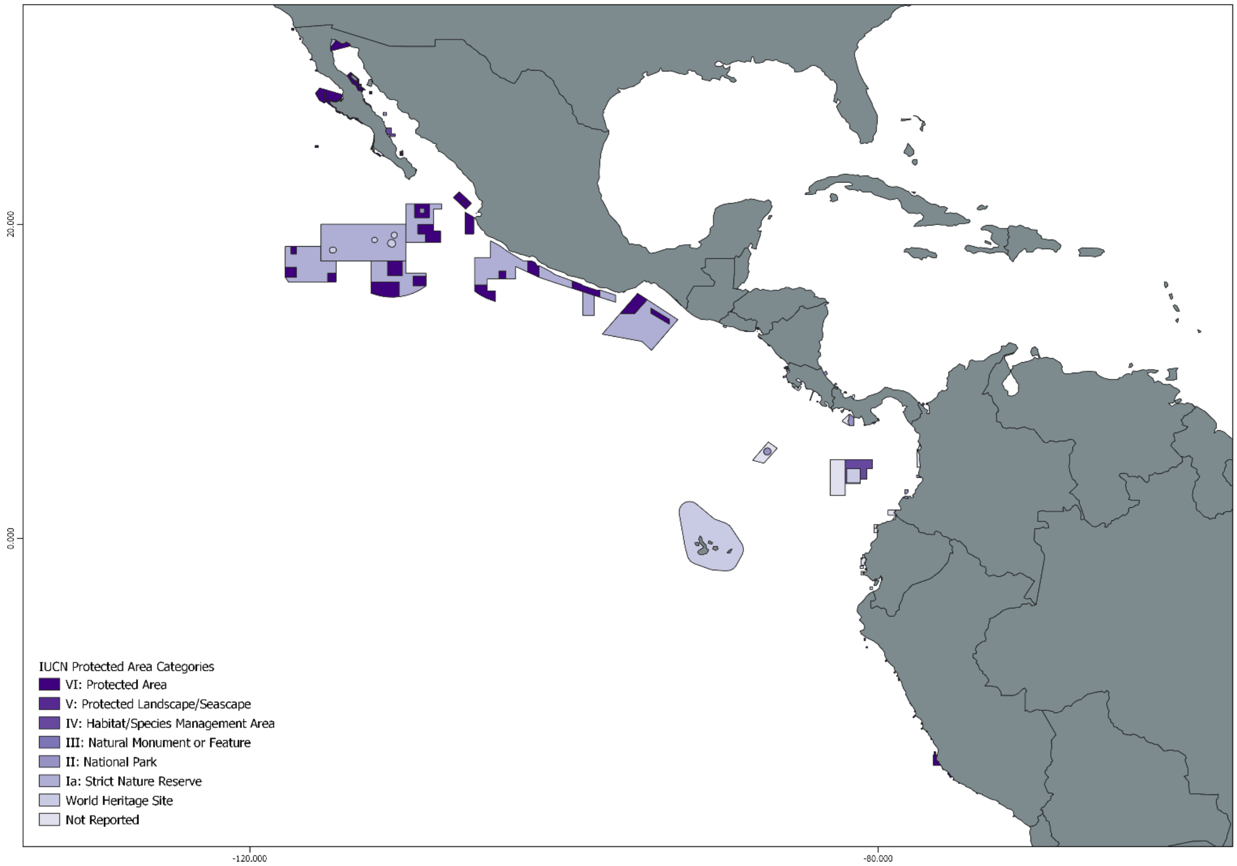


Figure 13. Marine protected area overview throughout *S. corona* distribution where more actively protected MPAs are dark purple shades and the areas not defined by the IUCN are the lighter shades.

Throughout this species distribution there are 123 MPAs as depicted in Figure 13 above. Of these 123 MPAs there are; 16: Ia, 18: II, 4: III, 20: IV, 1: V, 14: VI, and 6 World Heritage sites. There are no unassigned areas but there are 44 MPAs that are not reported. A majority of the MPAs for this examined distribution is the Ia type. The region that has the highest quantity of MPAs are within Mexico Pacific waters and 15 of the 29 are within the Gulf of California. The MPAs range from the highly protected VI sites to MPAs of a lesser protection level.

Sphyrna gilberti

Common name: Carolina hammerhead

As of 2013, *S. gilberti* was named as a new species within the family Sphyrnidae (Quattro et al. 2013). This species was originally believed to be synonymous with *S. lewini* but, was later determined to be a cryptic speciation of *S. lewini*. There was a total of five independent genetic variation studies conducted that were able to confirm a deep evolutionary partition between *S. lewini* and *S. gilberti* (Abercrombie et al. 2005; Quattro et al. 2006; Zemlak et al. 2009; Naylor et al. 2012; Pinhal et al. 2012). In 1967, Carter Gilbert was the first to suggest that there could be an evolutionary divergence within the species *S. lewini*. This suspicion was due to high variations between samples of *S. lewini* collected near Charleston, South Carolina. From there, Abercrombie et al. (2005) and Quattro et al. (2006) discovered this to be true in two separate unrelated studies. Abercrombie et al. (2005) happened upon these results when surveying globally the genetic identification of hammerhead sharks. These researchers suggested the existence of the cryptic species after realizing there was a fixed nucleotide difference in the nuclear ribosomal DNA internal transcribed spacer 2 (ITS2) locus. In an independent study by Quattro et al. (2006) this cryptic lineage was also discovered when examining both genetic and morphological variations of *S. lewini* in the western Atlantic Ocean. They found that variations in vertebral counts, mitochondrial and nuclear gene trees, and allelic distribution further supported Gilberts original assumption of a cryptic speciation between these hammerheads (Quattro et al. 2006). Pinhal et al. (2012) later estimated that the evolutionary divergence between *S. lewini* and *S. gilberti* occurred about 4.5 million years ago.

After comparing both species against 67 measurements, researchers failed to reveal any external characteristics that could be used as discriminators between the two species. Speculation revealed that the chondrocranium and distribution of ampullae could be different between the two species, however comparisons failed to reveal any differences. (Gilbert 1967; Quattro et al. 2013). The only significant morphological separation between *S. gilberti* and *S. lewini* is the number of precaudal vertebrae, with *S. gilberti* 83 – 87 vertebrae and *S. lewini* 92 – 99 vertebrae (Quattro et al. 2013).

Biology

Sphyrna gilberti is the largest hammerhead species of the six lesser known species in this study. Though this species is evolutionarily divergent from *S. lewini*, the placement in both ITS2 and mtCR loci suggest that this species is more closely related to the smaller hammerhead species of the eastern and western Atlantic (i.e. *S. corona*, *S. media*, *S. tiburo*, and *S. tudes*) (Lim et al. 2010). While this species is morphologically identical to *S. lewini*, there are some distinguishing features that can be used to differentiate these species from the other sphyrnids. *Sphyrna gilberti* has a cephalofoil expansion width that is 25 – 32% of its TL, median indentation, lateral indentation that is equal distances from the median indentation, and an inner narial groove present that extends from the nostril to the lateral indentation. The snout length is almost equal to the width of the mouth, with the corners of the mouth being even with the posterior margin of the head. Their teeth are all cuspidate with smooth edges, symmetrical, and weakly serrated. *Sphyrna gilberti* has eyes with a posterior orbit, perpendicular with the upper jaw, and a height that is 50% greater than nacelle height. The body is round to an oval shape in the cross section and becomes more rectangular anteriorly towards the caudal peduncle. *Sphyrna gilberti* has rounded pectoral fins that are moderately small and the fins' anterior margin is less than 50% of the head width. The caudal fin is profoundly forked and more than 25% of its TL, and the upper and lower precaudal pit is present. *Sphyrna gilberti* has a grey to brown dorsal coloration which then fades ventrally to a white color. Fin markings on this species include, a white to dusky coloration on the top of the ventral pectoral fin, while the lower portion of the caudal fin varies from dusky to a black tip (Quattro et al. 2013).

Life history

Since *S. gilberti* was recently classified as its own species, the life history on this species is poorly studied. Assumptions about their life history should not all be constructed from *S. lewini* because this species was considered to be evolutionarily different enough to be classified as its own species. The maximum size, size and age of sexual maturity, longevity, gestation period, and mating season are all unknown categories. While most life history aspects are unknown, there is data available on pup size at birth, estimated litter size, and potential nursery habitats. *Sphyrna gilberti* pups are born at a size of 397 mm TL while *S. lewini* pups are 451mm. Therefore, litter size might be equal to *S. lewini*. *Sphyrna lewini* has a litter size of 15 – 31 pups with an average of

17.2 pups. The catch data from a study conducted by Quattro et al. (2006) suggests that bays and estuaries of South Carolina have been suspected as potential nursery grounds for *S. gilberti* but is not confirmed. Most neonate catches were from St. Helena Sound and Bulls Bay from South Carolina (Quattro et al. 2006). Finally, the smaller size at birth could also indicate that *S. gilberti* reaches a smaller maximum size than *S. lewini* (Quattro et al. 2013).

Distribution

Sphyrna gilberti has a more conservative distribution relative to the circumglobal distribution of its cryptic counterpart, *S. lewini*. With their conserved distribution and identification difficulties this species distribution is for the most part unknown. Distribution was postulated from researchers that have collected samples of *S. gilberti* currently. Henceforth, their distribution could be from North Carolina to Florida with more recent findings including Brazil in their distribution (Abercrombie et al. 2005; Quattro et al. 2006; Chapman et al. 2009; Pinhal et al. 2012).

Figure 14. *S. gilberti* probability distribution based on *S. lewini* habitat preferences in regions where *S. gilberti* specimen have been collected. Dark blues indicate a high probability of occurrence lighter blues are less probable.

Figure 14 depicts the predicted distribution range for *S. gilberti*. This distribution was created from the predicted distribution of *S. lewini* based on environmental predictors, but only for the regions where *S. gilberti* might inhabit according to Quattro et al. (2013). This probability map suggests that population probability in the North American region is high until the southernmost tip of Florida. For South America, north and south Brazil have the highest probability rate of occurrence and it decreases towards central Brazil.

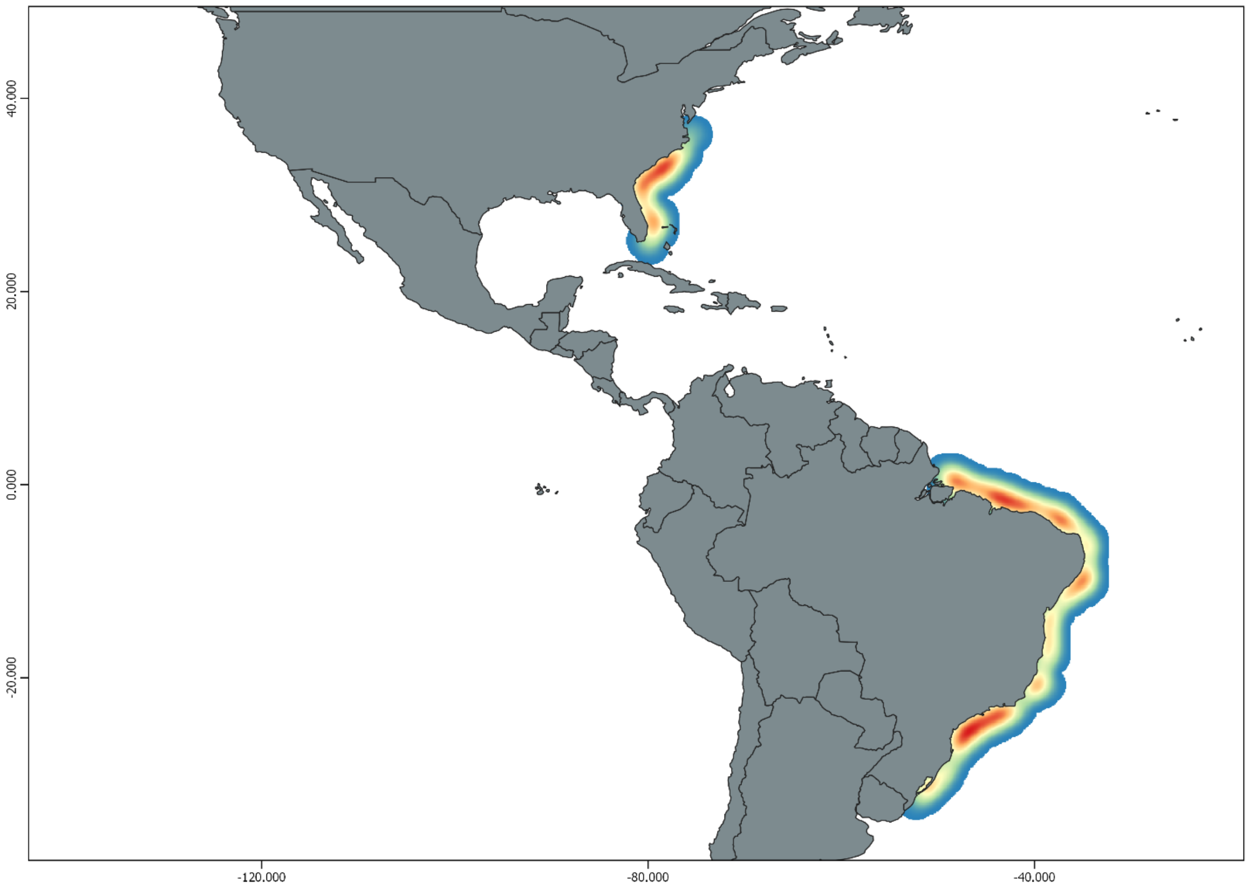


Figure 15. *S. gilberti* probability population density based on *S. lewini* habitat preferences in regions where *S. gilberti* specimen have been collected.

In North America, North Carolina to Georgia have potential for high population densities of *S. gilberti* (Figure 15). This population hotspot decreases north of North Carolina and south of Georgia. For the South American region of Brazil there are two probable hotspots that could potentially have a denser population then the rest of the region. There is potential for the highest population numbers to be throughout southern Brazil near State of Sao Paulo and Parana and northern Brazil around the State of Maranhao.

Fishing Pressure

The extent of fishing pressures on *S. gilberti* is unknown. Fishing pressures were postulated from *S. lewini* because they have overlapping distributions. *Sphyrna lewini* are currently considered over fished in large coastal shark fisheries (Miller et al. 2014). *Sphyrna lewini* is primarily targeted for their fins because they sell for premium market price due to their large size and high fin needle count (Abercrombie et al. 2005; Rigby et al. 2019; Vincent et al. 2014). *Sphyrna lewini* stock has collapsed in the northwestern Atlantic Ocean due to this unregulated and highly competitive fishery (Baum et al. 2003; Hayes et al. 2009). Aggregating populations of *S. lewini* make harvesting both in general and gender based easier and consequently makes this species more vulnerable to overexploitation. Therefore, it can be assumed that *S. gilberti*, which is morphologically indistinguishable from *S. lewini*, are subjected to the same pressures.

From 1992 – 2011, Brazil and USA were the leading two countries that accounted for almost 90% of total *S. lewini* catches in the Atlantic Ocean (i.e. 49% Brazil and 40% USA; Miller et al. 2014). In Brazil, adult *S. lewini* are mainly caught incidentally in tuna longline fisheries, juveniles are caught largely in driftnet fisheries, and neonates are fished in both coastal gillnet and inshore recreational fisheries (Kotas et al. 2008; Amroim et al. 2011). As of 2014, in USA Atlantic water *S. lewini* is mainly caught with bottom longlines by directed shark permit holders, as bycatch, and recreational fisheries (Figure 16; Hayes et al. 2009; Miller et al. 2014).

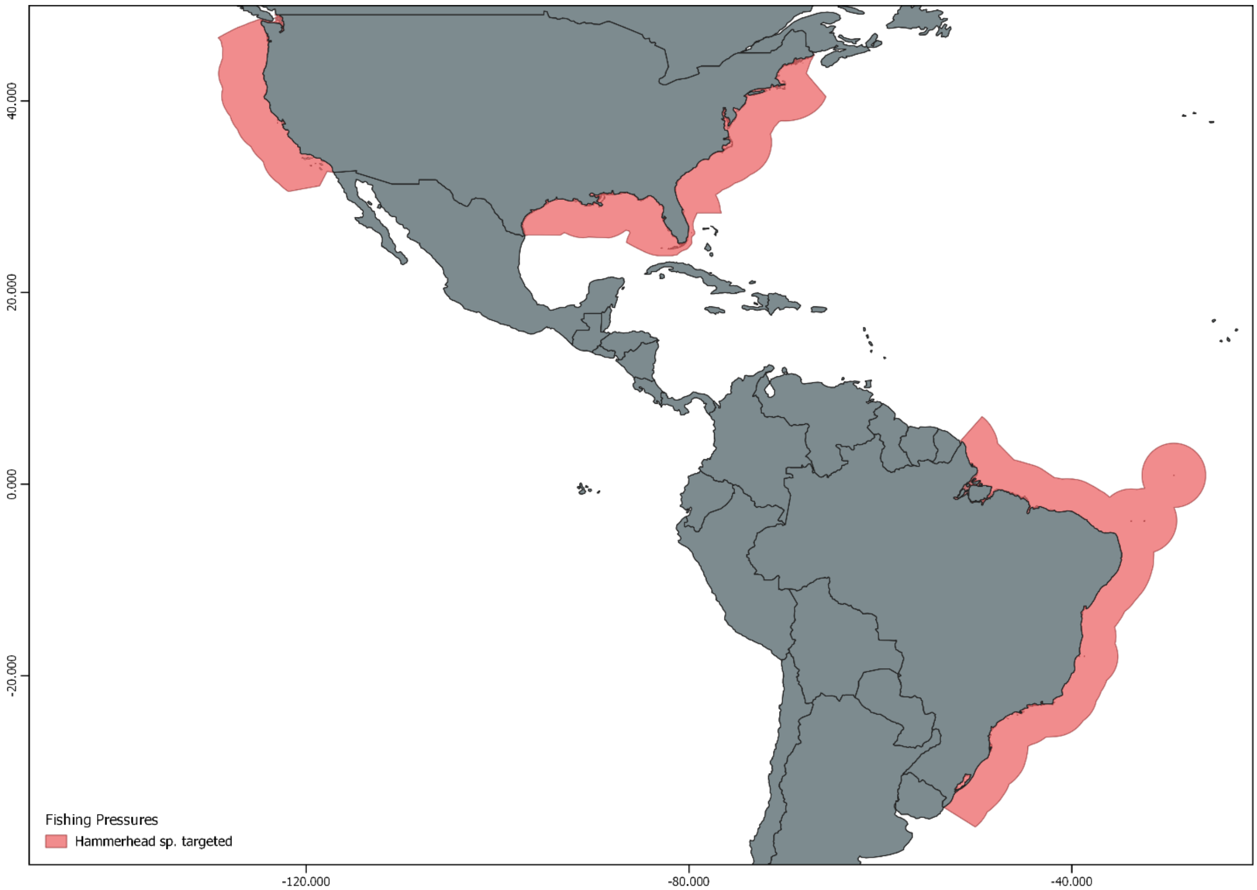


Figure 16. Assessment of potential fishing pressures throughout the predicted distribution of *S. gilberti*.

