Local ecological knowledge and the historical context of marine apex predators near Islas Marías, México

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Abstract

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Many shark species and populations are threatened globally due to human actions. Monitoring and protecting these top predators is crucial to maintaining healthy marine ecosystems. However, for many habitats, long-term, historical datasets necessary to track population changes are lacking. This is the case of Islas Marías, México, where the presence of a prison hindered monitoring efforts for decades. In this paper, we addressed a knowledge gap about changes in shark populations through the synthesis of fishers' local ecological knowledge (LEK). The compiled data allowed us to make a comprehensive list of the shark species diversity in the region. Fishers reported 15 species and one additional genus of sharks near Islas Marías. Overall, catch sizes and perceived abundance trends from 66 interviews suggest that populations of sharks near Islas Marías have been in decline since at least the 1960s. A thematic network

analysis revealed that shark declines were attributed to environmental, social, and market factors. These results highlight the importance of fishers' expert knowledge in reconstructing species population trends.

1. INTRODUCTION

1.1 Global shark declines

As top predators, sharks play important roles in structuring and connecting marine ecosystems through transfer of energy and mediating predation and competition (e.g. Baum and Myers, 2004; Dulvy et al., 2017; Heithaus et al., 2008). Thus, changes in the abundance and distribution of predatory sharks can have lasting impacts on entire ecosystems (Baum and Myers, 2004; Estes et al., 2011; Ferretti et al., 2010; Heithaus et al., 2008; Myers et al., 2007). Removal of apex shark predators has shown to increase the abundance and change the behavior of other mesopredatory species (Grubbs et al., 2016; Stevens, 2000), such as lower trophic level shark species (Hammerschlag et al., 2019; Speed et al., 2018), and moray eels (e.g. Clementi et al., 2021; Luiz and Edwards, 2011; Pinheiro et al., 2017). These effects on lower trophic levels from mesopredator release can shift food web dynamics and alter ecosystem functioning (Wallach et al., 2015). Shark removal can potentially impact other ecosystem functions, such as nutrient cycling (Schmitz et al., 2010), scavenging (Wilson and Wolkovich, 2011), and the ecological effects of invasive species trophic levels from mesopredator release can shift food web dynamics and alter ecosystem functioning (Wallach et al., 2015). The ecosystem effects of shark population declines can occur over large geographic regions. Many shark species are highly mobile and migratory, moving between different habitats and ecosystems, so declines of sharks in one habitat can have cascading effects on adjacent habitats (Heupel et al., 2015; Roff et al., 2018).

Anthropogenic threats, particularly overexploitation, have reduced global shark population abundances (Bargnesi et al., 2020; Baum and Myers, 2004; Dulvy et al., 2014; Ferretti et al., 2008; Marie et al., 2017), with consequences for ecological systems (Dulvy et al.,

2017). Sharks are particularly vulnerable to overfishing due to their longevity, slow growth, low reproductive rates, and late age of maturity (Baum and Myers, 2004; Cortés, 2000; Giovos et al., 2019)

1.2 Conservation challenges: Data gaps

Despite being one of the most threatened groups of marine species worldwide, sharks are among the most data deficient (Bonfil, 1994; Martínez-Candelas et al., 2020). Lack of time series data can create uncertainties about population trends and the magnitude of natural and anthropogenic changes that have occurred, which can be challenging for setting conservation goals (McClenachan, 2009; Thurstan et al., 2015). Such data limitations make it difficult to assess species status, characterize ecological changes caused by declines in shark populations, and create evidence-based management and recovery plans (Baum and Myers, 2004; Cheng et al., 2021; Hammerschlag et al., 2019; Leduc et al., 2021; Noble et al., 2020; Pérez-Jiménez et al., 2012; Saldaña-Ruiz et al., 2019).

1.3 Local ecological knowledge

To address the data deficiencies that can hinder shark conservation and management efforts, we can turn to historical ecology and long-term knowledge of resource users. Local ecological knowledge (LEK) is place-based knowledge held by fishers and other resource users, generated through experience and observations of a natural environment across one's lifetime or over generations (Brook and McLachlan, 2008; Bundy and Davis, 2013; Gilchrist et al., 2005). Fishers' LEK can help provide spatial and temporal changes in fishing activity (Sala et al., 2004) and species diversity, abundance, and distribution trends over time (Ainsworth, 2011; Ainsworth et al., 2008; Ames, 2007; Beaudreau and Levin, 2014; Colloca et al., 2020; McClenachan et al., 2012; Moreno-Báez et al., 2012; Rasalato et al., 2010). Fishers can additionally suggest

perceived causes of any changes, such as overfishing or environmental or climate change-related factors (Barausse et al., 2014; Colloca et al., 2020; Sala et al., 2004) and how fishers and fishing communities have adapted to such changes (Ames, 2007). LEK can also provide information on stakeholder perceptions that can in turn inform communication of science and policy strategies and understand levels of social acceptance among different management opportunities (Boubekri et al., 2022; Giareta et al., 2021).