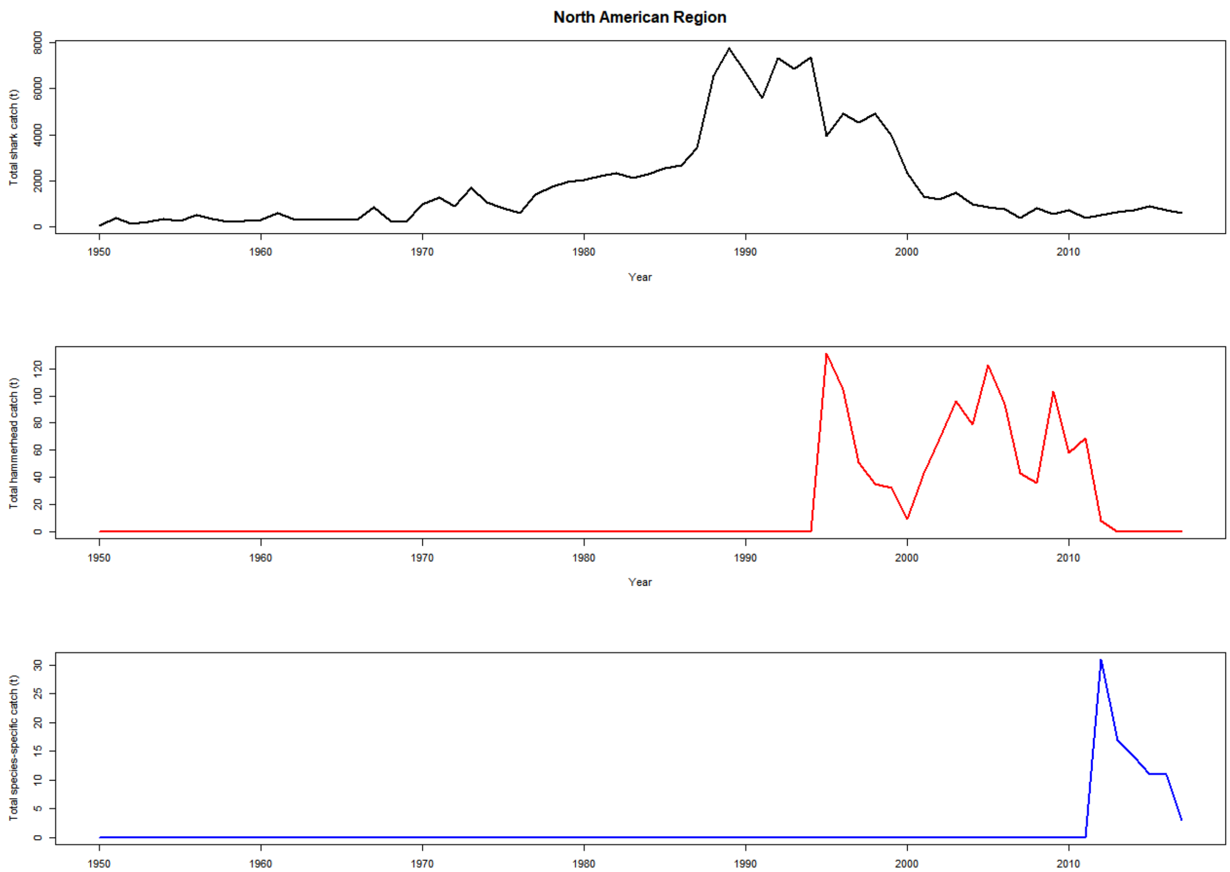


Figure 17. *S. gilberti* North American region of concern based on FAO capture fisheries statistics. North American region with total number of shark (black), total hammerhead (red), and total species-specific *S. lewini* (blue) catches reported in tons (t) by year.

In the North American region, all three fisheries examined were from USA fisheries data (Figure 17). Their shark fishery was a small steady fishery until the 1980s when the reported catch numbers rapidly increasing. By the late 1980s catch had reached a maximum of 8,000 t. Shark catch rate remained around 6,000 – 8,000 t for a few years. The decline in shark catches began in the mid-1990s. The largest decrease occurred in the late 1990s and into the 2000s, where catches tapered off and now vary around 1,000 t.

For both total hammerhead and *S. lewini* catches, reporting did not start until 1995 and 2011, respectively. Total hammerhead catch reports started in the mid-1990s with a peak of about 140 t of hammerheads. There was an immediate decrease in reported catch rates until a low was reached in the year 2000 of less than 20 t. Increased reports began again shortly after the low was hit in 2000 with another drop in take rates a few years later following the spike in mid-2000s. This decline lasted a year or two before there was an uptick in catches again. After 2010, the fisheries

went on an unsustainable decline. From 2013 and on there have been no reported catch of hammerheads overall. The total *S. lewini* data shows catch rates were not reported until early 2010. The initial reported numbers were about 30 t and could not be maintained and subsequently have been in a steady decline since.

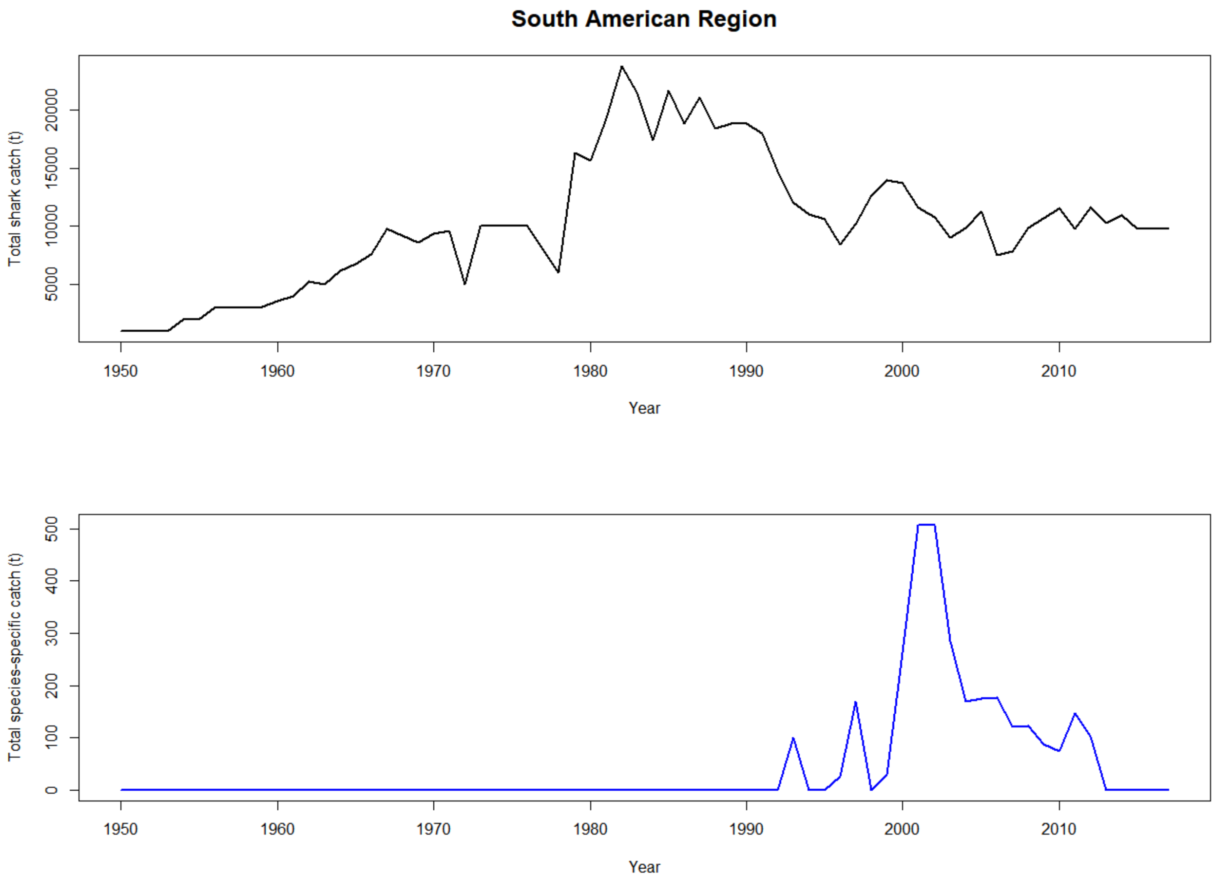


Figure 18. *S. gilberti* South American region of concern based on FAO capture fisheries statistics. South American region with both total number of shark (black), and total species-specific (blue) catches reported in tons (t) by year.

For South America, Brazil fisheries were examined. Their total shark fisheries are more sustainable than their *S. lewini* fisheries (Figure 18). In their general shark fisheries, the increase in reported catches were steady until late 1970s with few small decreases. In the late 1970s, catch rates amplified quickly to a maximum of about 25,000 t. The take rate remained high from 200,000 – 250,000 t for about a decade. A steady decrease in reported catches occurred around 1990 and did not reverse until the late 1990s. Since 2000, there have been few fluctuations throughout the years and catches remain within the 10,000 – 12,500 t range. Targeted *S. lewini* fisheries are vastly

more unsustainable than Brazil's total shark fishery. There were two minor spikes before maximum yield was reached in 2000. In the 2000s, catches reached a maximum of 500 t and remained for about a year before experiencing a decline in catch. From 2013 and on there has been a reported catch of zero.

Conservation

Sphyrna gilberti has not been reviewed by the IUCN. This species remains enigmatic and overlooked in hammerhead shark fishery management plans (Pinhal et al. 2012). *Sphyrna gilberti* might be less abundant than *S. lewini* because specimens are rarely encountered. This could indicate that this species is more susceptible to overexploitation than the endangered *S. lewini*. Given the decreasing *S. lewini* stocks and numerous fishing pressures *S. lewini* are subjected to throughout their distribution, it is reasonable to speculate that *S. gilberti* could be experiencing the same or more drastic population declines than *S. lewini* (Hayes et al. 2009; Quattro et al. 2013).

Though this species is not specifically included in any legislation like *S. lewini* since these species are difficult to tell apart these regulations for *S. lewini* might inadvertently apply to *S. gilberti*. For example, there have been regulations implemented in the USA that prohibits taking *S. lewini* in association with the commercial pelagic longline and recreational fisheries for tunas, swordfish, and billfish in the Atlantic Ocean. USA also reports to ICCAT which adopted recommendation 10-08 which prohibits the retention, transshipment, landings, storing, or offering for sale any part or whole carcass of any hammerhead shark of the family Sphyrnidae (with the exception of *S. tiburo*) (ICCAT 2010; Miller et al. 2014). The USA are members of ICCAT, IATTC, CCAMLR, NAFO, and WCPFC. They also have a NPOA – Sharks plan since 2001 which was established to ensure the conservation and management of sharks and their long-term sustainable use (DOC 2001). Although *S. lewini* were in a population rebuilding phase in north western Atlantic as of 2014, populations further south (i.e. Brazil) could be in danger of decline. Brazil is a member of ICCAT and have a NPOA that came into effect in 2005. Their objective is to raise awareness, reduce incidental catch, and improve/expand fisheries management programs. However, it is still in the process of developing domestic regulation that will help achieve 10-08 recommendation set forth by ICCAT (Miller et al. 2014).

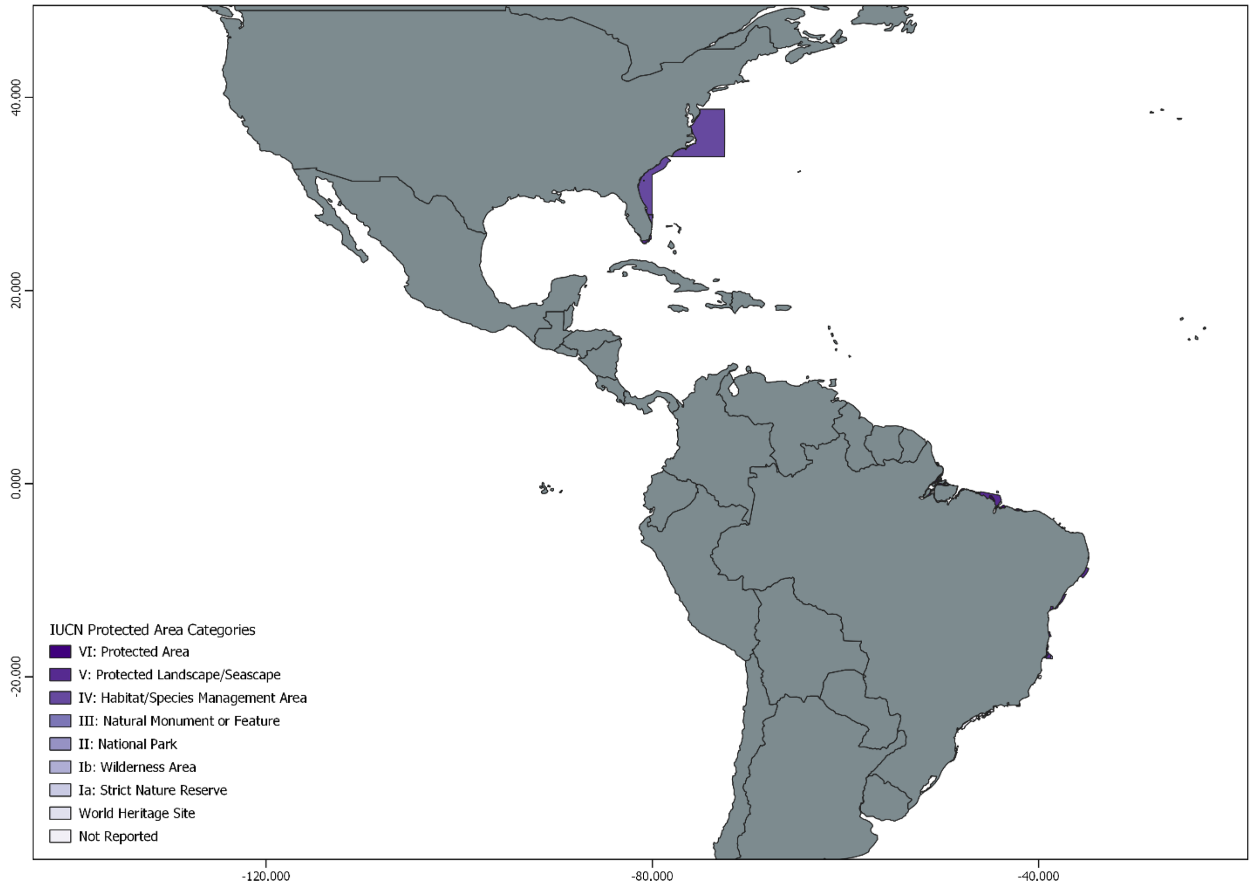


Figure 19. Marine protected area overview throughout *S. gilberti* distribution where more actively protected MPAs are dark purple shades and the areas not defined by the IUCN are the lighter shades.

There is a total of 264 MPAs throughout the predicted distribution of *S. gilberti* (Figure 19). Of the 264 MPAs, level V protection sites are predominate with 11: Ia, 6: Ib, 12: II, 16: III, 55: IV, 88: V, 23: VI, and 1: World Heritage Site. There are 52 sites that did not report their assigned IUCN category level. The majority of the MPAs are in USA Atlantic waters (e.g. 140 MPAs and 124 MPAs in Brazilian waters). Most of the MPAs in the USA waters are level V or protected seascape/landscape sites. There are only two total no take zones and five partial no take zones.

Sphyrna media

Biology

Common name: Scoophead

Sphyrna media is another small hammerhead species with a plethora of gaps throughout its historical data. *Sphyrna media* is closely related and difficult to distinguished from *S. corona*. *Sphyrna media* was first described by Stewart Spring in 1940. This species has a moderately broad and anteriorly arched mallet shaped cephalofoil. The head has weak medial and lateral indentation along the anterior edge. There are no prenarial grooves and the snout is short at only about one-third of the total width of the head (Compagno 1984). The mallet shaped head is moderately wide and has a considerable longitudinal expansion. The width of the mallet shaped head ranges from 22% to 33% of the species TL. *Sphyrna media* has a large and broadly arched mouth with 24 – 37 teeth in the upper jaw and 25 – 37 teeth in the lower jaw (Last 2002). The anterior teeth are long slender smooth edged cusps and the posterior teeth are cuspidate (Gilbert 1967; Compagno 1984).

The first dorsal of *S. media* is falcate and has a free rear tip over the pelvic insertion. The second dorsal is tall and about the height of the anal fin. The anal fin, while equal in height has a larger base than its second dorsal fin, with the base measuring to 7.2% to 9% of the TL. This fin begins before the origins of the second dorsal and its posterior margin is shallow and slightly concaved. The upper precaudal pit is transverse and crescentic (Gilbert 1967; Compagno 1984; Last 2002). *Sphyrna media* has a total vertebra count ranging from 101 to 196 (Last 2002). Their coloration dorsally is a grey to brown color with a light white ventral side and unmarked fins (Compagno 1984).

Life history

Data on the life history of *S. media* is lacking. This small sphyrnid can grow to be about 150 cm TL though it is unknown what sex this applies to. Size of maturity is thought to be 100 – 133 cm TL for the female and 90 – 100 cm TL for the male. Sexual maturity age and longevity is unknown for both sexes. The reproductive ecology for *S. media* is understudied, their gestation period, mating season, litter size, and reproductive age are all unknown life history aspects. All that is known for *S. media* reproduction is that they exhibit viviparous reproduction pattern and pups are born as 34 cm TL, other than this information not much more is known. (Compagno 1984; Casper and Burgess 2006). The only other information available for this species is potential diet.

In a study conducted in Trinidad and Tobago, a researcher found that this species preferred to feed on small elasmobranchs, octopods, squid, and flounders (Castro 1989). It is unknown if this diet varies between geographic location.

Distribution

This species inhabits coastal waters in both the western Atlantic and eastern Pacific Oceans. *Sphyrna media* has a presumed distribution from Panama to Brazil in the western Atlantic and from the Gulf of California to northern Peru in the eastern Pacific (Compagno 1984; Castro 1989). According to the known geographical catches, environmental predictors for *S. media* suggest that preferred habitats are in areas where the depths range from 29 – 100 m, temperature 23.38 – 28.85 Cº, salinity 31.05 – 35.26 psu, and distance from shore is 8 – 449 km (Kaschner et al. 2019).

Figure 20. *Sphyrna media* known distribution and probability distribution. (Green) actual known recordings of species and (blue) probability distribution based on habitat preference. Dark blues indicate a high probability of occurrence lighter blues are less probable.

There are more known catches of *S. media* in the eastern Pacific Ocean than the western Atlantic (Figure 20). Probability in the eastern Pacific Ocean is highest towards the mouth of the Gulf of California and remains high until Ecuador. At Peru, the probability of occurrence decreases considerably. In the western Atlantic Ocean, there is high probability of occurrence in the north Gulf of Mexico. The probability fluctuates going south to Honduras. There is a high likelihood of presence continuing south from Honduras until north Brazil. From there, the probability decreased slightly but, the environmental predictors suggest that this could still be a potential habitat for *S. media*. This species is less likely to occur in the Caribbean Sea around Cuba and Puerto Rico. The known distribution data for the western Atlantic only suggests that *S. media* is found from Panama to Brazil but, the predicted distribution suggests that species could potentially inhabit areas much farther north. The possible distribution could be as far North Carolina and could continue pass the known southernmost distribution of Brazil to Uruguay. The prediction model (figure 20) for the eastern Pacific further confirms the distribution of *S. media* within the Pacific Ocean.

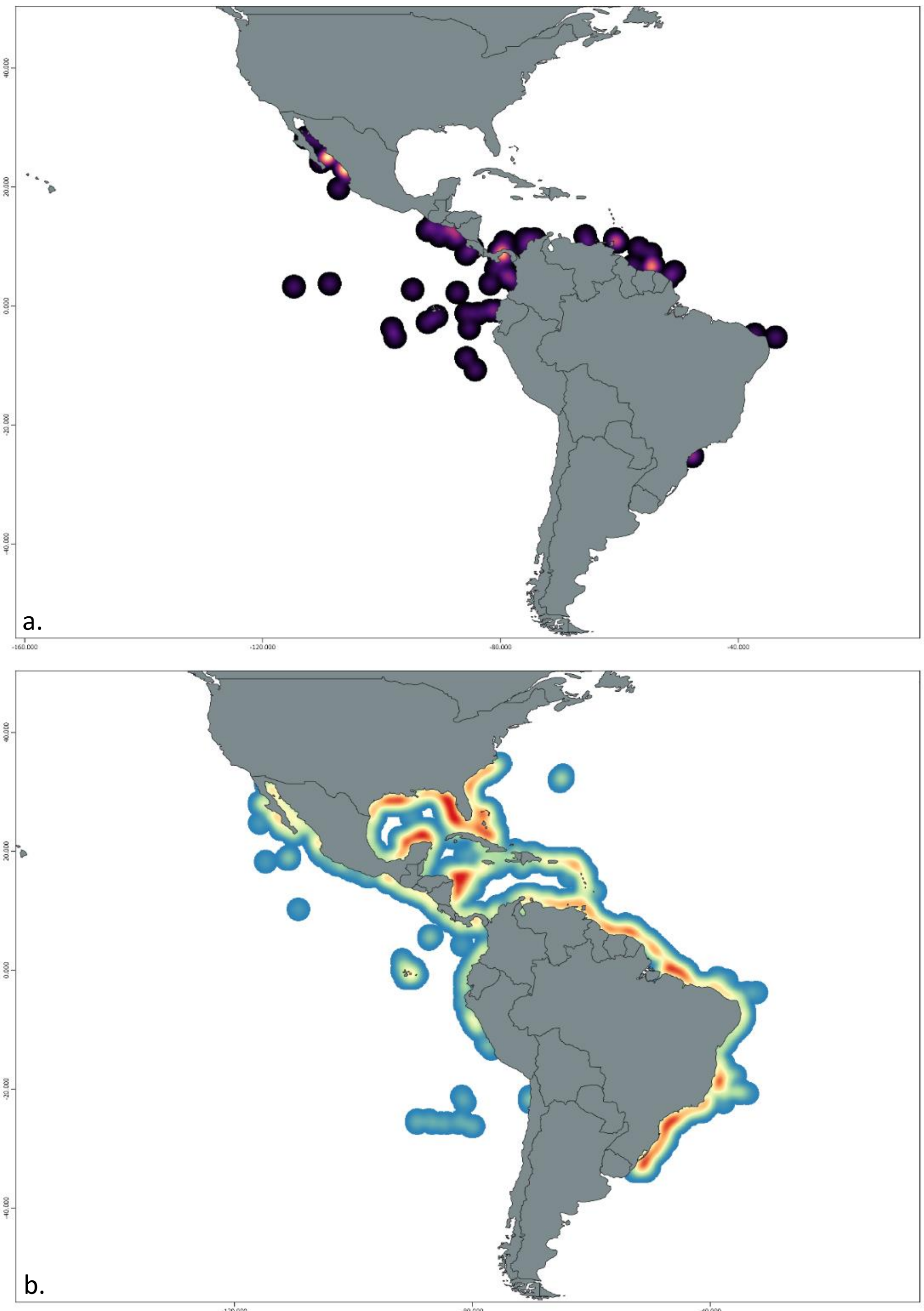


Figure 21. *S. media* (a) known population density and (b) probability population density.

In figure 21a there are two major population density hotspots and they both occur in the southern most point of the Gulf of California. Other hotspots include Panama, both Pacific and Atlantic oceans, south Venezuela, and Suriname. Figure 21b suggests that the highest population

density would be mainly in the Atlantic Ocean. The highest densities could be in the Gulf of Mexico, specifically Florida, Texas, and the southern tip of Mexico. Other potential high population densities could be North Carolina to the Bahamas and then Venezuela down to Uruguay. There are potential moderate hotspots in the Pacific Ocean but mainly in the Gulf of California.

Fishing Pressure

Sphyrna media is mainly fished for its meat, either for human consumption or for fishmeal (Compagno 1984). They are taken in fisheries utilizing bottom longlines, gillnets, and hook and line throughout their coastal range. There is little information available as to the extent of capture and exploitation rates (Compagno 1984; Casper and Burgess 2006; Perez-Jimenez 2014). However, similarly to *S. corona*, this species, is not targeted for their fins because of their small fin size and their market value is low in the global fin trade market (Abercrombie et al. 2005). *Sphyrna media* is heavily targeted for their meat in shark fisheries throughout its range (Fernandez et al. 2011). In the Central American region Costa Rica, Mexico, and Panama target this species in artisanal fisheries (Perez-Jimenez 2014; Rojas et al. 2016; Guzman et al. 2019). In South America, Ecuador, French Guiana, Galapagos, Guyana, and Suriname also target *S. media* in their artisanal fisheries and is frequently found in local fishing markets along the coast (Abo-Tubikh 2014; Kolmann et al. 2017; Hankinson 2019). Finally, in the Caribbean region, Trinidad and Tobago are known for targeting this species and landing them as bycatch in their shrimp and mackerel gillnet fishery (Shing 2005; Casper and Burgess 2006).

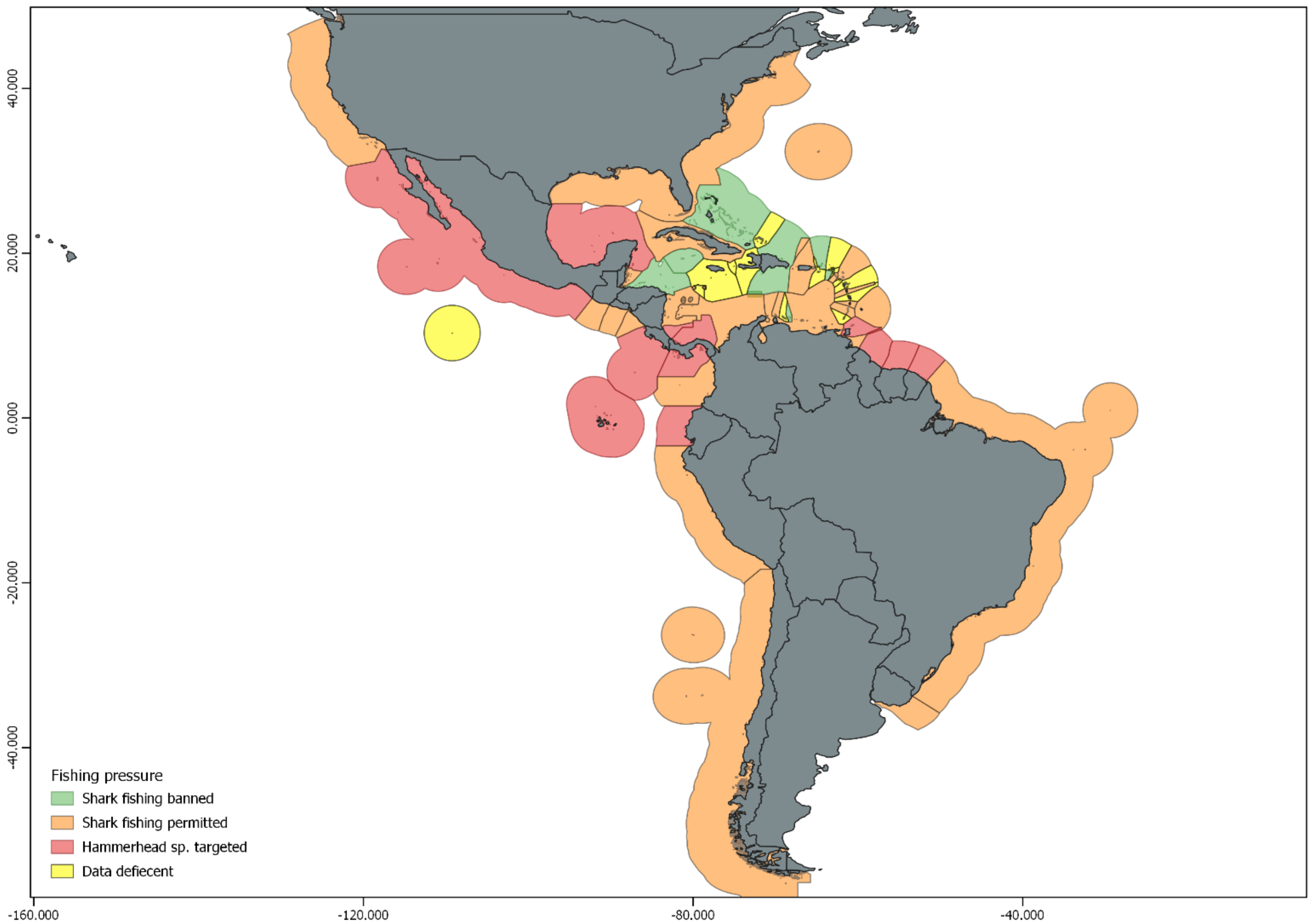


Figure 22. Assessment of fishing pressures throughout both known and predicted distribution of *S. media*.

There are nine countries that specifically report the targeted catches of *S. media*, 12 countries that are data deficient, and 10 countries that have successfully banned shark fishing (Figure 22). The remaining countries all report to a higher taxonomic level. The 12 areas that are data deficient are most notably small islands that do not report catches to RMFOs (e.g. Montserrat, Haiti, and Grenada). There are eight EEZs that have banned fishing and are recognized shark sanctuaries; Bahamas 2011, Bonaire 2015, British Virgin Islands 2014, Cayman Islands 2015, Dominican Republic 2017, Honduras 2011, Saba 2015, and Saint Maarten 2016. These shark sanctuaries range from smaller coverage in Saint Maarten at 499 sq. km to the larger coverage areas of 629,2933 sq. km in the Bahamas (Ward-Paige 2017).

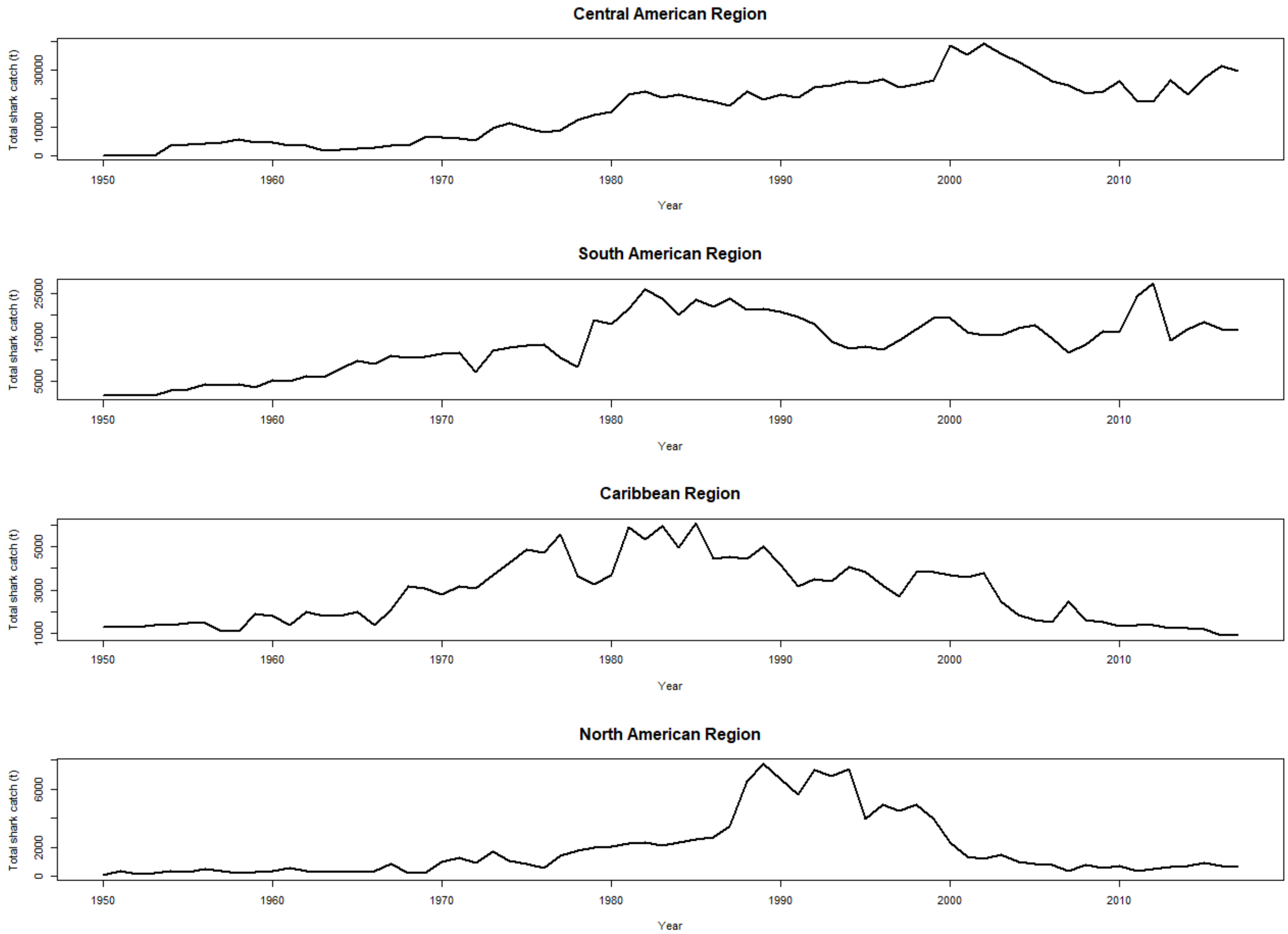


Figure 23. *S. media* distribution regional assessment of areas where sharks are caught but species is not specifically targeted based on FAO capture fisheries statistics. Regions of concern and total number of shark catches reported tons (t) by year.

Of the four regions examined both Central and South America have a more sustainable general shark fishery than the Caribbean and North American regions (Figure 23). In Central America, total shark catches increase gradually over decades beginning mid-1950s until 2000. A maximum of 40,000 t was reached and fished for a few years until there was a slow sloping decrease, reaching lower catch around 2010 of about 20,000 t. Since this time, catches are not stable but, they have not dropped below 20,000 t. These catches vary between 20,000 – 30,000 t through the years. In South America, reporting did not start until the mid-1950s, but this region hit a maximum of just over 250,000 t in the early 1980s. Reported catch rates stayed in the upper 200,000 t level until 1990. Small increases and decreases occurred throughout the years until 2010 when catches maxed out at 300,000 t. Then there was then a sharp decrease around mid-2010s and

reported shark catches have leveled out to be around 160,000 t. The Caribbean region saw a peak of catch around the late 1970s around 5,500 t followed by an immediate decrease in reported catches. In the beginning of the 1980s catch peaked to 60,000 t and stayed relatively constant for a few years. Since the 1990s, reported total shark catch rates have been on the decline with lowest catches rates at around 1,000 t. Another unsustainable shark fishery in the North American region. From the 1950s until mid-1980s total shark catch rates were relatively low in the 1,000 – 2,000 t take rate range. Close to 1990 there was a steep increase in reported catches maxing out at about 8,000 tons. This region maintained this catch rate until mid-1990s when a decrease had occurred. Currently, total shark catch rate has plummeted to below 1,000 t which is an unsustainable fishery.

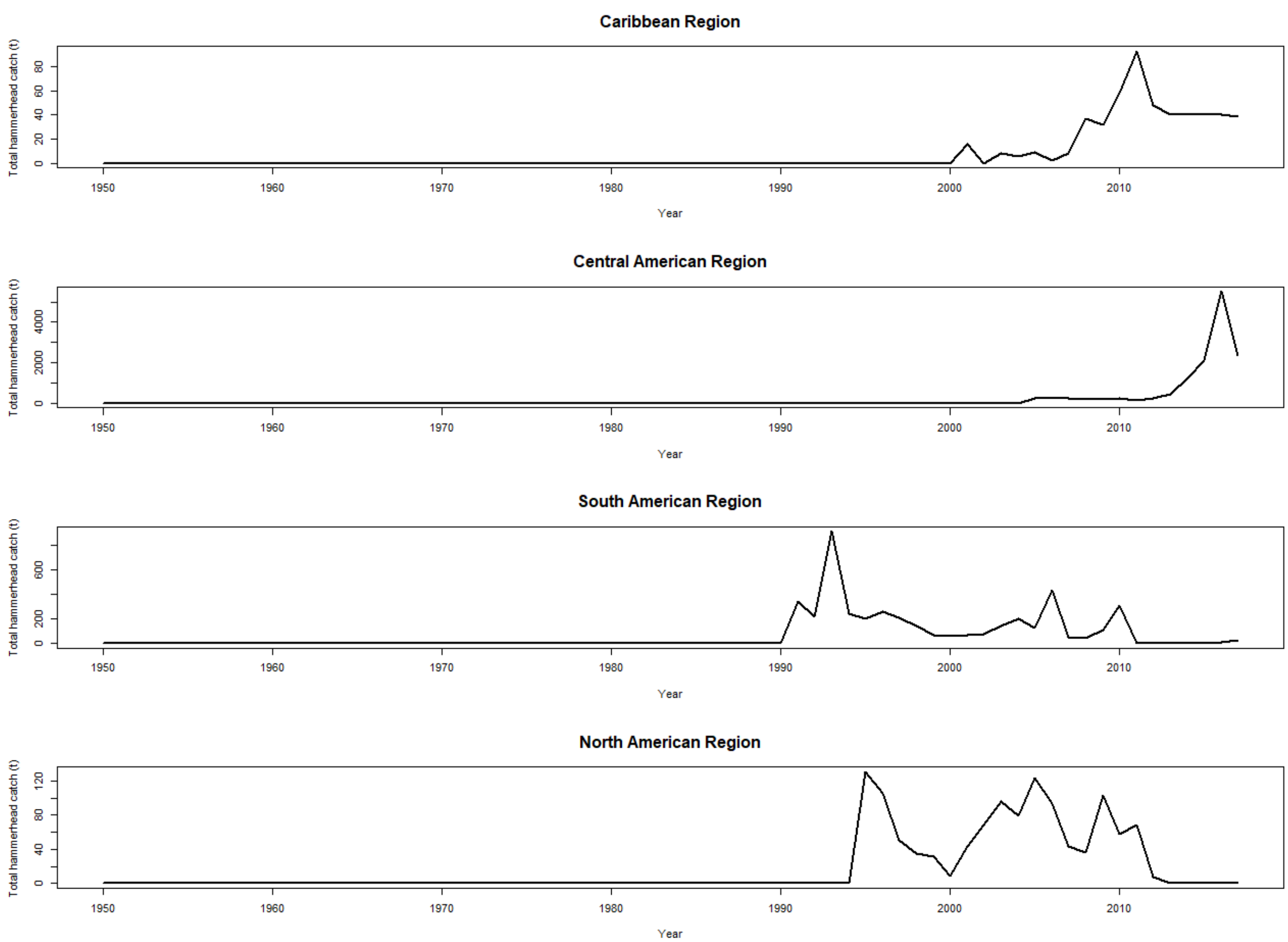


Figure 24. *S. media* distribution regional assessment of areas where hammerhead sharks are reported based on FAO capture fisheries statistics. Regions of concern and total number of hammerhead shark catches reported tons (t) by year.