1.4 Case study: Islas Marías, Mexico

The impact of the absence of long-term monitoring data is particularly evident in Islas Marías, Mexico. Also called Tres Marías Islands, this four-island archipelago is located in the Tropical Eastern Pacific (TEP) about 132 km off the coast of Nayarit. Named a Biosphere Reserve (2003) and UNESCO world heritage site (2007) for the high levels of marine and terrestrial biodiversity and endemism on and around the archipelago (CONANP-SEMARNAT 2010), Islas Marías is located in a unique oceanographic region, at the confluence of the California Current from the north, the Mexican Coastal Current from the south, and the Gulf of California, depending on the time of year (López-Pérez et al., 2016). The region is also influenced by northwesterly winds that drive thermocline formation and upwelling on the western coast of Mexico (Fiedler and Talley 2006). Being in this transitional region of tropical and temperate zones means that both tropical and temperate species can be present (Pérez-Jiménez et al., 2005). Islands in this region are important "stepping stones" of shallow habitat that allow marine species to move and migrate around the Mexican Pacific (Ketchum and Reyes-Bonilla 1997, 2001), and can act as corridors for many migratory species, such as sharks. Many of these recognized habitat corridors are being studied and are currently under protection through marine reserves (Ketchum and Reyes-Bonilla 1997, 2001).

There remains little data available on the role that this archipelago has as potential "stepping stone" habitats in the greater Mexican Pacific because the Federal Penitentiary of Mexico on Isla María Madre prevented the regular compilation of ecological data on and around the archipelago for decades. The prison's 114-year tenure meant limited access to the area and was thought to act as a de-facto marine reserve on the archipelago (CONANP-SEMARNAT 2010). However, fishing was permitted for the Penitentiary residents and employees using manual lines within permitted areas (CONANP-SEMARNAT, 2011), and there is both recent and historical evidence of shark fishing from at least the 1940s around the archipelago, despite the lack of shark landing locations in what catch data is recorded (CONAPESCA, 2018; Erisman et al., 2011a). Although official landing data remains scarce, shark fishers around the archipelago have knowledge of shark diversity and abundance in the area. More recent expeditions around the archipelago found little presence of sharks, despite the island chain occurring within the geographic range of twenty-one species of sharks in the Mexican Pacific (Erisman et al., 2011b; Tholan et al., 2020). Taken together, these observations suggest that overfishing may have occurred.

CONAPESCA (2010) lists Mexico as one of the top ten countries for shark harvest globally. Shark fisheries in the Mexican Pacific have important social and economic value, providing income and sustenance for many communities (McGoodwin, 1976). Fresh, frozen, or salt-dried shark make up about 90% of shark production in Mexico (Bonfil, 1994; Castillo-Géniz et al., 1998), but sharks are also exported for their fins, hide, and organs/offal to be turned to fish meal (Bonfil, 1994). The vessels and gear used vary by region, but most shark harvesting in the Mexican Pacific has been done by artisanal or small-scale fishers using vessels (called pangas) made out of fiberglass and using gillnets or longlines depending on the region (Bonfil, 1994;

Cartamil et al., 2011; De la Cruz-González et al., 2018; Moreno-Báez et al., 2012; Sala et al., 2004). When not targeted, sharks may be incidentally caught in other fisheries targeting bony fishes (Ramirez-Amaro et al., 2013). Shark fishing has declined in recent years, including along the Pacific coast (Pérez-Jiménez et al., 2005; Sala et al., 2004) and in the Gulf of Mexico (Bonfil, 1997; Castillo-Geniz et al., 1998).

The management of these fisheries has been limited, in part, by little data on catch compositions and fishing efforts, especially for artisanal shark fisheries (Smith et al., 2009; Torres-Herrera and Tovar-Ávila, 2014). Without long-term fishery and biological data, it also remains difficult to determine if fluctuations in catch are from direct changes in shark abundance or from changes in fishing effort (Bonfil, 1997). The fisheries data collective uses coarse taxonomic categories that sometimes span across multiple trophic levels or landings data with no information on fishing gear used or location of harvest (Erisman et al., 2011b). For example, until recently, harvested sharks in the Mexican Pacific were split into two categories – 'cazón', or sharks less than 150 cm in total length that can include both small adult sharks and large juvenile sharks, and 'tiburón', or sharks greater than 150 cm in total length (Castillo-Géniz et al., 1998; CONAPESCA-INP, 2004). This limits species-specific information and does not distinguish among shark life stages (Cartamil et al., 2011).

1.5 Study objectives

The Federal Penitentiary of Mexico on Isla María Madre prevented monitoring efforts and the collection of ecological data in the area for close to 114 years. The 2019 federal penitentiary relocation to mainland Mexico and the declaration of the Islas Marías archipelago as a natural preserve and conservation area provide the opportunity for monitoring and fishery management efforts in the area (Mega, 2019). We draw from fishers' LEK to assess the historic

context of marine predator changes in the Islas Marías archipelago, Mexico, to address the following questions: 1) What historical changes in species diversity and species abundance do small-scale fishers perceive near Islas Marías?; 2) What social and environmental factors do fishers attribute to these changes?