The Caribbean, unlike the total shark fisheries, has a smaller scale and only one country reported their hammerhead catches (Figure 24). The only region to report hammerhead catches was Trinidad and Tobago. They did not start reporting their hammerhead catch until 2000 and catch rates remain similar until 2010 where catch increased to 100 t. After this increase, hammerhead catch rates plateaued to a stable level around 40 t in recent years. Mexico was the only Central American country to report hammerhead catches. Catch reports started in mid-2000s and take rates increased until 2016 when they reached a maximum of around 6,000 t. It is unknown where the trend will go, but as of 2017, the trend is declining. For the South American region, Colombia, Ecuador, Guyana, and Uruguay reported hammerhead shark catches. South America reports started in 1990 and reached a maximum of about 1,000 t shortly after reports started. After 2010, the hammerhead fisheries became unstable and regions were reporting hammerhead catches of zero. North America experienced an unsustainable collapse to their hammerhead fisheries shortly after 2010, where catch rates went from highs of 140 t to reports of zero t.

Conservation

Sphyrna media was categorized as data deficient on January 31, 2006 and is not currently apart of any international or regional management plans. While a majority of countries throughout its distribution range have some form of regional or national action plan in place this species is overlooked in all of these plans. Most data suggest a serious need for attention in the Central American region. Throughout the Mexican Pacific Ocean this once prominent species are no longer recorded in these waters (Kato 1965; Hernandez-Cavallo 1967; Perez-Jimenez 2014). Their absence from fisheries is not a recent development with the decline seen over the years. Given the continued fishing pressures in the coastal waters of the Mexican Pacific and the entire eastern Pacific Ocean, researchers suggest this species should be reassessed as Endangered over all (Perez-Jimenez 2014). There could be other regions that may need to reassess this species status but for now most data has only been done on the *S. media* populations in the Central American region.

In the Central American region, all countries follow at least one RMFO. Most abide by the guideline of either ICCAT or IATTC. On a national level all but Guatemala and Nicaragua have a NPOA – Sharks established. Most have been discussed in previous sections (*S. corona*). Belize has a NPOA in place but, this mainly applies for high seas shark fisheries only (Belize High Sea Fisheries Unit 2015). Honduras had a NPOA established in 2005, before becoming a shark

sanctuary in 2011 (Ward-Paige 2017). In North America, only two countries were evaluated, USA (see *S. gilberti*) and Bermuda. Bermuda does not follow any regulation put forth by any RMFOs and does not have a NPOA. South American countries follow at least one of the following regional organizations ICCAT, IATTC, CCAMLR, or Caribbean Regional Fisheries Mechanism (CRFM). As with Central America most, countries where already discussed above in *S. corona* conservation section. The other regions not previously mentioned, Venezuela's NPOA was created in 2006 and revised in 2013. This NPOA focuses on establishing shark identification guidelines, creating monitoring programs, and establishing research programs. Chile adopted a NPOA in 2006 and Uruguay established one later in 2008 which was later revised in 2015 (Fischer et al. 2012). In the Caribbean, 9 out of the 29 countries do not follow any regulations from any RMFOs, Aruba, Bonaire, British Virgin Islands, Cayman, Dominica, Guadeloupe, Martinique, Saba, and Saint Eustatius. The 20 other countries follow at least one of the following RMFOs; ICCAT, IATTC, CRFM, or Western Central Atlantic Fishery Commission (WECAFC). Out of all 29 countries only three overall have documented NPOA – Sharks plans they are Antigua 2015, Cuba 2015, and Saint Kitts 2015. Two other regions, Barbados and Trinidad, had drafts submitted but as of 2016 were never approved (WECAFC 2016).

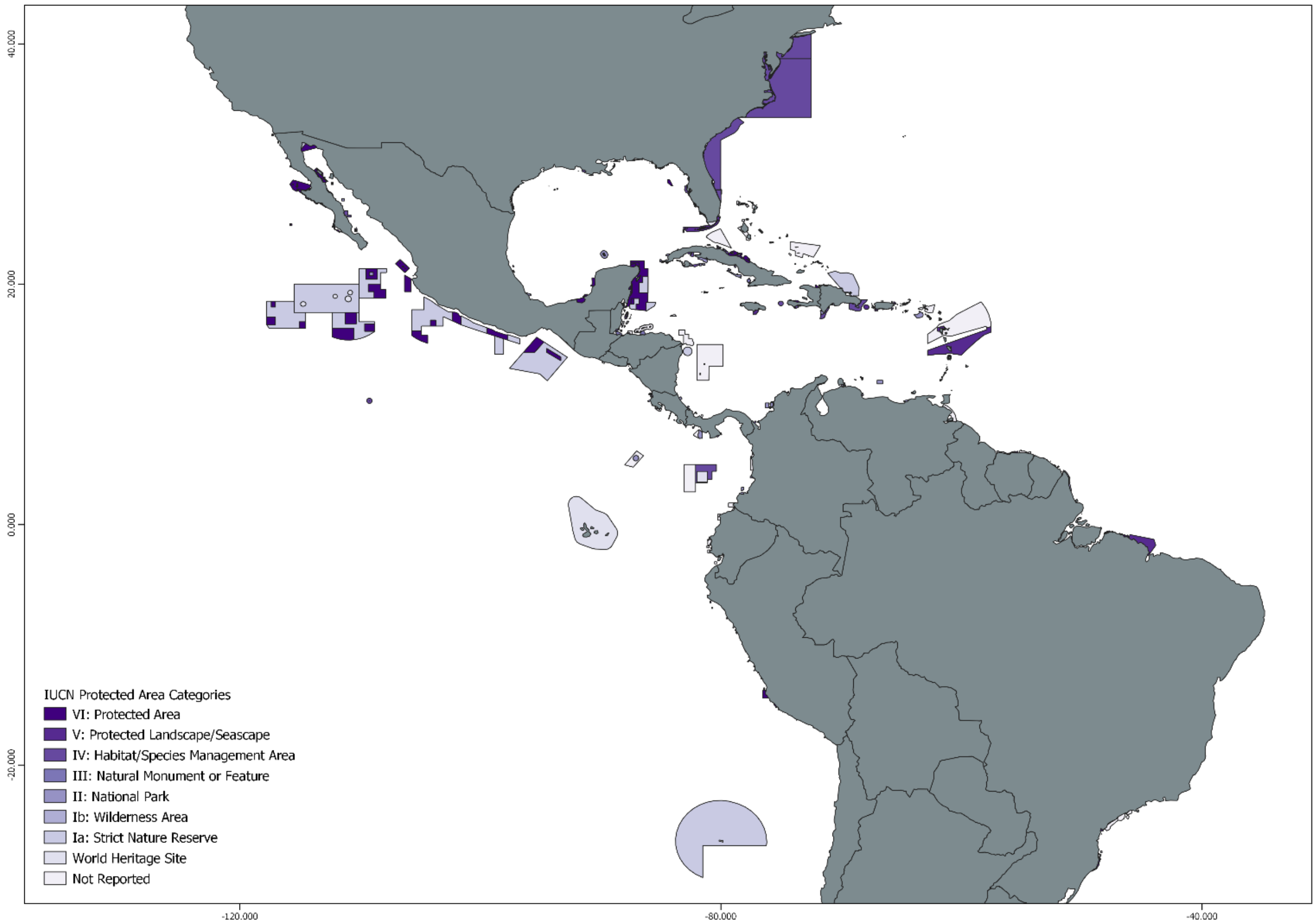


Figure 25. Marine protected area overview throughout *S. media* distribution where more actively protected MPAs are dark purple shades and the areas not defined by the IUCN are the lighter shades.

Along with the eight EEZs that have banned fishing and are recognized shark sanctuaries there are a total of 1,072 MPAs throughout the distribution range of *S. media*; 51 Ia, 11 Ib, 137 II, 38 III, 390 IV, 179 V, 67 VI, and 10 world heritage sites. There are no MPAs that are unassigned but there are 189 MPA sites that are not reported. The majority of the MPAs throughout these regions are habitat/species management areas. Some of these MPAs are no take zones with 62 total no take zones and 32 partial no take zones. A majority of these MPAs are with in USA EEZ waters. There are a total of 242 MPAs alone in USA waters both in the Gulf of Mexico and Atlantic Ocean (Figure 25). Most of the MPAs throughout this area are level V protected seascapes.

Sphyrna tiburo

Common name: Bonnethead

Biology

Sphyrna tiburo, while still lesser known than the three large hammerhead species, is considerably further researched than the other five lesser known species. There has been substantially more research conducted on life history, fishing pressure, and conservation of this species. This small sphyrnid, like *E. blochii* has a uniquely shaped cephalofoil distinguishable from the others in the Sphyrnidae family. The head is a broadly rounded shovel shape without any indentation present along the anterior edge. The lateral expansion is the smallest of all other hammerhead species and its expansion is more longitudinal then latitudinal. The head width is 18 – 25% of *S. tiburo* TL (Compagno 1984). A distinctive longitudinal bulge forms on the cephalofoil of *S. tiburo* from the elongation of three rostral cartilages. This bulge develops at maturity along the anterior margin of the head and is thought to be attributed to a developmental event linked to reproductive maturity. Furthermore, there is no difference in head shape between the sexes in the embryonic and juvenile stages (Kajiura et al. 2005).

Sphyrna tiburo differs from most elasmobranchs because they have a relatively low mass specific bite force, lack a robust fused jaw, and hypertrophied feeding musculature (Summers et al. 2004; Huber et al. 2005; Mara et al. 2010). Their upper jaw is less protrusible, they have prolonged jaw abductor activity patterns, and have an enlarged maximum gape (Wilga and Motta 2000). The mouth is broadly arched with short non-serrated anterior teeth and molariform posterior teeth (Compagno 1984). In the upper jaw the first tooth is erect and symmetrical then the teeth become increasingly oblique towards the corners of mouth. The upper jaw has shorter teeth with a broad base and narrow cusps. The first through the third teeth in the lower jaw are symmetrical and erect becoming slightly oblique posteriorly. For both jaws, teeth three to 10 or 11 are the largest set of teeth (Gilbert 1964; Last 2002).

Sphyrna tiburo does not have any prominent fin markings (Compagno 1984). Their first dorsal fin is moderately falcate and begins over the inner margins of the pectoral fin. The second dorsal and anal fin are relatively elongated and about equal heights. The second dorsal posterior margin is resolutely concaved. The anal fin is similar in height to the second dorsal but is larger in overall size compared to the second dorsal fin. Its base is 6.4 – 8.5% of *S. tiburo* TL and the posterior margin is more straight than concaved (Compagno 1984; Last 2002). Lastly, the pelvic

fins are not falciform and their posterior margins are nearly straight. *Sphyrna tiburo* has a total vertebrae count of about 142 – 173. *Sphyrna tiburo* has a coloration ranging from grey to a grey brown dorsally and a light ventral side with small dark spots along the side of their body.

Life history

Sphyrna tiburo has a complex life history with traits that can be influenced by geographic location. These variations within life history traits have been seen in populations of *S. tiburo* only separated by three latitudinal degrees. Trait differences include size and age at maturation, time of fertilization, rate of embryonic development, size at birth, gestation period, and energetic investment in offspring (Parsons 1993a). Three prominent geographical areas have been surveyed where *S. tiburo* was rigorously evaluated; The western North Atlantic, both East and West Florida, and the Gulf of Mexico. Overall, *S. tiburo* has one the highest fecundity rates, rapid growth, shortest life span, and smallest sizes at maturity of all other hammerhead species (Cortés 2000; Carlson and Baremore 2003; Lombardi-Carlson et al. 2003).

In the western North Atlantic Ocean (i.e. North Carolina to Florida), *S. tiburo* populations tend to be smaller than the other populations. Females size range from 26.2 cm to 104.3 cm and males had a range of 24.5 cm to 82.5 cm off the coast of North America (Ebert and Stehmann 2013; Frazier et al. 2014). While in other regions such as the eastern Gulf of Mexico (EGoM) females reached maximum size at about 130 cm TL and males at 100 cm TL (Pratt and Casey 1990; Parsons 1993a; Cortés and Parsons 1996). Throughout Florida, females reach a maximum size at about 103 cm and males at 82 cm. This is the general census for Florida, however there are even differences between the Florida populations of *S. tiburo*. In Tampa Bay female adults are significantly larger in length than those in Florida Bay. In Florida Bay, adult females averaged about 90.9 cm ± 4.9 cm TL and the maximum at about 103.7 cm. In Tampa Bay, the average was 100.3 cm ±6.1 cm TL and the maximum was 116cm (Parsons 1993a; Carlson and Parsons 1997). Generally, *S. tiburo* females tend to grow larger than males (Parsons 1993a).

For the western North Atlantic Ocean population of *S. tiburo* the maximum age for females is 17.9 and males 16.0 years of age. Females matured at 81.9 cm and about 6.7 years while males matured at a smaller and younger age of 61.8 cm and 3.9 years. (Frazier et al. 2014). In the EGoM, females mature in the size range of 80 – 95 cm TL or between the ages of two to three years while the males mature between 65 – 85 cm TL at around two years of age (Pratt and Casey 1990;

Parsons 1993a; Cortés and Parsons 1996; Castillo-Geniz et al. 1998). The maximum observed age for this species in this region was between seven and eight years for females and five to six for males. However, it is assumed that the maximum age for *S. tiburo* females is higher than what was observed, about 10 – 12 years for the maximum (Cortés and Parsons 1996; Lombardi-Carlson et al. 2003). In Florida, *S. tiburo* mature at a much younger age in both regions studied. Females matured at around 2.2 years or 2.3 to 3.0 years in Tampa Bay and Florida Bay, respectively. For both sites males mature at about the same age, 2.0 years (Parsons 1993 a,b). Both the Florida and Tampa Bay female populations are considered mature around 83 – 85 cm TL, while the males in the Tampa Bay population mature, 80 cm, at a body size 10 cm larger than the males in the Florida Bay (Parsons 1993a,b). Overall, both females and males in the western North Atlantic have significantly higher maximum observed ages, mature at an older age, and mature at a larger size than that of the EGoM and Florida populations (Frazier et al. 2014).

All *S. tiburo*, regardless of distribution, reproduce annually, are placental viviparous, and have the shortest gestation period of all known shark species (i.e. 4.5 to 5 months) (Manire et al. 1995). The western north Atlantic population of *S. tiburo* typically have an early Autumn parturition and are born in late September (Cailliet et al. 1986; Branstetter 1987; Frazier et al. 2014). The average litter size for this region is about 8.8 pups (Frazier et al. 2013). For the Gulf of Mexico population, average fecundity is about 9.7 pups (Pratt and Casey 1990; Cortés and Parsons 1996). Mating occurs off Florida in November, but the sperm is stored until fertilization during March or April (Parsons 1993b; Manire et al. 1995). Peak fertilization occurs between late March and early April in Florida Bay and between late April and early May in Tampa Bay. Gestation is 4.5 month for Tampa Bay and 5.0 months for Florida Bay residence (Parsons 1993b). Parturition in Florida Bay occurs in mid-to-late August and early September in Tampa Bay (Lombardi-Carlson et al. 2003). *Sphyrna tiburo* from Tampa Bay produce fewer but larger offspring than their more constant tropical Florida Bay counterpart. The Florida Bay population produces an average of 9.3 pups and Tampa Bay population fecundity is 8.9. The difference in the timing of reproductive events are likely related to latitudinal differences in seasonal temperature and photoperiod (Parsons 1993b).

Though most of the life history traits vary based on location, diet however, remains similar for this species. *Sphyrna tiburo* specializes in feeding almost exclusively on crustaceans. This species primarily feeds on blue crabs (C*allinectes sapidus*) and stomatopods (*Squilla*) (Martin and

Palumbi 1993; Cortés et al. 1996; Lessa and Almeida 1998). They also have been seen preying upon shrimp, isopods, barnacles, bivalves, cephalopods, and small fish (Bigelow and Schrieder 1948; Compagno 1984). This species is a ram feeder and consume their prey by utilizing their widely gaped jaw and fast closure abilities (Wilga and Motta 2000). In addition to consuming invertebrates, *S. tiburo* have been observed consuming copious quantities of seagrasses from the habitats they live in. *Sphyrna tiburo* have enzymes within their gut contents that can break down the cellulose and other carbohydrates found within these seagrasses. This finding made *S. tiburo* the first documented omnivorous shark species (Leigh et al. 2018).

Distribution

Sphyrna tiburo is an abundant small sphyrnid that inhabits shallow coastal tropical and subtropical waters of the western Atlantic and eastern Pacific. This species is a common long-term resident of coastal estuaries and bays over seagrass (Parsons 1987; Heupel et al. 2006; Cortés et al. 2016). *Sphyrna tiburo* tend to live over muddy and sandy bottoms at depths ranging from 10 – 80 m (Compagno 1984). It is relatively common for juveniles and mature females to inhabit estuarine waters during the late spring to early autumn months (Ulrich et al. 2007). It has been documented that shallow sea grass areas along the coast of Florida are common nursery grounds for this species. This suggests that this species probably utilizes similar habitats as that of the Florida coast as nursery habitat throughout its range (Hueter and Manire 1994, Bethea et al. 2014). *Sphyrna tiburo* is also known for their sexual segregation (e.g. males tend to dominate in estuaries while the adult females were more dominant in the deltas). This distribution of the adult female *S. tiburo* could be related to the higher energy demands to support their higher productivity (Springer 1967; Bethea et al. 2014).

This species has a wide distribution despite the low dispersal rates from population to population (Kohler and Turner 2001; Kohler et al. 2013). *Sphyrna tiburo* is extant to Aruba, Bahamas, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, Brazil, Colombia, Costa Rica, Cuba, Curaçao, Ecuador, El Salvador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Peru, Suriname, Trinidad and Tobago, United States, Venezuela, and Bolivarian Republic of Venezuela (Lessa et al. 1998; Heithaus et al. 2007; Froeschke et al. 2010). In recent studies, *S. tiburo* have been shown to be one of the top three most abundant species in the Gulf of Mexico and Florida coastal areas (McCallister et al. 2013; Bethea et al. 2014).

This species has specific environmental factors that influence their abundance in a habitat such as salinity, water temperature, depth, bottom type, and prey abundance particularly crab abundance (Ubeda et al. 2009; Froeschke et al. 2010; Giglio and Bornatowski 2016). These key factors are crucial and play an important role in the movement, distribution, and abundance of *S. tiburo* in a region. For juveniles, temperature and salinity were of the two most influential factors affecting occurrence (Ward-Paige et al. 2014). *Sphyrna tiburo* prefer depths from 10 – 26 meters, temperatures of 22.37 – 28.17 ºC, salinity of 29.91 – 36. 18 psu, and a distance from the shore of 7 – 101km (Cortés et al. 2016; Kaschner et al. 2019).