2. METHODS

2.1 Local ecological knowledge interviews

We conducted 102 semi-structured interviews with fishers using a pre-defined questionnaire with both open- and closed-ended questions between August and September 2021 at six coastal fishing communities in Nayarit state: Boca de Asadero, Boca de Camichín, Chacala, La Cruz de Huanacaxtle, La Peñita de Jaltemba, and San Blas (Figure 1). Nayarit is the closest mainland to Islas Marías, and the artisanal fleet in these communities have previously or currently fish around the archipelago. Pérez-Jiménez et al. (2005) and Tovar-Avila et al. (2011) describe the shark fishery in Nayarit being mostly composed of vessels less than 10 m in length and using mainly gillnets and longlines to target many different shark species.

Participants, whose primary occupation currently is or previously was fishing for at least part of the year were recruited by identifying key participants through researchers at National Fisheries Institute (INAPESCA) that have worked in the area for decades (Tovar-Avila, pers. comm., 2021). Once the initial key participants were interviewed, we used snowball sampling, where interviewed fishers recommend other suitable active or retired fishers to participate (Becker et al., 2003; Goodman, 1961). Prior to the interviews, participants were provided background information on the research using non-technical language (Bender et al., 2014; Selgrath et al., 2018) and assured that their responses would be summarized anonymously. Participants could end the interview at any time or skip questions.

The first part of the interview consisted of general background information (such as age and fishing experience) and current fishing practices in general, specifically around Islas Marías, and specifically in regard to shark fishing. To understand perceived changes in species diversity, we asked fishers their top target shark species near Islas Marías, and to name the locations where they saw sharks when fishing for other species for every decade they were actively fishing. To understand perceived changes in species abundance, we asked fishers what their maximum catch for one day (a representation of effort) for shark species was in kilograms. For these fishers, the catch weight of individual species is not recorded. At the end of their fishing effort, all sharks are weighed together as one coarse unit. Fishers were then asked if they thought the abundance of main target shark species has changed compared to the present decade (2010-2021). For each species that fishers described, they were asked if abundances were "much more abundant", "more abundant", "the same", "less abundant", or "much less abundant" compared to present-decade levels. Following the interview approach from Beaudreau and Levin (2014), participants were asked to base abundance characterizations on their own observations and to skip time periods when they were not fishing or had insufficient knowledge. Finally, fishers were asked to explain the reasons for changes in shark diversity and abundance (if known) and their views of future management scenarios for the Islas Marías archipelago. The full interview guide is in Appendix A.

Anticipating that shark species would be described using their local names in Nayarit, we created a table of all potential shark species that could occur in waters around Islas Marías. We then created a document with all those species, their potential local names as described in Furlong-Estrada et al. (2014), Torres-Herrera and Tovar-Ávila (2014), and Tholan et al. (2020), and photographs of species in and out of the water to refer to during interviews to confirm

species identification. Fishers gave varying levels of detail, and some did not answer every question.

2.2 Data analysis

To address objective (1), we first used descriptive statistics to summarize information from the interviews. The number of answers and percentage of the total number of answers for each question on general background information, shark diversity, catch weights, perceived abundances, and management preferences were registered.

To address objective (2), a thematic analysis (Braun and Clarke, 2006) was conducted with the qualitative data pertaining to changes in catch weight and perceived abundances over time. Interview transcripts were examined through an iterative process to identify recurrent themes that were then used as categories for the analysis (Fereday and Muir-Cochrane, 2006). Initial codes were first identified as representing specific causes or factors related to changes in catch weight or perceived abundances. Those codes were then categorized into sub-themes ("basic themes") and overarching themes ("organizing themes") (Attride-Stirling, 2001).

3. RESULTS

The ages of fishers interviewed ranged from 18 to 91 years old. Years of fishing experience ranged from 2 to 66 years (Table 1). The age distribution was skewed towards ages <25 and between 50-70 years old (Figure S1). Eighty-three (81.4%) of the fishers are still fishing, while 19 (18.6%) are retired. The number of days per week participants fish varied from 1.5 - 7 days, with a mean (±SD) of 5.2 (±1.4) days. Participants reported fishing 4 to 12 months of the year, with a mean of 11.5 (±1.6) months. When asked how often they fish near Islas Marías, 19 fishers (18.6%) said never, 1 (0.9%) said once, 22 (21.6%) said occasionally, and 60 (58.8%) said regularly. However, only 31 fishers still actively fished there at the time of the

interviews (2021). Across fishers, the mean (±SD) percentage of a fisher's total catch being from around Islas Marías was 15.9 (±17.8) % for the 1960s, 20.5 (±22.8) % for the 1970s, 14.6 (±19.2) % for the 1980s, 10.5 (±16.7) % for the 1990s, 8.0 (±13.2) % for the 2000s, 6.0 (±11.4) % for the 2010s, 6.5 (± 3.5) % for the 2020s.

3.1 Fishing communities

The locations where the interviews took place were traditionally shark fishing towns, however in recent times shark fishing is opportunistic and not fishers' top choice. That being said, fishers from all towns repeated that big sharks used to be close to shore and now they have to go further offshore to see or catch them.

Fishers from La Cruz De Huanacaxtle fish near Islas Marías the most because they go so far to target yellowfin tuna (*Thunnus albacares*) due to current high market prices. The fishers from this community travel to Islas Marías with the priority of looking for yellowfin tuna around 1.5 miles from the coast of either Islas Marías Cleofas or Islas Marías San Juanito. If they cannot find yellowfin tuna, or if surveillance does not allow them to fish near the coast, their next option is to fish 7-10 miles from the coast in search of sharks.

Compared to La Cruz De Huanacaxtle, few fishers from La Peñita de Jaltemba have fished near Islas Marías. Some of the younger fishers have briefly fished near the archipelago for *Lutjanus guttatus*, which involves using divers and seines about two miles from the coast of Islas Marías. Fishers are aware of potential tourism increasing off the archipelago but are not as worried about that affecting their work as fishers from La Cruz De Huanacaxtle. Shark fishing essentially stopped in this town a little over twenty years ago. Previously off of La Peñita de Jaltemba, older fishers describe how there used to be a shark fishing camp at Isla del Coral and

how today you can see discarded longline gear there previously used for sharks that are now rusted or rotten.

Compared to the other communities, many of the fishers interviewed from Chacala now focus on tourism. In the 1980s, Chacala was a place where young fishers became shark fishers because of the PIDER-PESCA program, a government program consisting of shark fishing on the high seas, the Baja, Islas Marías, and Revilla. This is an important memory for many since a vast majority participated in that fishing since they were young (around 18 years old). The value of sharks eventually decreased, and the government granted the fishing cooperatives loans for shrimp boats so the same fishers could continue to work. This lasted about ten years until the early 2000s.

San Blas was the largest fishing community interviewed, with over 2000 fishers. Fishers stay near shore to fish in the estuaries and also go out to the high seas. Fishers here catch larger sharks compared to some of the other study communities, but only do so by fishing around Isla Isabel. Some will go to Islas Marías to fish for bony fish, such as mahi-mahi (*Coryphaena hippurus*). They carry up to three different types of fishing gear to be able to target any species and cover the high costs of the trips.

In Boca de Camichín, the main activity is oyster farming at the mouth of the San Pedro River. There is one cooperative that assigns oyster permits with over 300 members currently. The cooperative does have permits for fish, sharks, and oysters; however, the cooperative does not receive any of the products. There are three permit holders that the fishers work for despite being a part of the cooperative. Even if fishers are not part of the cooperative, they will still work for the permit holders.

Boca de Asadero is a small community with only about 15 fishers living in the town. Fishers from other places will keep their boats or use the ports in Boca de Asadero, which means there are about 100 fishers in total. Community members are concerned about nearby shrimp farms from other towns because they pollute the water and reduce the presence of fish, divert water from the estuary, and have removed mangroves. There are approximately four shark permits for the whole town. The majority of fishers currently target *Scomberomorus sierra* because this species is quite abundant, while fishers are seeing decreases in other species.

Common names varied across and within localities and landing sites, where different names could apply to the same species or the same common names to different species or time periods.

3.2 Management

When asked if there are any places near Islas Marías that were once productive fishing grounds but now depleted, 17 fishers (17%) said Islas María Cleofas, 5 (5%) said Islas María Magdalena, 1 (1%) said Islas María San Juanito, 3 (3%) said Islas Marías unspecified, 25 (25%) reported no areas, and 46 (45%) said they do not know. Sixty-four (64%) fishers think that fishing will be a valuable source of income in the future, while 36 (36%) disagree.

Sixty (59%) fishers support the current restrictions on commercial fishing around Islas Marías, whereas 37 (36%) oppose them and 5 (5%) are neither for nor against. Fifty-eight (58%) of fishers support the current restrictions on recreational fishing around Islas Marías, whereas 37 (37%) oppose them and 5 (5%) are neither for nor against. Preferred fishing management strategies for the archipelago ranged from preferences for unregulated fishing to not allowing fishing in the area (Table 2).

3.3 General Shark Fishing

Across the six locations, 29 fishers listed sharks in their top three overall target species across all decades. When fishers reported their top three overall target species for each decade, sharks represented 7.1% of all species listed in the 1960s, 14.3% in the 1970s, 8.5% in the 1980s, 4.2% in the 1990s, 3.8% in the 2000s, 2.6% in the 2010s, and 3.1% in the 2020s. Out of the 102 fishers interviewed, 93 of the fishers have intentionally fished for sharks. Only 36 fishers still fish for sharks at the time of the interviews in 2021 (Table 3). When asked what percentage of fishing vessels in their communities currently take part in shark fishing for at least some part of the year, 58 (57%) said none, 22 (22%) said less than 10%, 14 (14%) said 10-50%, 7 (7%) said about 50%, and one (1%) said greater than 90%. When asked in a typical week how many days fishers catch sharks, six (11%) said 1-2 days, 25 (45%) said 3-4 days, 10 (18%) said 5-6 days, and 15 (27%) said seven days. The main gear used are longlines and gill nets, with several mentions of harpoons and other hook-and-line gear.