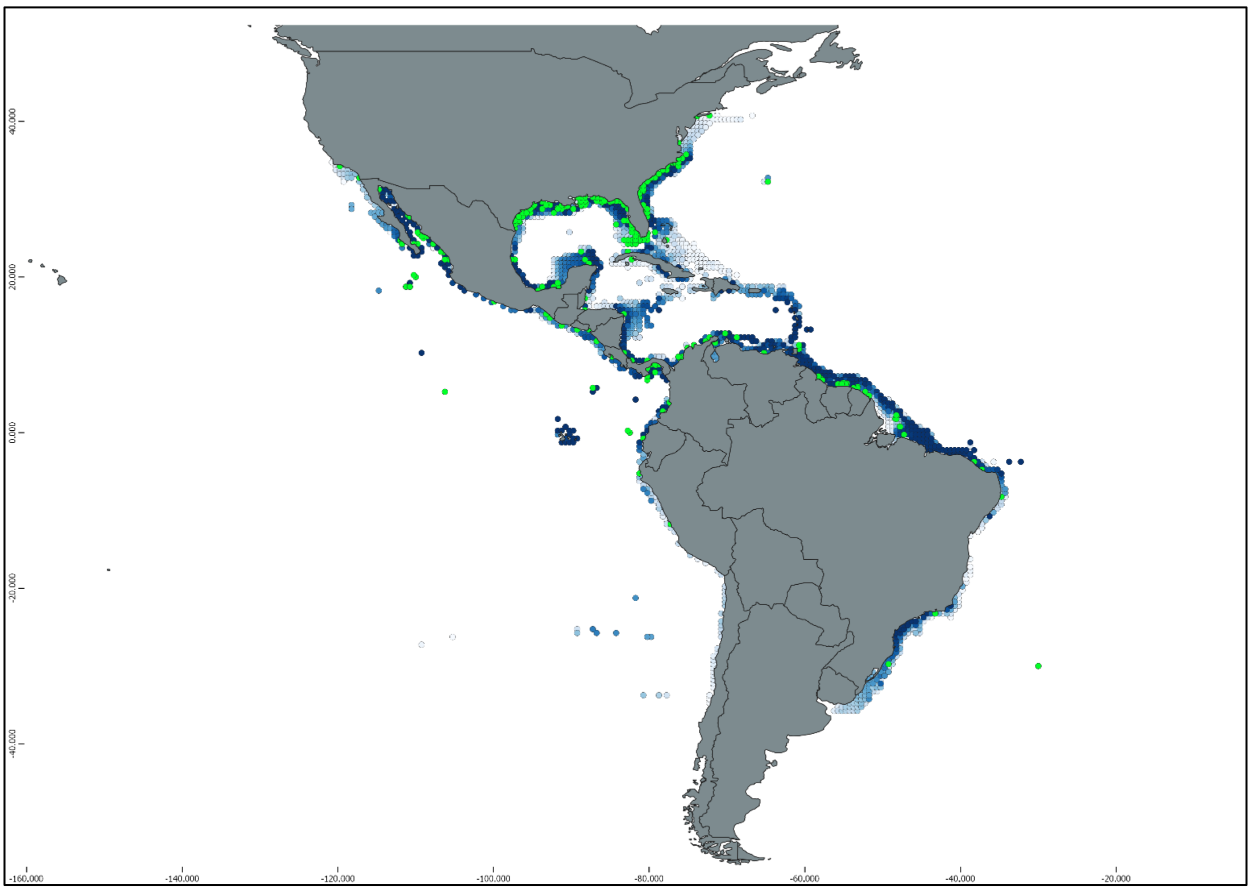


Figure 26. *Sphyrna tiburo* known distribution and probability distribution. (Green) actual known recordings of species and (blue) probability distribution based on habitat preference. Dark blues indicate a high probability of occurrence lighter blues are less probable.

In the western Atlantic Ocean, this species can be found from Brazil all the way to New Jersey and sometimes even Rhode Island (Ebert and Stehmann 2013; Cortés et al. 2016). *Sphyrna tiburo* inhabiting the north western Atlantic waters are typically only abundant during summer months but they migrate southward as the water temperature decreases in autumn and winter months (Compagno 1984). In the eastern Pacific Ocean, this species has been reported from southern California to Ecuador. Additionally, *S. tiburo* is common in the GoM but tend to be more abundant in the Caribbean (Ebert and Stehmann 2013).

Sphyrna tiburo in the western Atlantic Ocean have a high probability of occurrence throughout the range with probability decreasing around the middle of Brazil. In the Caribbean, there is a lower chance of occurrence than the other regions of the western Atlantic. The probability of *S. tiburo* inhabiting waters North of New Jersey is small. In the eastern Pacific, probability of occurrence is small from Chile north until Ecuador. Probability of occurrence increases and remains high throughout the distribution into the Gulf of California. *Sphyrna tiburo* is more likely to occur within the Gulf of California and their probability of occurrence decreases on the opposite side of the Gulf.

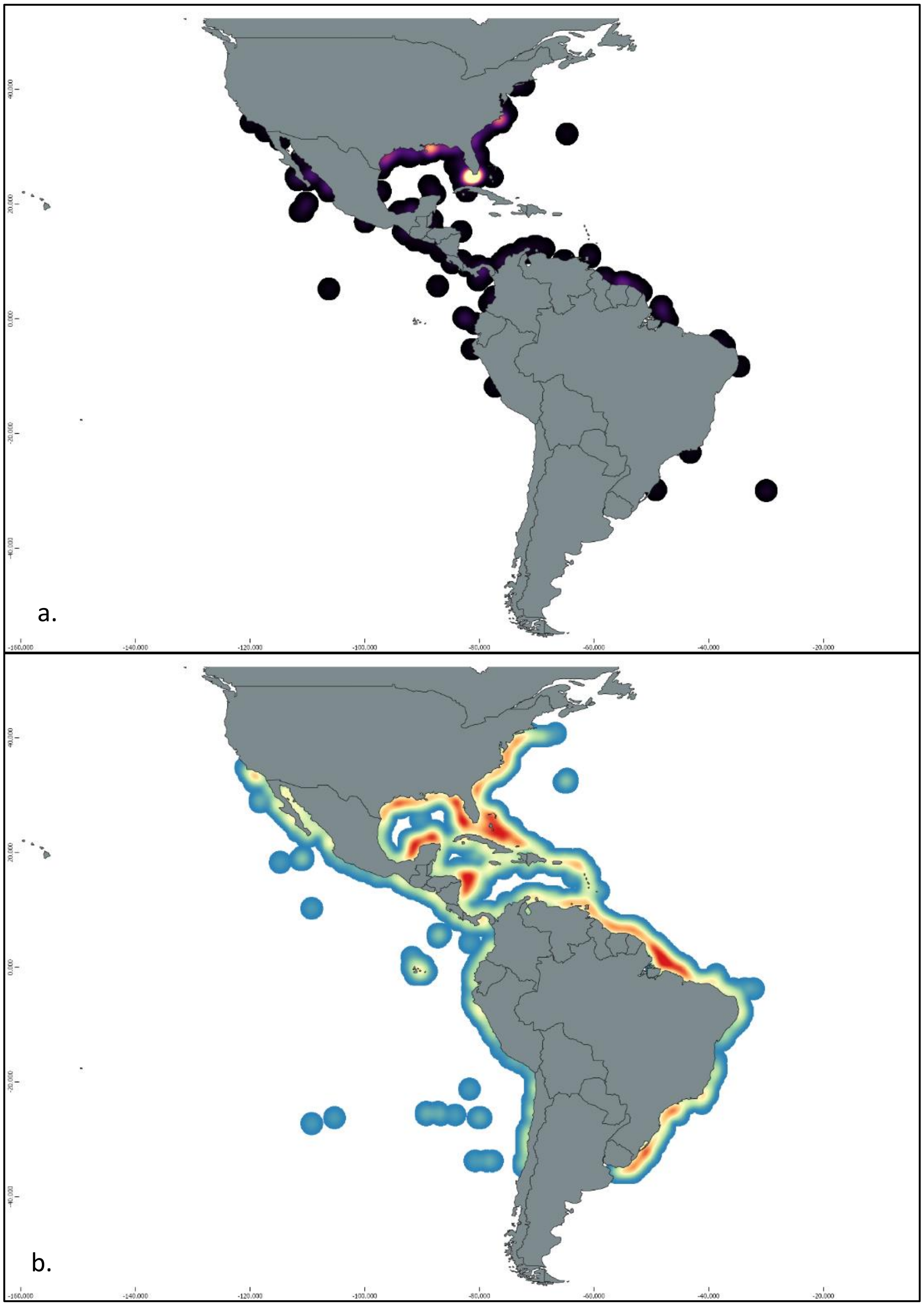


Figure 27. *S. tiburo* (a) known population density and (b) probability population density.

The known hotspots for *S. tiburo* are in the north eastern Atlantic Ocean. The largest most defined hotspot is the tip of Florida followed by the waters by Louisiana, Texas, and North Carolina. Other less prevalent densities throughout the range of *S. tiburo* are in the Gulf of California, Panama, and Suriname (Figure 27a). There are many more possible hotspots for this

species. A majority of the western Atlantic Ocean is shown to have numerous potential hotspots for this species (Figure 27b). There are more potential high population density locations in the western Atlantic Ocean than there are in the eastern Pacific Ocean.

Fishing Pressure

Sphyrna tiburo is one of the more resilient shark species with a higher than normal recovery rate. This species has one of the fastest turnover rates of all the sphyrnids, with short gestation time which aids in them outproducing losses to predators and overfishing. Early maturation age and smaller sizes benefit this species, from a higher probability that their offspring will survive and reach maturity to being able to reproduce quicker than other species (Smith et al. 1998). This species is actively pursued in directed fisheries and it is regularly caught as bycatch due to their higher abundance. (Castro et al. 1999).

This species is commonly captured in small fisheries such as; gillnets, shrimp trawls, trammel nets, bottom long lines, and hook and line. *Sphyrna tiburo* are generally utilized for its meat either fresh, fresh frozen, fried salted for human consumption, or processed into fishmeal. (Compagno 1984; Cortés et al. 2016). Though normally caught in smaller fisheries, these species are commercially important in the United States of America, Mexico, Brazil, Belize, and several Caribbean countries (Motta et al. 2005; Ulrich et al. 2007; McCallister et al. 2013). They are heavily harvested throughout the coastal waters of the Gulf of Mexico, Trinidad and Tobago, and Ecuador (Henry 1992). In Mexican artisanal fisheries, *S. tiburo* is the second most important species accounting for about 15% of all artisanal landings (Castillo-Géniz et al. 1998). In the Gulf of Mexico, *S. tiburo* is frequently caught as bycatch in shrimp trawls. (Castro et al. 1999).

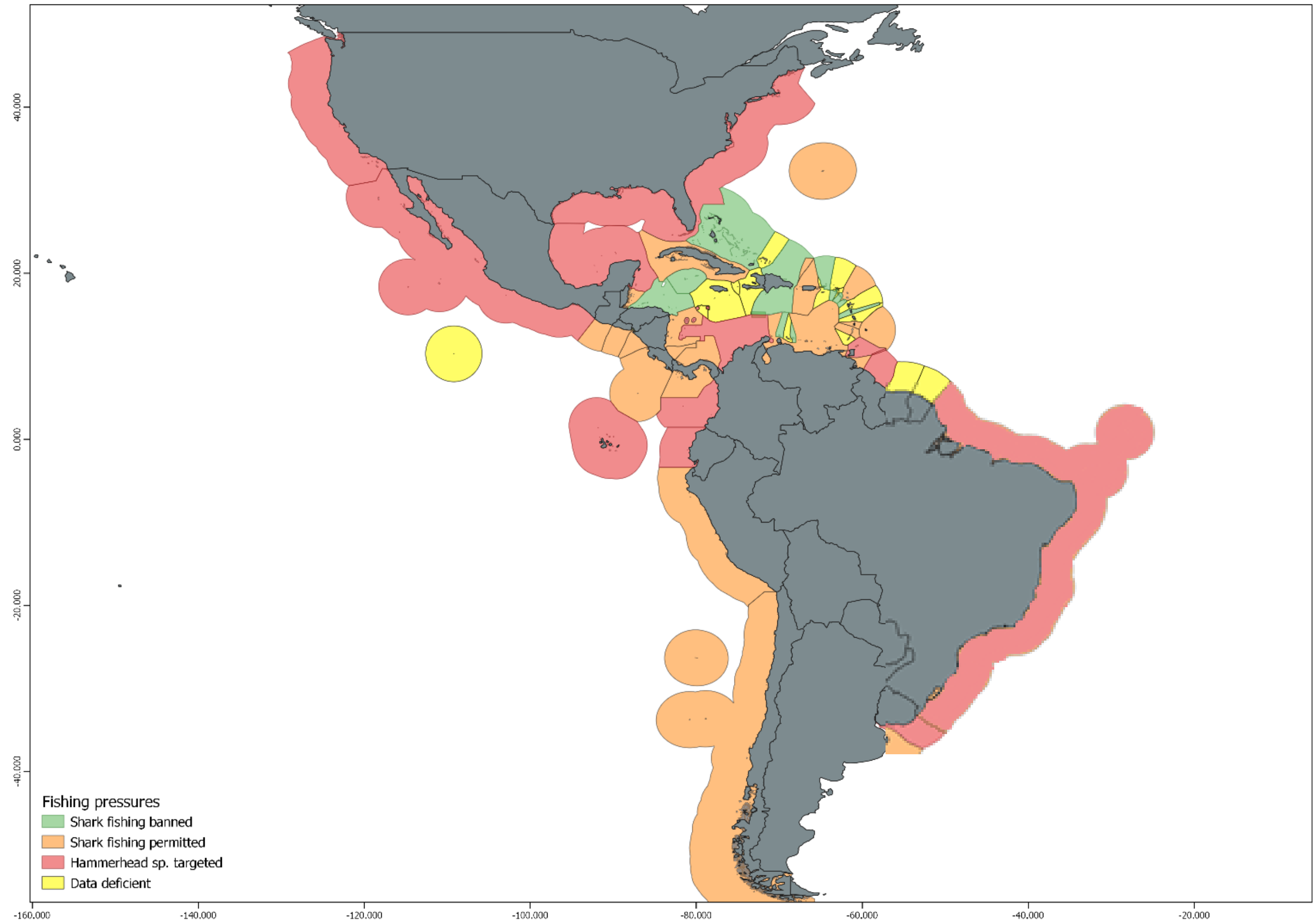


Figure 28. Assessment of fishing pressures throughout both known and predicted distribution of *S. tiburo*.

There are nine regions that specifically target *S. tiburo* in different types of fisheries. Unlike *S. corona* and *S. media* which are not sought after due to their small size, *S tiburo* are highly sought after. As with other similar species (e.g. *S. media*) distribution, there are eight EEZs that are recognized shark sanctuaries throughout the range of *S. tiburo* (Ward-Paige 2017). Though most islands in the Caribbean are data deficient, previous studies have shown that *S. tiburo* is an important commercial species for some of these regions, but not specifically named.

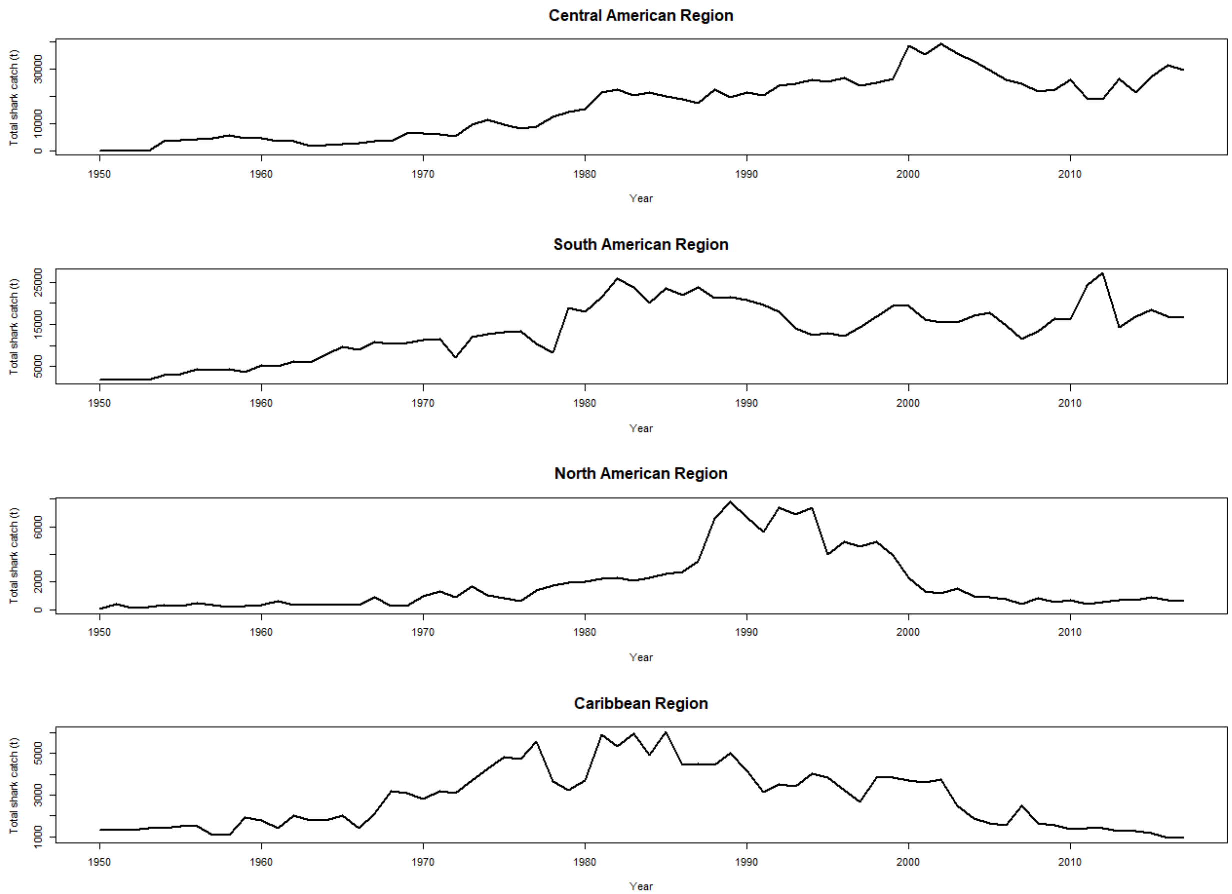


Figure 29. *S. tiburo* distribution regional assessment of areas where sharks are caught but species is not specifically targeted based on FAO capture fisheries statistics. Regions of concern and total number of shark catches reported tons (t) by year.

As with *S. media*, of the four regions examined both Central and South America have a more sustainable general shark fishery than the Caribbean and North American regions (Figure 29). Fishery within the last two regions have fished at unsustainable levels and created practices that that are unmanageable.

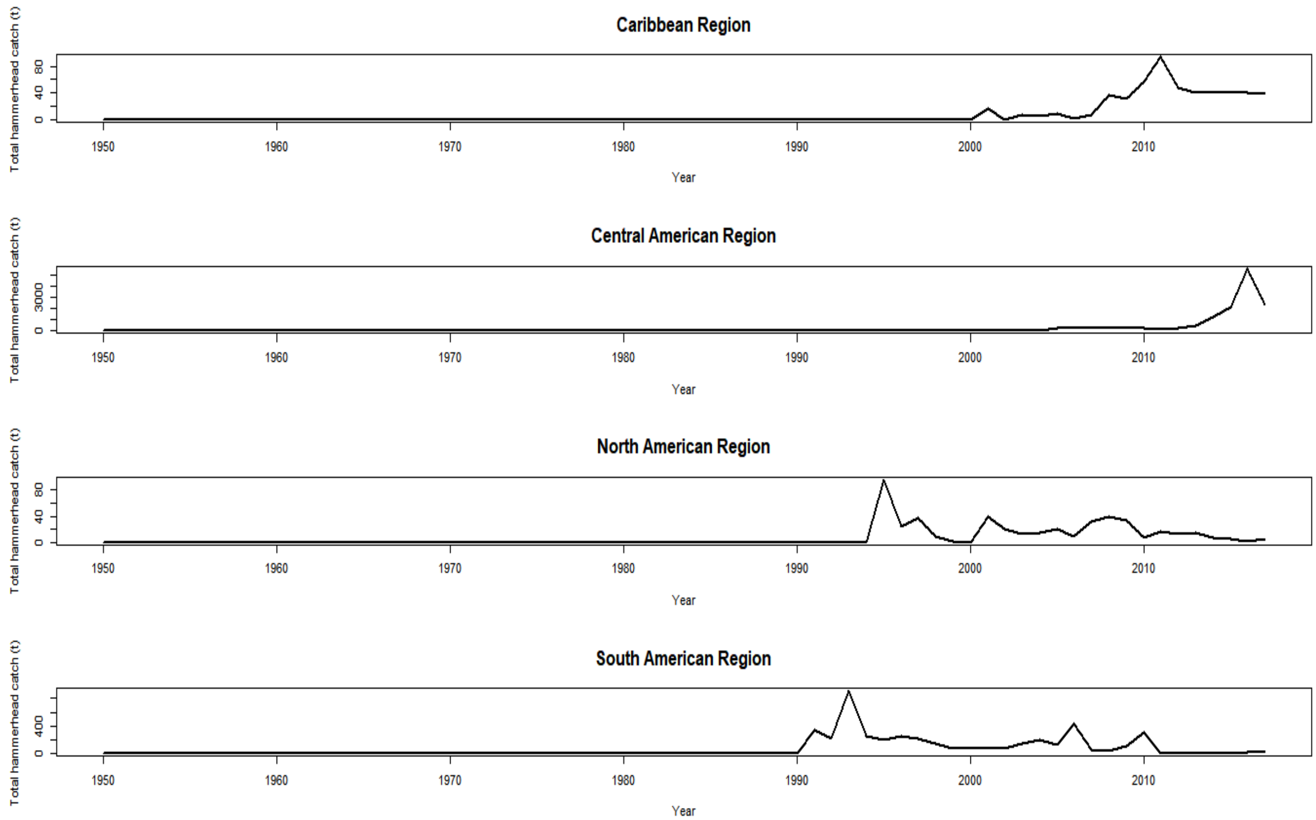


Figure 30. *S. tiburo* distribution regional assessment of areas where hammerhead sharks are reported based on FAO capture fisheries statistics. Regions of concern and total number of hammerhead shark catches reported tons (t) by year.

As with *S. media,* in the Caribbean hammerhead catch rates are plateaued at a stable level, the Central American region has a declining catch rate, and the South American region has hammerhead fisheries that are unstable with reported hammerhead catches of zero tons. The North American region, more specifically the United States of America, is the only region that explicitly reports their catch to species-specific level for *S. tiburo*. Figure 30 shows the species-specific catch data for *S. tiburo* throughout the USA's fishing. *Sphyrna tiburo* were first reported in the mid-1990s at about 100 t. Following this original intake report, there was a steady decline until catch rates were reported at zero tons in 2000. Recently, catch of *S. tiburo* have varied slightly throughout the decade now averaging out in the lower teens to single digits in tons.

Conservation

Sphyrna tiburo was last assessed by the IUCN on December 15, 2014 and it was determined that due to a stable population trend this species was listed as of least concern (Cortés et al. 2016). *Sphyrna tiburo* are not currently assessed as an overfished species despite the pressure from both targeted and bycatch fisheries (Frazier et al. 2013; Cortés et al. 2016). This species is considered at lesser risk due to its abundance, high population growth rate, and overall resiliency to overfishing (Cortés 2005; Cortés et al. 2016). However, some countries deem it necessary for the status of least concern to be reassessed in specific regions. Researchers suggest that the Gulf of California, east Pacific region of Mexico, Colombia, and Ecuador stocks of *S. tiburo* should be re-evaluated (Bizzarro et al. 2009; Smith et al. 2009; Perez-Jimenez 2014). Studies have shown that areas where the species was once abundant are now completely absent. Some have seen these changes on a relatively short time scale. For example, in 2005 Cortés found that *S. tiburo* in both the Atlantic and Pacific waters around Mexico were abundant in the shallow estuaries and bays. Although in a study done in 2014, throughout those same regions found that the once teeming habitats now become sparse. The study went to suggest that not only had *S. tiburo* been extirpated from the south Pacific region but also notice the same findings in the Gulf of California (Castro 2011; Perez-Jimenez 2014). As with *S. media*, there are several countries that have NPOAs or follows the rules and regulations set forth by designated by the RMFOs (see *S. media* conservation).

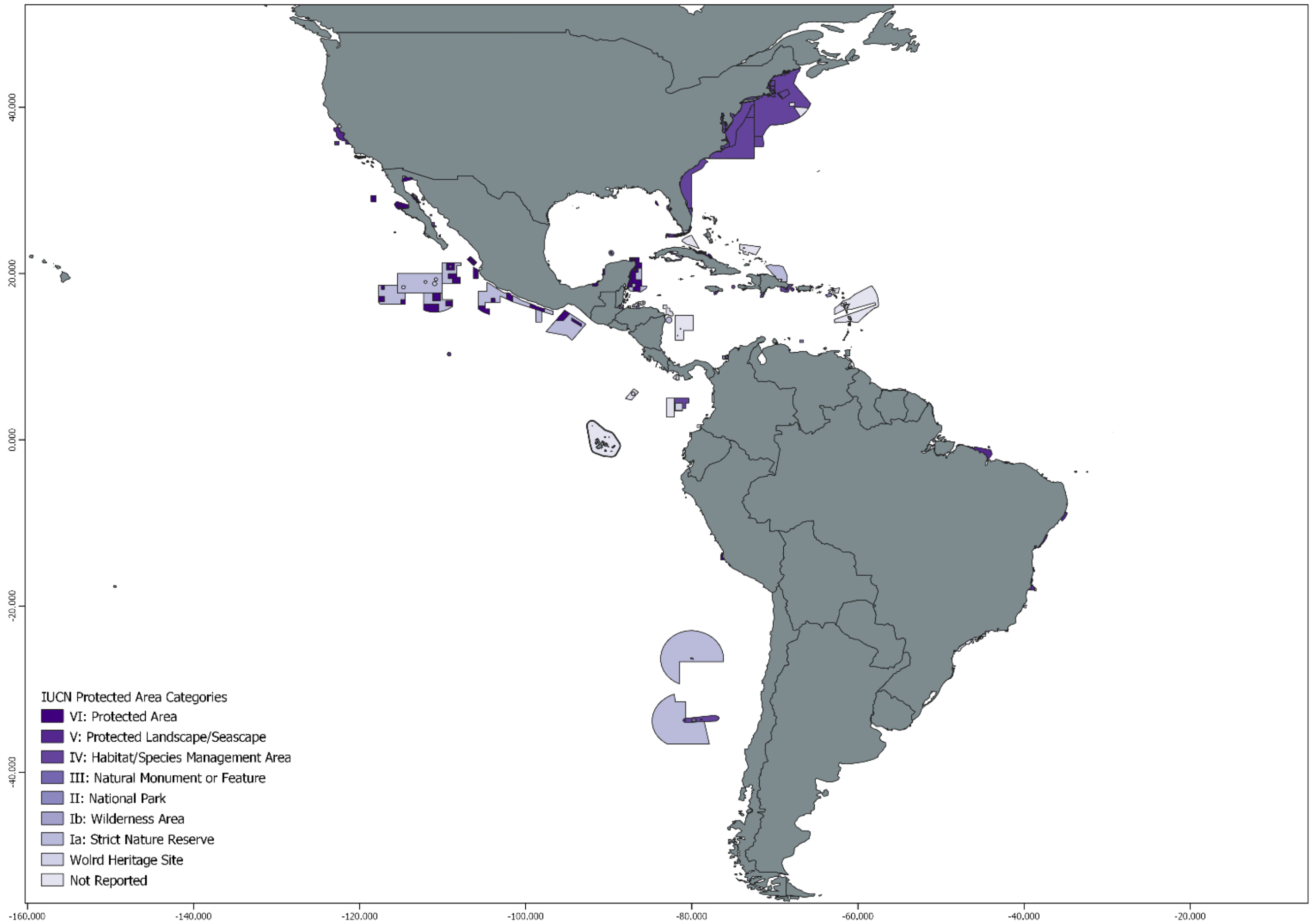


Figure 31. Marine protected area overview throughout *S. tiburo* distribution where more actively protected MPAs are dark purple shades and the areas not defined by the IUCN are the lighter shades.

There is a total of 1,509 marine protected areas throughout the range of *S. tiburo*. A majority of MPAs are level IV habitat/species management areas with a close second to level V protected landscape/seascape. There are 96 Ia, 13Ib, 149 II, 55 III, 467 IV, 411 V, 82 VI, 11 world heritage site, and 225 MPAs that have not reported their IUCN level categories. Of this 1,509 MPAs, there are 101 total no take zones and 36 that are partial no take zones.

Sphyrna tudes

Biology

Common names: Golden hammerhead, Smalleye hammerhead, Curry shark

Sphyrna tudes, a small hammerhead species that was first described by Archille Valenciennces in 1822. This species has a moderately broad arched and mallet-shaped head with latitudinal expansion measuring about 28% – 32% of its TL. There are both medial and lateral indentations present and a unique deeply indented prenarial groove in the center of the head. The snout is shorter than most sphyrnids, less than one-third of the total width of its head (Compagno 1984; Last 2002). Even though the cephalofoil is smaller in lateral expansion than the three larger hammerhead species, *S. tudes* has a comparable number of electro sensory pores to *S. lewini*. The number of dorsal pores is positively correlated regarding both the pores located ventrally and on the width of the head (Mara et al. 2015). The common name 'Smalleye hammerhead' suggests this species has proportionally small eyes that are located slightly anteriorly to the upper jaw (Bigelow and Schroeder 1948). These small eyes are thought to be an adaptation to the murky water habitats they inhabit (Castro 1989). The mouth of the smalleye hammerhead is narrowly arched and moderately large with anterior teeth that range from long, slender, and weakly serrated to smooth cusped and, posterior teeth that are mostly cuspidate. Teeth in the upper jaw are more oblique and become increasingly slanted towards the corners of the mouth (Gilbert 1967; Compagno 1984; McEachran and Fechhelm 1998).

The first dorsal fin of *S. tudes* is slightly falcate originating behind the pectoral insertion and the free rear tip is over the pelvic insertion. The second dorsal is relatively tall but smaller than the height of the anal fin. The anal fin's posterior margin is shallowly concaved and there is no deep notch present. The upper precaudal pit is transverse and crescentic. The total vertebral count is 195 – 202 (Compagno 1984). *Sphyrna tudes* has the most unique coloration of all sphyrnids. For example, the embryo to newborn stage has a coloration of grey on the dorsal side with a pale underside and a dusky to dark color on both the first dorsal and upper caudal fin. In the juvenile phase, the coloration changes to a yellowish grey on the dorsal side and a bright yellow to orange color ventrally with metallic or iridescent hues. After *S. tudes* reach sexual maturity, the bright juvenile coloration tends to fade. Adults become a grey brown to golden color above which then fades to a pale yellow on their underside (Gilbert 1967; Compagno 1984; Castro 1989).

Life history

The life history of *S. tudes* varies based on their geographical distribution. The overall maximum size range for *S. tudes* males is 110 – 134 cm, but in Trinidad the largest male recorded was only 121 cm TL. Females have a maximum size range from 120 – 148 cm, with Trinidad's maximum at 120 cm TL and Brazil at 148 cm TL (Sadowsky 1965; Compagno 1984). At birth pups can measure at about 30 – 31 cm TL (Castro 1989). Studies conducted on the Trinidad *S. tudes* population showed that males matured at 80 cm and females at 98 cm. However, studies off the coast of Brazil estimated size of maturity for males to be 90 cm and females from 115 – 120 cm. Studies revealed that both sexes in Brazil were maturing at considerably larger sizes than those of the Trinidad population (Sadowsky 1965; Lessa et al. 1998; Last 2002). The underlying cause of this difference is still unknown.

Not only are geographic variation in maturity apparent but aspects of reproductive biology vary as well. Overall, *S. tudes* is a viviparous species with a one-year reproductive cycle similar to *S. tiburo*. Off the coast of Trinidad, mating occurs annually in August followed by a ten-month gestation period. Litter sizes range from 5 – 12 pups and are born in shallow water in depth about 9 – 18m from late May to early June. Newborn and juvenile (i.e. less than 40cm) sharks are typically found in shallower waters before migrating to deep depths. Adult males and juveniles of both sexes form schools based on size at deeper depths of 27 – 36 m. While adult males were seen at deeper depths, the mature females tend to stay more inshore in shallow waters 9 – 18 cm (Castro 1989). In Brazil, mating may occur from June to October and the larger sexually mature females give birth in the mangroves to a larger litter size ranging from 5 – 19 pups (Lessa et al. 1998; Stride et al. 1992).

Diet is subject to change throughout the life history of *S. tudes*. There is a connection between the carotenoid pigment in their primary prey items and the color of the shark. Juveniles are bright yellow to orange underside as they mainly feed on penaeid shrimp. When stomach contents were examined the partially digested shrimp created an orange paste that matched the coloration of the shark skin. An ontogenetic shift causes *S. tudes* to change their diet. Subadults and adults which have that orange to golden coloration with metallic or iridescent hues get this coloration from ingesting sea catfish (Ariidae) and their eggs. The eggs are a bright yellow color and the catfish itself secretes a golden colored mucus (Castro 1989). Other prey items include

small bony fishes, newborn *S. lewini* pups, swimming crabs, and squid (Cortés 1999; Giglio and Bornatowski 2016).

Distribution

This small hammerhead shark inhabits shallow coastal waters over muddy bottoms such as mangroves and estuaries (Castro 1989; Giglio and Bornatowski 2016). *Sphyrna tudes* can typically be found throughout the Caribbean and South American coastal oceans. This species is extant to Brazil, French Guiana, Guyana, Suriname, Trinidad and Tobago, Uruguay, and Venezuela (Alvarez-Leon et al. 2013). In Trinidad *S. tudes* are typically only found on the southeast side near the Orinoco Delta region and Matelot to Mayaro Pont over the muddy bottom. Despite extensive sampling around the entire Trinidad region this species is seemly confined to those specific environmental predictors (Castro 1989; Lessa et al. 1998).

There is some debate over the distribution of this species. *Sphyrna tudes* has been historically confused with two different species of hammerhead sharks. Until 1950 *S. tudes* was referred to *S. mokarran*, and then between 1950 and 1981 *S. tudes* was considered synonymous with *S. couardi* which is now no longer a species but genetically identical to *S. lewini* (McEachran and Seret 1987). This misperception caused great uncertainty over the distribution of this species. While most can agree with the Western Atlantic Ocean distribution, there is conflict over the specimens found within the Mediterranean Sea. Researchers presume that any species found over in the Mediterranean was likely misreported and actually *S. lewini* (previously *S. couardi*) (Cadenat and Blache 1981; Mycock et al. 2006). A survey of the *S. tudes* populations in the Mediterranean Sea needs to be performed to ascertain whether there is a Mediterranean Sea population or whether the locality is erroneous (McEachran and Seret 1987; Castro 1989). *Sphyrna tudes* prefer habitats where depth ranges from 2 – 40 m, temperatures of 18.48 – 28.06 °C, salinity 26.84 – 37.75 psu, and distance from shore between 7 – 86 km (Kaschner et al. 2019).

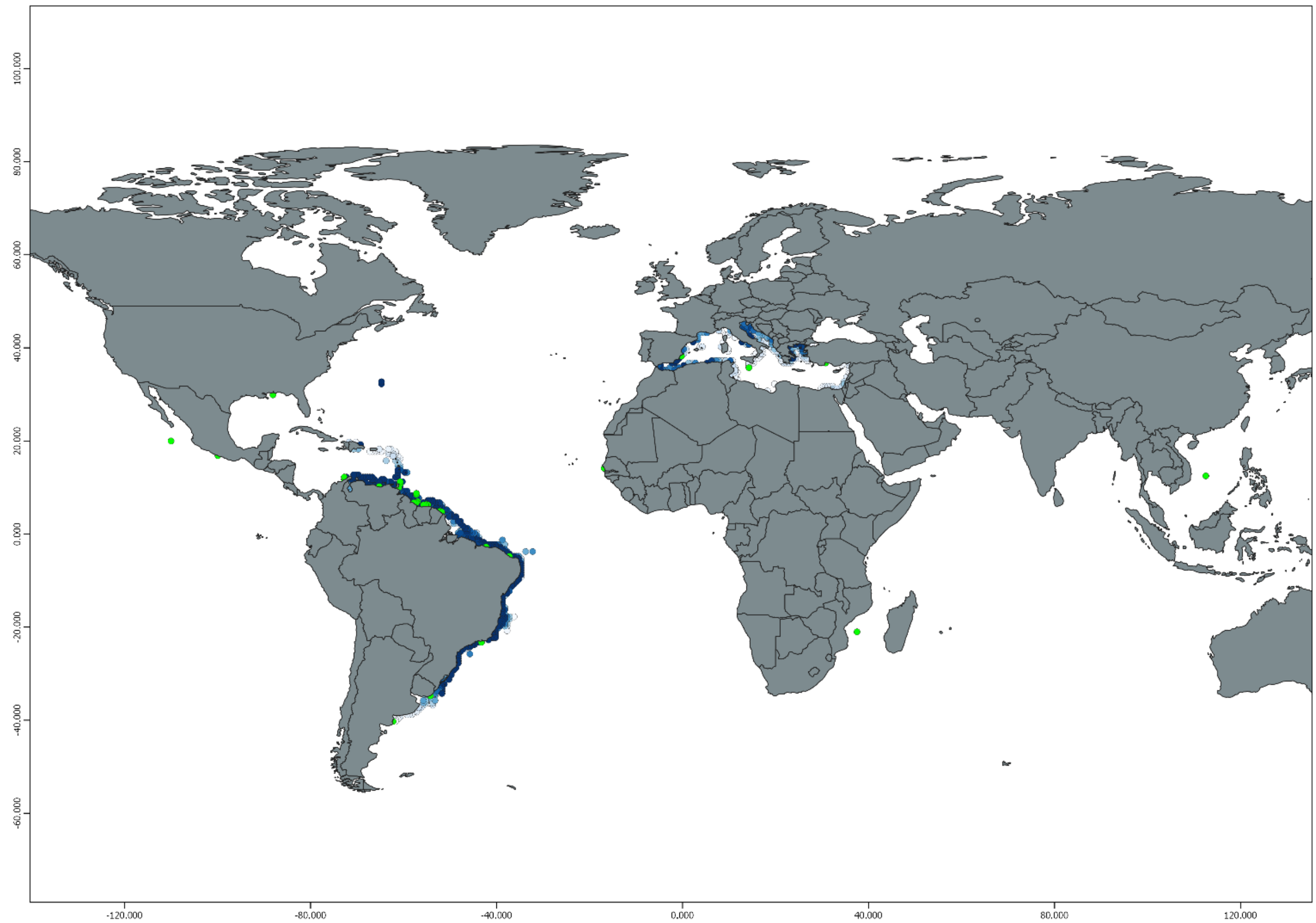


Figure 32. *Sphyrna tudes* known distribution and probability distribution. (Green) actual known recordings of species and (blue) probability distribution based on habitat preference. Dark blues indicate a high probability of occurrence lighter blues are less probable.

Known occurrence and probability distribution based on environmental preferences were both examined for all regions including the Mediterranean Sea (Figure 32). A majority of the known recorded sightings for *S. tudes* are located around the South American region. There are few known occurrences of *S. tudes* in North America and even less found within the Mediterranean Sea. There are outliers near Madagascar, Mozambique, and off the coast of Vietnam. Overall, probability of occurrence for *S. tudes* is higher in the South American region than the Mediterranean. Probability increases noticeably in the coastal waters of Venezuela and continues with high rates towards Brazil. The probability starts to taper off near Uruguay. In the Mediterranean, probability of occurrence is highest for the region in the Adriatic Sea, Aegean Sea, and the Alboran Sea.