3.4 Shark Diversity

Sixty-six fishers answered the interview questions on shark diversity, shark catch weights, perceived abundances. These fishers reported 15 species and one genus (not identified to species) of sharks caught off at least one island in Islas Marías (Table 4, Table S1). *Sphyrna* remains grouped at the genus level because common names in Nayarit for species within this genus are the same. Other than *Triaenodon obesus*, *Nasolamia velox*, and *Mustelus lunulatus*, all species have been caught in every decade since the 1970s. Following habitat classifications from Saldaña-Ruiz et al. (2019), *Alopias pelagicus*, *Carcharhinus falciformis*, and *Prionace glauca* are oceanic species, *Isurus oxyrinchus* and *Sphyrna* spp. are both oceanic and pelagic species, and the other 11 species are fully coastal.

Five species remained in the top three target species across all decades (Table 5). In the 2000s, the most reported shark species, defined as the one mentioned as a top target species most frequently by interviewees, *Carcharhinus limbatus*, switched places with the second most reported shark, *Sphyrna* spp. The third most reported shark was *Carcharhinus leucas* until the 2010s when *A. pelagicus* were reported more often. For the 1990s, *Carcharhinus brachyurus* was reported more than *C. leucas.*

3.5 Shark Abundance

In addition to listing their top three target shark species for each decade, the same fishers gave the maximum shark catch recorded for each decade. When landing sharks, fishers often do not weigh catch based on individual species and instead do it based on their total shark catch. This means that maximum shark weights represent the combination of all sharks caught that landing from a single trip. Mean weights varied across each decade, but do show a general decline over time (Figure 2). Out of the 66 fishers, 48 reported declines in their total shark catch weight over the time they have been fishing, and the rest reported no change.

Fishers also indicated their perceived abundances of main target shark species over time in relation to the current decade (or the decade an individual stopped fishing if they were retired). Individual fishers may conceptualize abundance based on their own life experiences or backgrounds, so we summarized overall abundance trends over time. No fishers said that shark abundances were ever less abundant in previous decades. Nine fishers reported no changes in shark abundance since they have been fishing, and the rest denoted varying levels of shark abundance declines. Overall trends of the top five target shark species generally show declines in perceived abundances over time (Figure 3). Mean abundance trends remain above the ‘same

abundance compared to the present decade' category, so for all decades the perceived abundances were greater in the past to varying degrees.

3.6 Factors fishers attribute to changes

Some fishers gave their reasoning for why top target shark species or maximum catch changed over time. In the 1960s, fishers described high demands for shark meat and fins, suggesting that market factors influenced their high catch weights. From the 1970s to present day, all other factors associated with changes in catch weights were related to declines over time. Some fishers described how their catch weights decreased because they stopped fishing for sharks as much. This was a result of switching to targeting more non-shark species and increased cost of shark fishing, both of which suggest that market and fishers' behavior influenced the changes in catch weights. All other reasons fishers gave for declines in catch weights were associated with declines in shark abundance at usual fishing areas. Fishers described how they would either need to increase fishing efforts at usual fishing sites to get the same amount of catch or travel greater distances to new fishing areas to get the same amount of catch. Sometimes these behavior changes appear to be secondary causes of underlying biological changes, such as changes in distributions of sharks that would cause the fishers to need to travel further offshore.

Reasons associated with declines in shark abundance mostly related to overfishing of sharks specifically or sharks being incidentally caught in other fisheries. A couple of fishers also attribute climate-related ocean changes as causing shark abundance declines. Overall, reasons for fishers stopping shark fishing, changes in their top target shark species and catch weight, and changes in perceived abundances were similar.

Fifty-nine (59%) fishers are concerned about the number of sharks in the area possibly declining, while 41 (41%) are not. If sharks did decline in number, 4 (4%) fishers think that their

non-shark landings would increase, 44 (48%) think they would decrease, and 44 (48%) think they would stay the same.

4. DISCUSSION

Without landing records being separated by species, it remains difficult to assess and estimate long-term changes in stocks (Torres-Herrera and Tovar-Ávila, 2014). Since catch statistics are not species-specific, only catch trends of aggregated taxa could be assessed in the past (Pérez-Jiménez et al., 2005). LEK can provide an understanding of abundance changes across a longer period compared to available data and offer additional information that official landing data does not include. The shark diversity reported by fishers in this study helps expand what we know about shark ecology in the area and confirms that this archipelago is likely important "stepping stones" of shallow habitat in the Mexican Pacific (Ketchum and Reyes-Bonilla 1997, 2001). Fishers describe overall changes in abundances of the shark species reported, attributing environmental, social, and market factors to those changes.

4.1 Present-day shark fishing

Although this study confirms the historical importance of Islas Marías as important shark fishing grounds, most fishers do not fish around the archipelago at present. Additionally, most fishers in Nayarit mainly target bony fish species today, only catching sharks opportunistically or incidentally. Over time, fewer fishers have described any species of sharks as being in their top three target species across all marine resources harvested. The main fishing gear used are either longlines and gill nets because those can be used to target multiple species; however, harpoons or hook-in line were also infrequently mentioned, similar to summaries of fishers' activities in Tovar-Ávila et al. (2017). These findings are similar to those of other studies that described

declines in shark fisheries in the Gulf of Mexico (Bonfil, 1997; Castillo-Geniz et al., 1998) and in the central Pacific coast (Pérez-Jiménez et al., 2005).