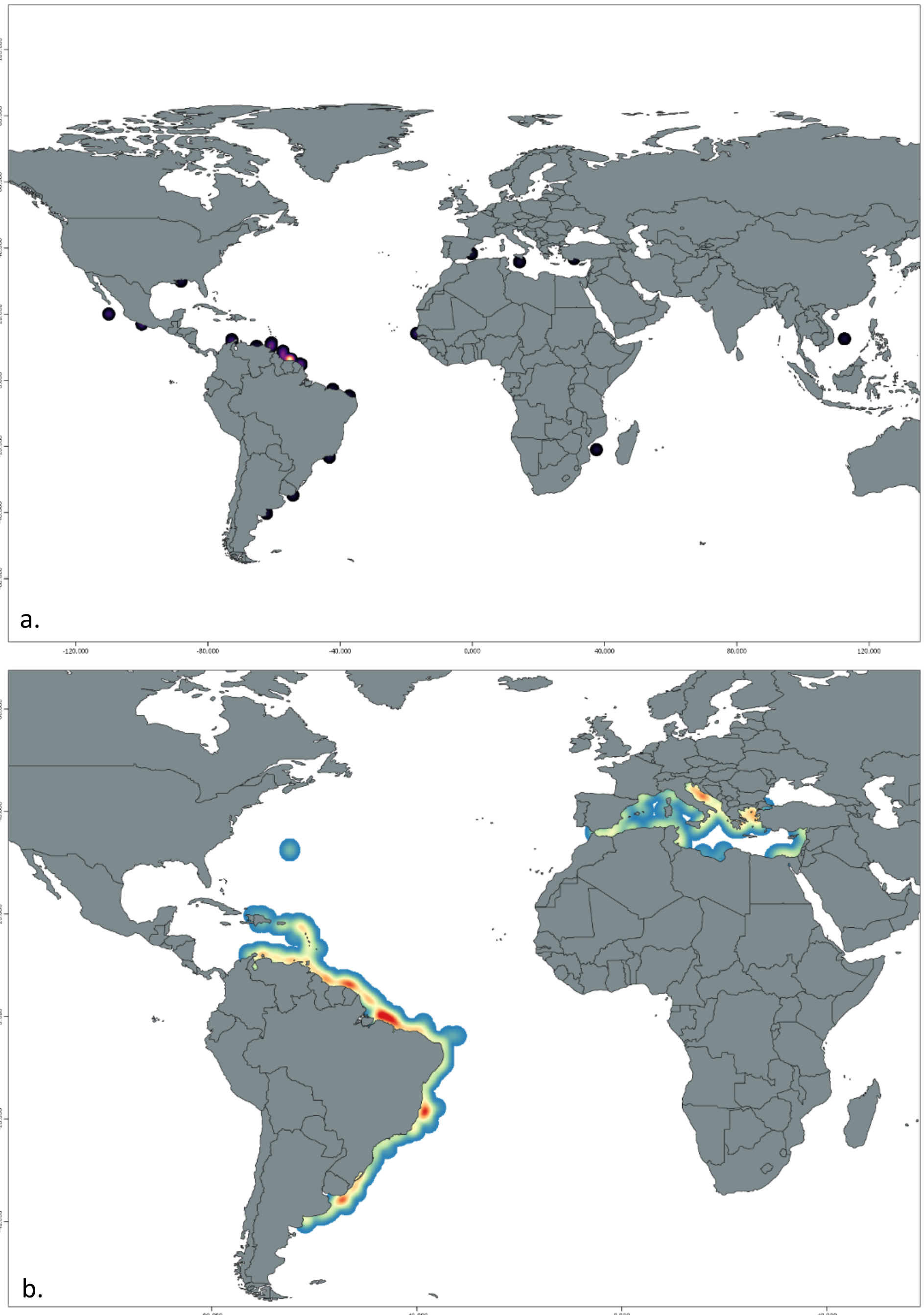


Figure 33. *S. tudes* (a) known population density and (b) probability population density.

There is an evident population density hotspot around the coastal waters of Suriname (Figure 33a). There are smaller population densities present around other regions, but these are not nearly as dense as the hotspot near Suriname. There also could be numerous potential population hotspots for *S. tudes* throughout the East coast of South America (Figure 33b). The areas with the

highest probable density in the coastal waters near South America for this species are Suriname and the north end of Brazil. As for the Mediterranean, there are a few potential areas for moderate hotspots in the Adriatic Sea and Aegean Sea.

Fishing Pressure

Sphyrna tudes is captured in a variety of artisanal fisheries throughout its range (e.g. gillnets, longline, hook and line, and ponta de linha; Lessa et al. 1998; Giglio and Bornatowski 2016). Gillnets are the most efficient device cited for capturing this species throughout all life stages (Castro 1989; Brasil 2014). Some of the most productive shark fisheries in South American waters occur at depths of 27 – 36 m. These depths are the preferred *S. tudes* habitat for juveniles and adults. *Sphyrna tudes* adults prefer inshore coastal waters in depths of 9 – 40 m and the juveniles use shallow coastal nursery areas which predispose this species to be captured in inshore multi-species artisanal gillnet fisheries. As well as being targeted, *S. tudes* is also caught as bycatch in shrimp trawling fisheries (Castro 1989; Mycock et al. 2006). Even though this species is regularly taken in fisheries there is a lack of published information on catch data.

Historically *S. tudes* was considered an economically important species for Trinidad Tobago and parts of South America (i.e. Brazil) because of its abundance in shallow depths. Extensive unchecked gillnetting operations would pull thousands of individuals which would have sold or shipped to other regions of South America (Castro 1989). There has been reported declines in catches over the years in Trinidad and throughout Brazilian coastal waters (Mycock et al. 2006). It is thought that the drastic population decline was caused by the intense and unrestricted inshore coastal gillnet fisheries coupled with this species limited fecundity (Castro and Woodley 1998; Castro et al. 1999).

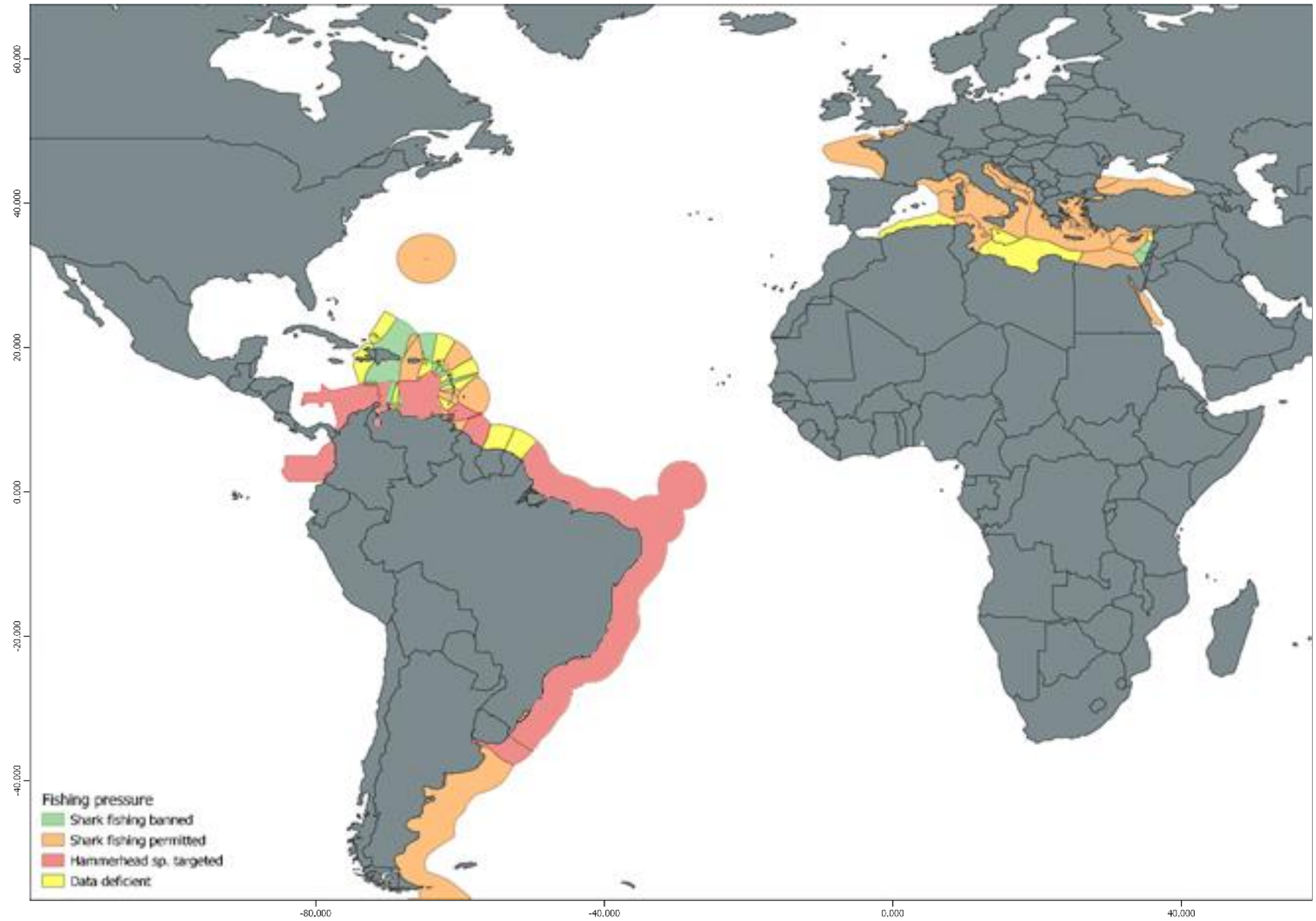


Figure 34. Assessment of fishing pressures throughout both known and predicted distribution of *S. tudes*.

Sphyrna tudes is specifically targeted by six countries which include Brazil, Columbia, Guyana, Trinidad and Tobago, Uruguay, and Venezuela. Eighteen regions are data deficient and lack sufficient documentation about shark catches (Figure 34). Most of the data deficient regions are comprised of small island chains excluding the countries surrounding the Mediterranean Sea Algeria, Libya, Malta, and Syria. There are six regions that have banned shark fishing completely and five of which have been discussed in previous sections. The sixth country that has banned shark fishing is Israel where shark fishing became illegal throughout Israeli's EEZ in 2005 (Camhi et al. 2009).

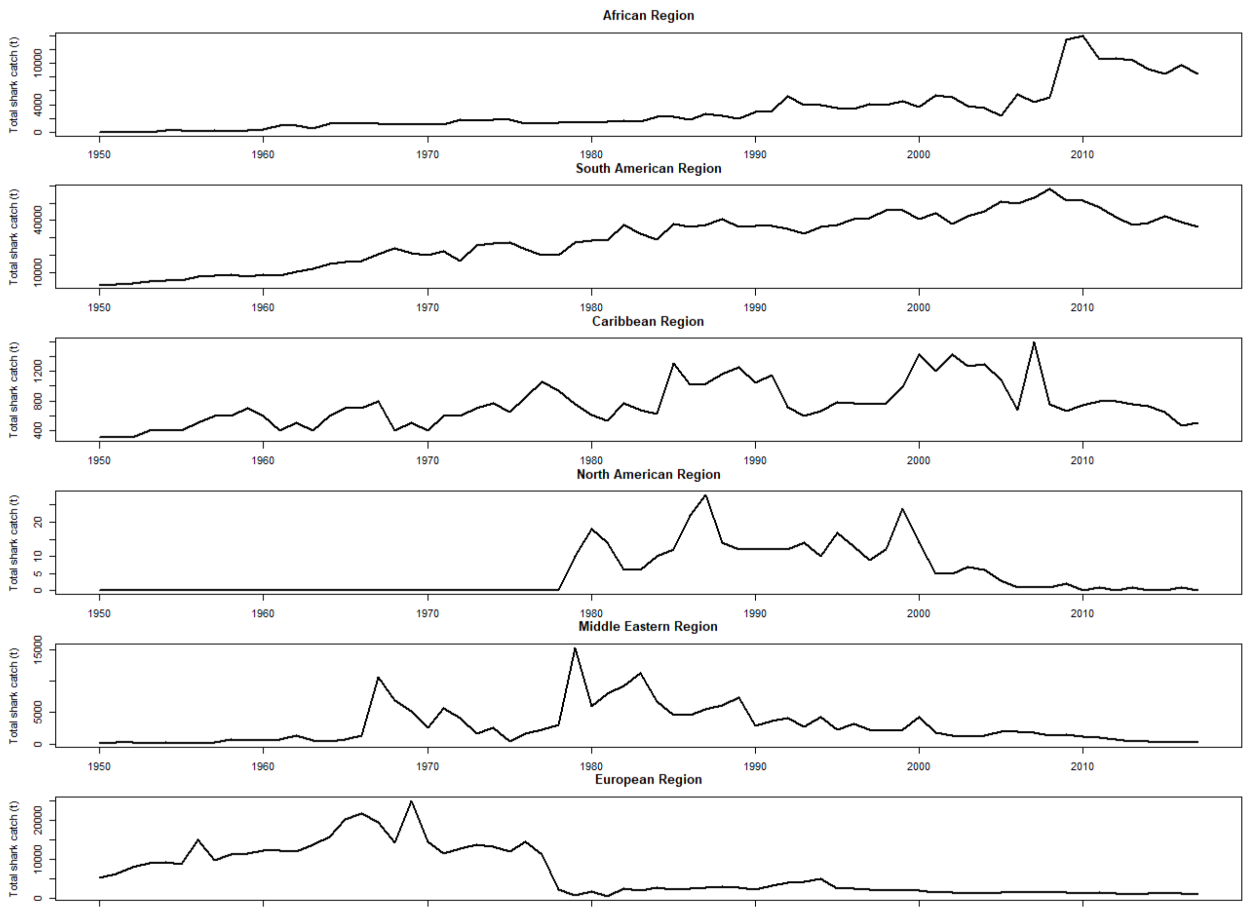


Figure 35. *S. tudes* distribution regional assessment of areas where sharks are caught but species is not specifically targeted based on FAO capture fisheries statistics. Regions of concern and total number of shark catches reported tons (t) by year.

In the African region, shark fisheries were steady beginning mid-1950s until late 2000s (Figure 35). A few years before 2010 the maximum yield was reached at around 14,000 t before decreasing slightly. After an initial decline in catch rates for this region there has been a relatively stable fishery, as of 2017. In the South American region from the1950s until 2010, catch rates were consistently growing. Before 2010, a maximum catch of about 60,000 t was reported before a gradual decline began. As of 2017, the reported catch rates were near 35,000 t. In the Caribbean region, total shark catch rates experienced more fluctuations. The first major increase occurred in the mid-1990s and catch rates remained high for a few years before decreasing. The next influx was in 2000 where catch rates remained relatively stable until the late 2000s. There was a year of reported decrease followed by a large increase where 1,600 t of shark were caught during this time. Following this sharp intake, reported catch rates began to decline and as of 2017 the trend shows

a continued downward trajectory. In the North American region, Bermuda, shark fishing increased in the late 1970s and catches varied between five to a maximum of about 30 tons. Beginning in 2000, shark fishing declined to an unsustainable level where fishing averaged two tons per year until 2017 when the fisheries brought in zero tons. In the Middle Eastern region, two major catch increases led to substantial decreases. The first nominal increase occurred in the mid-1960s at around 11,000 tons when previous reports were in the hundreds or low thousands. This increased take rate did not last long and promptly declined until the late 1970s. Reports of 15,500 tons of sharks were reported followed by a less prominent decrease in catch. Shark catch rates remained in the upper thousands until 1990 when there was a steady decrease in reported shark catch rates in the low hundreds of tons. The last region, Europe, was different than most trends. This region started off with high reported shark catch rates and gradually increased from 1950 until 1970, where the tonnage maximized at around 25,000 tons. From there, Europe experienced a decline in reported shark catches and rates plummeted in the late 1970s. From 1980 until 2017, the reported rates are about 900 to 2,000 tons.

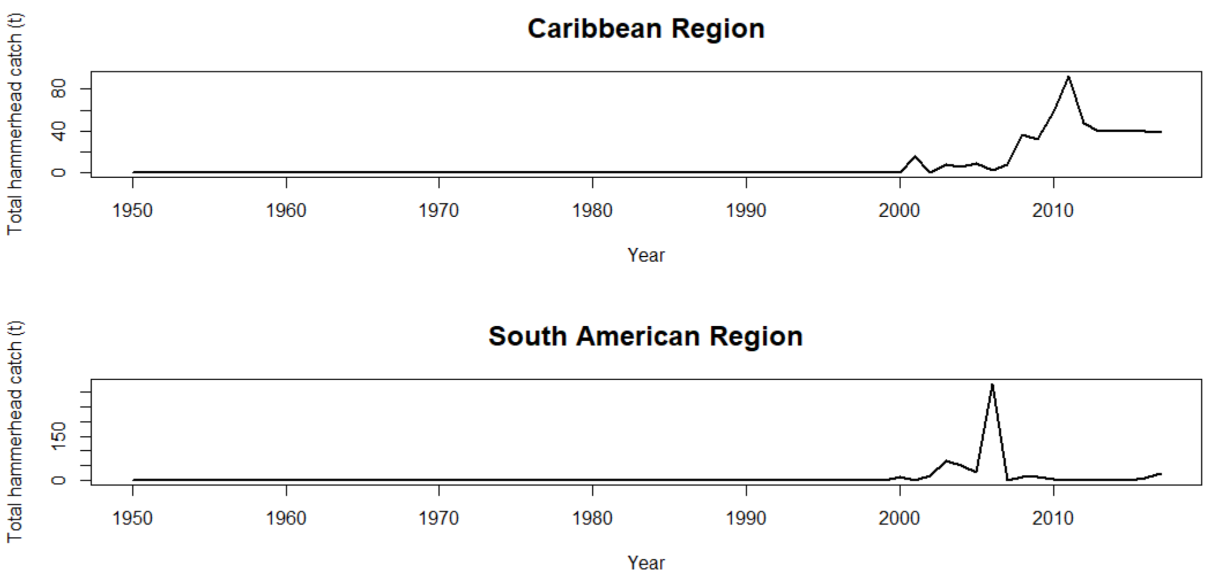


Figure 36. *S. tudes* distribution regional assessment of areas where hammerhead sharks are reported based on FAO capture fisheries statistics. Regions of concern and total number of hammerhead shark catches reported tons (t) by year.

In the Caribbean, Trinidad and Tobago was the only country that reported its total hammerhead catch (Figure 36). Reports began in 2000 and remained low until 2010 when this region reported a maximum of 100 tons followed by a slight decrease to about 40 tons. This catch rate has remained stable for about six years. In the South American region, hammerhead shark catches were not reported until the 2000 where take rates remained small and stable until mid-2010s. Catch rates then went from 50 and 60 tons to 350 tons. Following this increase, the reported catches drastically decreased and there were some years where fishermen reported catches of zero tons. In 2017, there was a minuscule increase but nothing to note a sustainable yield.

Conservation

Sphyrna tudes was last evaluated by the IUCN on January 31, 2006 and was classified as vulnerable. This conclusion was made after assessing the limited life history, fishing pressure, and population trends available. Their small litter size, declining population trend observed by multiple countries, and amount of pressure faced to overfishing makes this species more vulnerable to overexploitation (Castro et al. 1999; Mycock et al. 2006; Giglio and Bornatowski 2016). There is currently no species-specific conservation action in place for *S. tudes* (Mycock et al. 2006). The Caribbean, North American, and South American regional and national shark action plans have been discussed in previous sections.

Brazil has made species-specific conservation efforts for *S. tudes*. Along with Brazil's 2005 NPOA, in 2015 they attempted to ban fishing for *S. tudes* in Brazilian waters. This ban was ultimately unsuccessful because of the challenges with lack of resources and overall political interest in conservation (Giglio et al. 2014; Di Dario et al. 2015). Conservation in this area is a necessary feat because of the well documented population decline, where there has been little to no records of this species in these waters for over a ten-year period (Brasil 2014; Giglio and Bornatowski 2016). Based on data collection researchers suggest that the populations of *S. tudes* have declined by at least 80% throughout Brazilian waters (Brasil 2014). Brazil is not the only region to experience this severe population decline, populations of *S. tudes* off Trinidad and Tobago have also been in decline for years (Mycock et al. 2016).

In the Mediterranean, all regions report to at least one RFMO. The counties examined all reports to the GFCM and only two regions, Syria and Turkey, report to ICCAT in addition to the GFCM. All regions follow the Mediterranean RPOA, but do not have individual NPOAs in place

(CMS 2015). The Mediterranean RPOA – Sharks plan calls for the conservation of cartilaginous fishes in the Mediterranean Sea and focuses on the legal aspects, monitoring, data collection, management, and assessment procedures of cartilaginous fishes (RAC/SPA 2014). Though Israel does not have a NPOA, all elasmobranchs are protected in Israeli waters including shark fishing and finning are illegal (Camhi et al. 2009).

Throughout the European region, all areas report to at least one RFMO and follow at least one RPOA. Overall, every country report to the GFCM. Regions such as Albania, France, and Italy report to ICCAT, IOTC, and GFCM. Italy and France report to several other RFMOs than the surrounding countries. France is an active participant of four other RFMOs including NAFO, WCPFC, IATTC, and CCAMLR. Italy participates in the aforementioned RFMOs as well as five others: the Fishery Committee for the Eastern Central Atlantic (CECAF), North East Atlantic Fisheries Commission (NEAFC), South-East Atlantic Fisheries Organization (SEAFO), SPRFMO, and WECAFC (CMS 2015). All of these countries follow either or both of the Mediterranean or European RPOA – sharks plans and do not have NPOA in place. The European RPOA is the action plan for the conservation and management of sharks. With three specific objections, this action plan encourages coherent communication between internal and external community policy for sharks, ensure sustainable directed shark fisheries and regulate shark by catch, and broaden knowledge of about shark species and shark fisheries (COM 2009).

In the African region, the examined countries report to ICCAT and all but one report to the GFCM, Liberia. In addition to the other countries around the Mediterranean Sea, these regions also follow the guidelines put forth for the Mediterranean RPOA – Sharks. None of these countries have NPOAs though it should be noted that Egypt has banned shark fishing but only on the Red Seaside of the territory (CMS 2015).

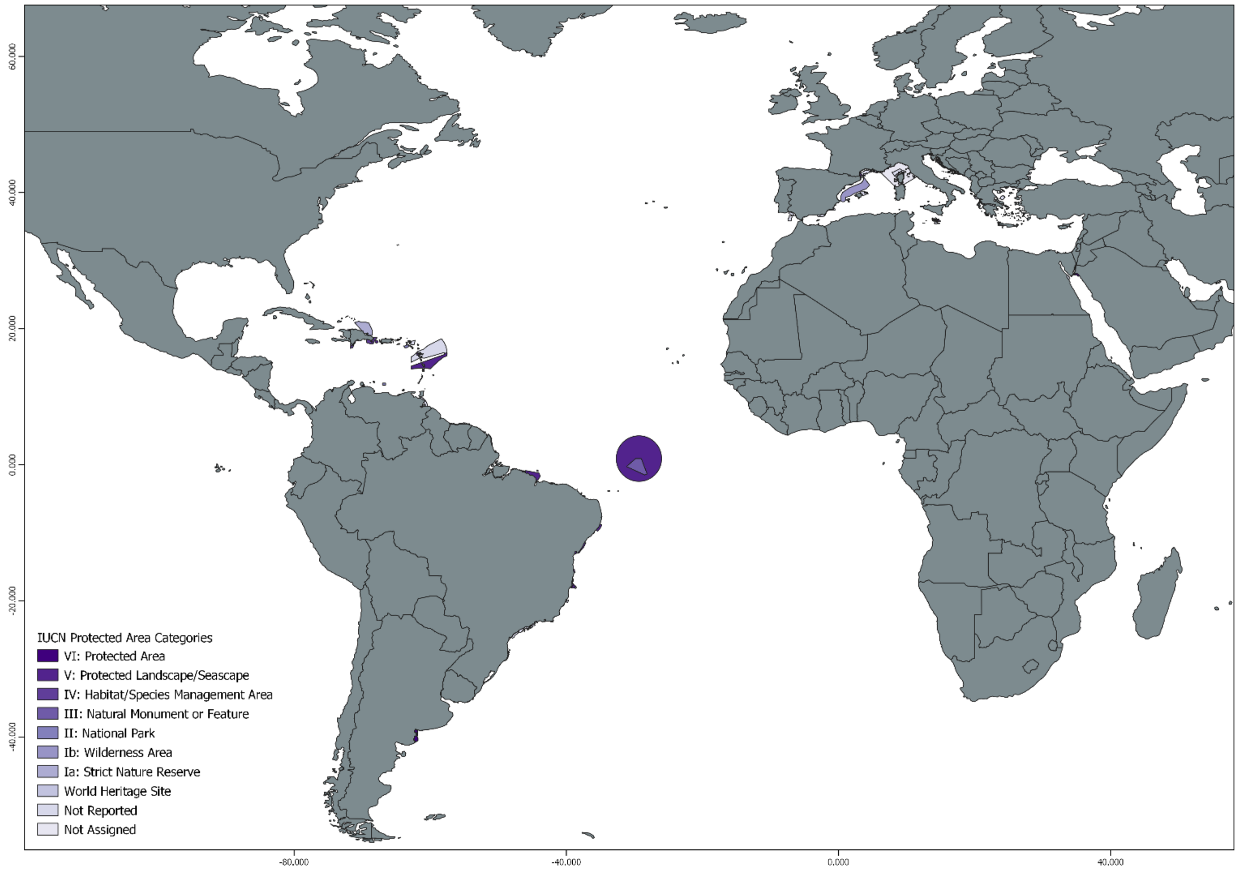


Figure 37. *S. tudes* marine protected area overview where more actively protected MPAs are dark purple shades and the areas not defined by the IUCN are the lighter shades.

There is a total of 18,112 Marine Protected Areas throughout this species range. There are 45 Ia, 4 Ib, 100 II, 33 III, 392 IV, 125 V, 88 VI, and 4 world heritage sites. The most common is the category IV MPA though this is the most prominent categorized MPA there are more MPAs that have not reported their categories (Figure 37). There are 983 areas that have not reported and 37 MPAs that have not been assigned a category by the IUCN. Out of the 18,112 MPAs throughout *S. tudes* range there are a total of 62 no take zones 42 of which are complete no takes and 20 are partial no take zones.

Discussion

Eusphyra blochii

A majority of the life history and biology data for *E. blochii* are from older studies (Stevens and Lyle 1989; Castro et al. 1999). The most recent research stems from a study completed in 2016, but this data mainly confirmed information put forth from the Steven and Lyle study completed in 1989. The life history information for *E. blochii* is surmised from research conducted in parts of Australian and Indian waters (Stevens and Lyle 1989; Castro et al. 1999). There are clear variations within some life history aspects between these two oceans. Therefore, further evaluations of this widely disperse species need to be completed in order to collect a comprehensive life history and biology for *E. blochii*.

The known and frequently cited distribution of *E. blochii* is mainly based on local knowledge since population surveys are rare (e.g., Madagascar, Somalia, and Vietnam). Without proper surveys, the known distribution could potentially be inaccurate. For example, regions once believed to have population hotspots could no longer have an abundance of *E. blochii*, while other regions could have higher densities of this species then originally speculated. Additionally, there could be a number of unrealized potential habitats for this species (Figure 2). Surveys of fishing markets and known reported landing sites in regions associated with *E. blochii* can provide a rapid and relatively inexpensive source of data (White and Dharmadi 2007; Bizzarro et al. 2009).

Much of the fishing pressure for this species occurs in regions often associated with developing countries. Therefore, this leaves large areas of fishing ground that are still poorly managed or even known for that matter (Anderson and Simpfendorfer 2005). Several trends were documented for reported hammerhead cached (Figure 6). In the African region, a sustainable yield was reported for hammerhead catches. The populations of sphyrnids in that region when caught at 2,000 t or over cannot withstand the fishing pressure and thus the population declines. When caught in less tonnage, the species in this region can bounce back and fishing remains stable. In both the Asian and African region, more sustainable fishing is at around 1,000 t. Hammerhead populations in the Asian region will decline when caught over a period of time in numbers of upward of 2,000 t to 4,000 t. Currently, no hammerhead populations have been able to recover in the Asian region even with no catch increase (Figure 6). This decreasing trend is not attributed to a decline in shark fishing, but rather suggest a decline in the hammerhead populations in this region. Catches of *E. blochii* throughout the Asian region, particularly southeast Asia, have

decreased over the years because of unregulated and unrestricted fisheries. Consequently, these have led to a collapsed fishery and further propelled the population decline (Stobutzki et al. 2006; Smart and Simpfendorfer 2016).

There are several data gaps for *E. blochii* and some areas that could help bridge the gap include collecting data for population size and actual distribution, update life history information, and study harvest levels and population trends.

Sphyrna corona

Sphyrna corona is one of the rarer species of hammerhead and is severely data deficient in a number of study areas. Within the life history traits alone, some of the more crucial information is missing. For example, data are lacking to determine the age at which both sexes of *S. corona* are sexually mature, the size at which a female reaches sexual maturity, and both sexes maximum age. Other important life history traits that are semi-known and still disputed are, the size of *S. corona* pups and the litter size. Researchers have suggested measurements for these two data points, but most are considered inaccurate due to limited data sampling (Last 2002; Mycock 2004). There have also been disagreements with distribution records amongst the scientific community. Some suggest *S. corona* have been extirpated from many of the waters this species is previously claimed to be located (Bizzarro et al. 2009; Smith et al. 2009; Perez-Jimenez 2014). These claims need to be investigated further to determine the true distribution of this uncommon sphyrnid.

Three countries (i.e. Columbia, Mexico, and Panama) specifically target *S. corona* in an already restricted distribution. Figure 12 shows that populations of hammerheads in Central America, can be maintained with small fishing pressure. However, once fishing intake exceeds 6,000 t, the fishing practice becomes unsustainable and fishing decreases. In the South American region, their realized maximum yield is around 1,000 t in which if the yield is kept below this than the sphyrnid population tends to remain stable. For both regions, the lower hundreds (i.e. 200 t) is the ideal take rate which will allow for the hammerhead population to remain stable and abundant. With heavy concentrated fishing in three main known population hotspots (Figure 10a), protection and conservation can be focused on these regions with extra emphasis on Columbia because this is where the most recently known sightings of *S. corona* were recorded there (Rico-Mejia and Rueda 2007).

Further research needs to be conducted on this uncommon species especially with regards to their population and biology. Conservation efforts necessary for their survival should focus on species awareness, management, education, and action plans with this species specifically named. Secondarily, conservation efforts should be attempted to increase MPA level of protection. A majority of the MPA throughout this species range are lower-level protections. An increase in category would ensure higher protection from unregulated fisheries and require more monitoring. This can be a relatively straightforward task as these MPAs already exist and would only require a reclassification. Finally, *S. corona* should be re-evaluated by the IUCN from near threatened to vulnerable. This species almost met all of the requirements for vulnerable status in the 2004 evaluation. With increased fishing pressure and notable declines throughout their habitats in 2020, this species should be reassessed and potentially reclassified pending an IUCN evaluation (Mycock 2004).

Sphyrna gilberti

This species was not accepted and recognized by the scientific community until 2013. Most of the information known about *S. gilberti* was constructed from the data collected on *S. lewini* (Pinhal et al. 2012). These two species are morphologically similar and the lack of distinguishable morphological traits between *S. gilberti* and *S. lewini* make identification and research on *S. gilberti* more difficult. There have been some species-specific research conducted which determined differences in life history traits between these two species. The maximum size, size and age of sexual maturity, longevity, gestation period, and mating season are all unknown for *S. gilberti*. The distribution for this species is also largely based on speculation and the range must be studied further for accurate data.

The total hammerhead catches throughout the presumed range in Figure 17 shows that after the initial catch rate increased, the fishing decreased but was able to recover. Figure 18 in the species-specific graph shows that the population can withstand small catches of about 200 t. The population could only withstand maximum fishing pressures (i.e. 500 t) for a year before there were reported declines in the catch rates. The population slowly recovered after a few years with less fishing pressure. In both Figure 17 and 18, there is a decline after 2010 and this is due to *S. lewini* being included on the Endangered Species Act (ESA) and prohibited from being caught in fisheries (Miller et al. 2014).

Sphyrna lewini is categorized as critically endangered and was listed on the ESA on September 2, 2014. This species holds the following protection status; ESA endangered for Eastern Pacific distinct population segment (DPS), ESA Endangered Foreign for Eastern Atlantic DPS, ESA threatened for Central, Southwest Atlantic and Indo-Pacific DPS, and CITES Appendix II throughout all of its range (Miller et al. 2014). Since *S. gilberti* is morphologically similar to *S. lewini*, this species could partially receive protection since any *S. lewini* caught must be returned to the ocean. While this bodes well for this species, conservation should focus on South Carolina because this region has the highest relative abundance of *S. gilberti*. Most specimens screened throughout the South Carolina waters were neonates and juveniles suggesting, a prime nursery habitat vital for the persistence of this species and allow for further studies of *S. gilberti* (Quattro et al. 2006). This finding could lead researchers to assume that all life stages will be seen in these coastal waters since the adult females will return to have pups. Numerous studies could be completed in these waters including comprehensive life history studies and biology research to tagging and tracking this species to determine distribution, aggregation, and migration patterns.

Sphyrna media

Most of the research conducted on the biology, life history, and distribution of *S. media* has not been updated since the 1980s (Compagno 1984; Castro 1989). This elusive species has several unknown key life history traits including age of maturity and longevity for both sexes. There is also little known about *S. media* reproduction (i.e. no information on gestation period, mating season, and the litter size). Maximum size is one of the only known measurements, as maximum size was recorded for the largest *S. media* caught but the sex was not reported. There is not enough data to support if this is the actual maximum size of the species. Distribution of this species could possibly be larger than originally speculated as Figure 20 suggests that the population could potentially be more widespread with the entire north western Atlantic Ocean as a prospective unstudied habitat for this species.

In Figure 24, the Caribbean region has a sustainable catch rate for hammerhead species within their range. A catch rate around 60 t seems manageable for the populations of hammerheads to withstand, while anything over 100 t cannot be sustained. In Central, South, and North American regions they have not found sustainable intake rates. Central America reached their maximum yield at around 6,000 t and have a declining catch rate ever since. In South America, the

hammerhead populations were stable at catch rates of 200 t or lower. In North America, there were two clear population rebounds suggesting that lower catch rates while still producing for the fisheries can maintain the integrity of the species. There is a clear need for more data on this rare species. In 2006 and 2014, Casper Burgess and then Perez-Jimenez called for further data to be collected on *S. media* habitat, life history, biology, and catch rates to better understand their population biology for fisheries purposes.

Sphyrna tiburo

Sphyrna tiburo is, of this study, the most researched species of hammerhead and is not vastly lacking in data. This abundance of data does not make for this species to be overlooked. With the ever-changing ocean and increasing fisheries more data should be collected to properly set fisheries intake rates. Since this species has a higher than normal rebound rate, they will be less affected by fishing pressure in comparison to other sphyrnids. However, some regions have seen marketed declines in this species abundance (Bizzarro et al. 2009; Smith et al. 2009; Perez-Jimenez 2014). Most of these regions that have reported declines are the regions that most rely on these fisheries (McCallister et al. 2013).

In Figure 30, the hammerheads fished throughout the Caribbean and North American region thrive best when fished in the lower 60 to 40 t range. While in the South American region, hammerheads throughout the region seem to be able to withstand slightly higher intake rates of 200 t. The results of the Central American region were inconclusive. For example, their later reported numbers show a sharp increase, but the trend for the hammerheads throughout this region is currently declining. These declines in population where fisheries heavily rely on *S. tiburo* emanate a need for population surveys.

Sphyrna tudes

As with other species of sphyrnids, *S. tudes* has intraspecific life history traits influenced by their geographic distribution. Most studies on this species have been centralized around Brazil and Trinidad with little expansion (Sadowsky 1965; Lessa et al. 1998). There is a lack of data with this species located in other regions throughout its distribution.

The distribution for this species is debated. Individuals previously considered to be *S. tudes* in the Mediterranean are now more likely to be *S. lewini*, but still included when citing distribution.

Sphyrna tudes does not inhabit these regions rather a more restricted distribution (Cadenat and Blache 1981; Mycock et al. 2006; Ferretti et al. 2008). This is advantageous based solely on conversation purposes, but also a disadvantage because they inhabit a narrow margin of inshore area which is greatly affected by habitat degradation, overfishing, and pollution (Silva Junior et al. 2012; Moura et al. 2013). All life cycles of this species are found throughout these muddy bottom mangroves and estuaries and therefore should be focused on for species conservation (Castro 1989; Giglio and Bornatowski 2016).

Figure 36 shows that the hammerheads caught in the Caribbean region can maintain a steady population when caught in smaller increments of about 40 t. While in the South American region, the hammerhead population never seemed to recover from the intense fishing. Conservation actions are needed for *S. tudes* as well as more research on life history between different countries, harvest, use of caught fish (Mycock et al. 2006). Research needs to be done on the habitat use, habitat partitioning, and migration patterns in order to develop effective conservation management plans for *S. tudes* (Giglio and Bornatowski 2016).

Conclusion

This thesis reviewed and compiled the collective information on the life history and biology of six lesser known species of hammerhead sharks. The current knowledge of interactions with fisheries targeting these species around the world was also documented. Currently, data is scarce for the biology, life history, and catch rates of these species therefore leading to inaccurate stock assessments and data gaps vital for the management of these species. If these lesser known hammerheads continue to be overlooked in conservation assessments, their extirpation from once bountiful waters is forthcoming. With all of the available data compiled into this thesis, it is undeniable that these lesser known hammerhead species are highly threatened and thus require more research to resolve the contemporary data gaps listed above. Further research will improve our understanding of the conservation needs for each hammerhead on the levels of an individual, a population, and as a whole species.

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Appendix 1: Overview depicting what life history traits are known and unknown for all six species of lesser known hammerhead species.

Life history traits	*E. blochii*	*S. corona*	*S. gilberti*	*S. media*	*S. tiburo*	*S. tudes*
Maximum age	●				●	
Maximum size	●	●		●*	●	●
Average size	●				●	●
Sexually maturity age	●				●	
Sexually maturity size	●	●*		●	●	●
Mating season	●				●	●
Parturition	●				●	●
Gestation period	●				●	●
Average litter size	●		● (orange)		●	●
Litter size	●	● (orange)	● (orange)		●	●
Size at birth	●	● (orange)	●	●	●	●

●	Known data
● (orange)	Estimated data
	Unknown for species
*	Unknown for which sex