4.2 Shark diversity

Based on the high shark diversity around Islas Marías, the archipelago is likely important habitat for shark species in the Mexican Pacific. Despite recent expeditions around Islas Marías finding little presence of sharks (Erisman et al., 2011b; Tholan et al., 2020), fishers identified 15 species and one genus out of the 21 shark species thought to be in the region. Based on Torres-Herrera and Tovar-Ávila (2014), the likely species of *Sphyrna* spp. are *Sphyrna lewini*, *Sphyrna mokarran*, and *Sphyrna zygaena*.

All species identified near Islas Marías by the fishers have been described as being in the Mexican Pacific (Saldaña-Ruiz et al., 2019; Robertson and Allen, 2015), in the Gulf of California (Furlong-Estrada et al., 2014), and all but *T. obesus* in unspecified locations off the central coast of Nayarit (including Isabel Island or Islas Marías) (Torres-Herrera and Tovar-Ávila, 2014). *C. leucas*, *C. limbatus*, *Carcharhinus obscurus*, *Galeocerdo cuvier*, *T. obesus*, *Ginglymostoma unami*, *M. lunulatus*, and two species of *Sphryna* spp. (*S. lewini* and *S. zygaena*) have all been described around Islas Marías specifically by either CONANP-SEMARNAT (2010), Erisman et al. (2011b), Pérez-Jiménez et al. (2005), or Tholan et al. (2020). Pérez-Jiménez et al. (2005) described the rest of the species that fishers mentioned in this study, other than *C. brachyurus*, as being identified either south of Islas Marías or near Isabel Island. While Erisman et al. (2011b) and Tholan et al. (2020) reported low shark sightings around the archipelago, each of the shark species identified off Islas Marías were reported in the most recent decade by at least one fisher. Additionally, not considering changes in catch sizes or difficulty

finding species, there are no shark species identified in the earlier decades that fishers have not identified in the present decade, suggesting some degree of stability of these species in catches.

Of the shark species mentioned near Islas Marías, *M. lunulatus* is the only one listed as Least Concern by the IUCN. The rest are listed as Endangered or Critically Endangered (*A. pelagicus*, *C. obscurus*, *N. velox*, *G. unami*, *I. oxyrinchus*, and two *Sphyrna* species - *S. lewini* and *S. mokarran*), Vulnerable (*C. brachyurus*, *C. falciformis*, *C. leucas*, *C. limbatus*, *Negaprion brevirostris*, *R. longurio*, *T. obesus*, and *Sphyrna* species - *Sphyrna zygaena*), and Near Threatened (*G. cuvier* and *P. glauca*).

Based on landing data in 1995 and 1996, *S. zygaena*, *C. falciformis*, and *P. glauca* were the most important shark species for fishers from La Cruz de Huanacaxtle (Pérez-Jiménez et al., 2005). The fleet out of La Cruz de Huanacaxtle has not caught sharks south of Islas Marías in the Central Gulf of California since the late 1990s (Pérez-Jiménez et al., 2005), which is consistent with our findings. Pérez-Jiménez et al. (2005) suggests this could reflect declines in catch rates of all shark species in the Gulf of California. The most common group of species caught by fishers were *Sphryna* species, which supports the finding of Torres-Herrera and Tovar-Ávila (2014) that *Sphyrna lewini* was the second most abundant species in catch records. Although Torres-Herrera and Tovar-Ávila (2014) found *R. longurio* to be the most abundant species, *R. longurio* was tied for the seventh most abundant species identified by interviewed fishers out of all six communities.

A. pelagicus being reported more in the 2010s and 2020s could be a result of fishers from La Cruz Huanacaxtle targeting yellowfin tuna around the north and south sides of the archipelago. The longlines they use for yellowfin tuna and sharks are similar, so if they cannot find yellowfin tuna, they will try for sharks even further offshore from Islas Marías in pelagic

habitat preferred by *A. pelagicus*. Often, interactions with sharks were based off of targeting non-shark species like this yellowfin tuna case.

4.3 Shark abundance

Beyond shark diversity, LEK allowed us to estimate abundance trends, which would not be possible with the available regional catch data. Regardless of a fisher's top three target shark species over time, trends of declines in overall catch weights were fairly consistent. Declines in shark catches have been reported in other regions in the Mexican Pacific and even on the broader national scale (SAGARPA, 2010). Fishers in western Baja California from Cartamil et al. (2011) and the Gulf of California from Saldaña-Ruiz et al. (2017) describes declines in catches of elasmobranchs in recent decades.

Environmental, social, and market changes were all reported as factors explaining declines in shark fishing over time. The market-related factor of high demand for shark meat and fins being associated with high catch weights in the 1960s supports other findings of shark fishing becoming more popular in the 1960s post the Second World War based on the value of shark fins, hides, meat, and fishmeal increasing (Castillo-Géniz et al., 1996). Fishers' responses are consistent with the shark fishery in Mexico being maximally exploited in the 1980s and 1990s, as described by Pérez-Jiménez et al. (2005). All factors attributed to changes in catch weights from the 1970s until present day were related to declines in catch. Tovar-Ávila et al. (2011) attributed declines in shark fishing near Isabel Island to environmental or socioeconomic factors, similar to what the fishers in this study described. For example, shark fishing has been replaced by bony fish fishing around Isabel Island because of shark overexploitation (CONANP, 2005). Many fishers in this study described how they fish for non-shark species more now as a result of external costs of shark fishing or higher demand for bony fish. Additionally, some

fishers associated their declines in catch weights with declines in abundance of target shark species.

Most factors attributed to declines in abundance were associated with overfishing target shark species or incidentally catching sharks as bycatch in when targeting other species. Many of these sharks have low biological productivity, although some are more resilient than others (Walker, 2005). All the sharks identified near Islas Marías in this study have either a low or medium level of biological productivity (Furlong-Estrada et al., 2014). Some species may be able to be resilient against fishing due to different life history strategies, however the lower biological productivity may help explain the declining trends in abundance associated with fishing activities. *S. lewini*, for example, is a slow growing species with late sexual maturity, so it likely will not recover from fishing pressure as well as other species (Smith et al., 1998).

Similar to findings of declines in shark landings in the rest of the Mexican Pacific, Tovar-Ávila et al. (2017) found that shark landings around Isabel Island varied based on seasonal variations in oceanographic conditions and biological factors, such as migratory habits. Most of these species, such as *A. pelagicus*, *P. glauca*, *C. falciformis*, and *Sphryna* spp. are highly migratory and have large home ranges (Sosa-Nishizaki et al., 2008). These movements and migrations can explain why catch and abundance levels may vary. For example, *C. falciformis* makes seasonal movements from the Gulf of California south to Central America in March-April (when it is often caught by fishers in the Mexican Pacific) and then return north to the Gulf of California in July through September (Saldaña-Ruiz et al. 2019). Castillo-Géniz et al. (2008) describes the migratory movements of *S. lewini* being less known in the Mexican Pacific. Additionally, species that are pelagic and do not have aggregating behavior may have less

obvious trends in abundance changes over time, since their presence is likely to be more variable in the region.

4.4 Local ecological knowledge considerations

LEK of fishers interviewed in this study contributes to better understanding of species occurrence and abundance over time, particularly in areas where other forms of biological and fishery monitoring have not occurred. LEK of fishers in Nayarit provided information on the historic context of shark populations in the Islas Marías archipelago, including changes in species diversity and abundance. Fishers also provided insights into changes in their own fishing activity near the archipelago over time and offered perceptions of social and environmental factors that contributed to both shark and fishing activity changes over time.

Fishers mainly based their changes in shark diversity and abundance over time on the shark species they targeted or caught incidentally. Other information known about shark species in the Mexican Pacific comes from fishery-related data or sampling, which can create a bias towards shark species that are targeted or incidentally caught in fisheries (Saldaña-Ruiz et al., 2019). The majority of interviewees mentioned that sharks not being fished are only seen on the surface when there is floating matter, such as sticks or debris, that aggregate prey and, in turn, attract sharks. We found that fishers' interactions with sharks often varied based off of their behavior on the water targeting non-shark species. Since each community has different target species, their shark interactions may differ.

The data gathered from this study can be used as a point of comparison for evaluating changes in shark diversity and abundance. LEK can provide valuable insights when complemented with other forms of biomonitoring (Bessesen and González-Suárez, 2021). Accurate species identification is an important component of producing reliable LEK. When

possible, information from interviews can be corroborated with other sources of data (McKelvey et al., 2008). For example, we confirmed that all shark species have previously been described in the broader Mexican Pacific, and when uncertain about identification, grouped some species like the *Sphyrna* spp. Lack of species and location-specific landing data and factors such as variability in fishing gear, duration of trips, and number of fishers per boat make estimating catch-per-unit-effort in these fisheries difficult. It can thus remain challenging to quantitatively evaluate changes over time. For this reason, individual values, such as catch weights and abundance levels were described as greater trends on decadal scales to avoid individual bias.

Bodies of knowledge, such as LEK, can stand on their own without being conformed into Western science frameworks. We found strong agreement between LEK and the limited scientific knowledge of shark diversity and abundance available in the region. Combining other information sources with LEK can help reduce uncertainties associated with LEK (Beaudreau and Levin, 2014; Huntington et al., 2004). However, when integrating different sources of information, the goal should not be to validate one way of knowing over another, but rather to offer complementary information, highlight mechanisms that can explain diverging conclusions, and identify future directions for exploration (Huntington et al., 2004). For example, comparing LEK from this work with other sources of data in the region highlighted a couple different ideas for further investigation. Distribution patterns can provide further understanding of the roles of sharks in the Mexican Pacific and help to better estimate changes in movements and migrations for factors like climate change or where anthropogenic impacts, such as fisheries interactions, are likely to occur (Saldaña-Ruiz et al., 2019). Since many of these sharks are highly migratory, understanding their movements over different spans of time can provide historical baselines for changes in the distribution.

At the southern end of the Gulf of California, Islas Marías is a proposed shark nursery (Saldaña-Ruiz et al. 2019). Nearby Isabel Island is an important area for concentration of juvenile hammerhead shark species at times when oceanographic conditions are favorable (Tovar-Ávila et al., 2017). We did not ask fishers if they caught juveniles or adults, so understanding the age of sharks as a proxy for their resilience in fisheries is difficult. For some sharks, exploitation can be sustainable if the youngest age-classes are targeted (e.g., Simpfendorfer, 1999). Pérez-Jiménez et al. (2005) suggests that fishers in this region may already have been targeting this age class just by nature of fishing in areas where there are mostly younger ages of sharks present. Understanding shark distribution across ages around the archipelago can provide insight into its role as nursery grounds for further protection.

In western Baja California, interviews from fishers suggest that in addition to abundances of sharks decreasing in recent decades, there have also been descriptions of declining average size of shark species caught (Cartamil et al., 2011). Closer to Islas Marías, there has been decreases in length of *S. lewini* around Isabel Island (Tovar-Ávila et al., 2017). Investigating changes in the length of sharks caught in the fishery over time can help provide insight into how the average size of sharks may be changing in the environment.

4.5 Conclusion

Similar to findings from other LEK about long-lived species, we found that LEK provided insights into changes in species abundance over time (Beaudreau and Levin, 2014; Chan et al., 2019). With the potential for more access and fewer restrictions in the archipelago, scientific research around Islas Marías may increase and this study can be used to complement future work. To successfully reach the objectives set by CONANP-SEMARNAT (2010) to preserve the archipelago, it will be important to consider fisher perspectives and preferred

management strategies. This study suggests that management plans may benefit from being adaptable to the localities that continue to fish sharks in Nayarit and implementing schemes that benefit the fishing communities while preserving shark populations. When thinking about the future of management around the Islas Marías archipelago, it is important to consider the support of local communities, which can increase the success of conservation initiatives (Dolrenry et al. 2016; Giareta et al., 2021; Karnad, 2022). With so many shark species identified in the area, this archipelago is a priority for marine conservation efforts. Despite declines over time in shark fishing, these species still provide important supplies of food and employment for small-scale fishers in Nayarit. Additionally, many fishers believe that there are areas around specific islands in the archipelago that are no longer productive fishing grounds, particularly Islas Marías Cleofas. When designing future management strategies, considering perceived depleted areas by fishers may help guide spatial planning.

The wealth of knowledge from resource users in these communities can be used to better understand these social-ecological systems and to implement successful community-based management and decision-making practices (Torrents-Ticó et al., 2021). This can be done by working with communities to understand perceptions of changes and values and norms related to the ecosystems or species of concern, which conservation actions are most supported, and ways that different actions will influence the livelihoods and safety of those in the communities (Torrents-Ticó et al., 2021). Our study showed that LEK of small-scale fishers in Nayarit can help address information gaps for data-poor species, such as sharks. We thus encourage the use of fishers' LEK when collecting baseline data to inform management and decision-making actions.

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Figures and Tables

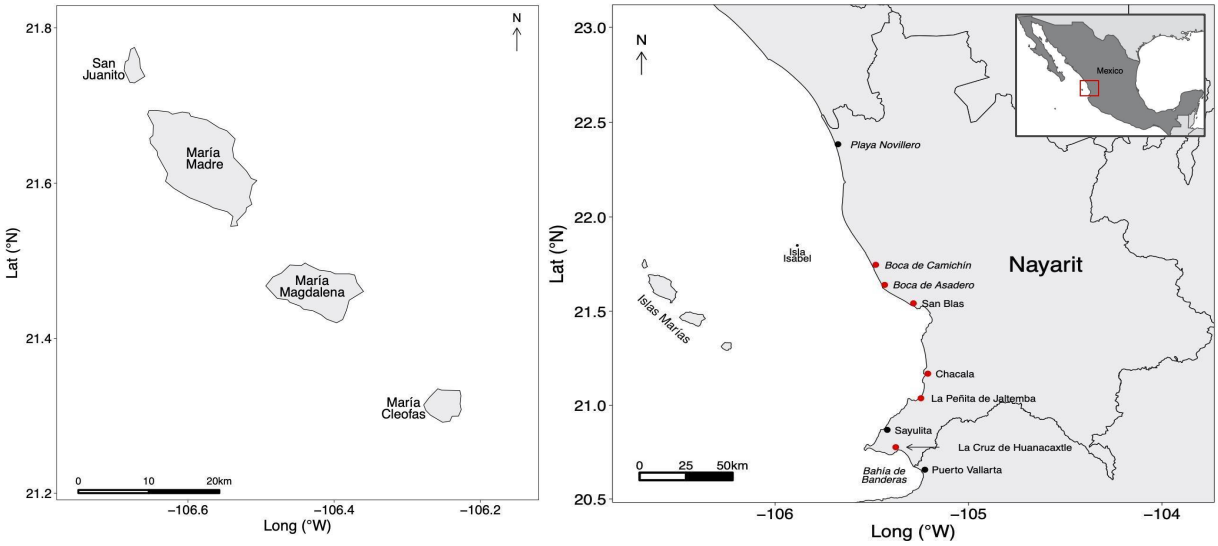


Figure 1. Map of the study site. Communities with red circles indicate those where interviews took place.

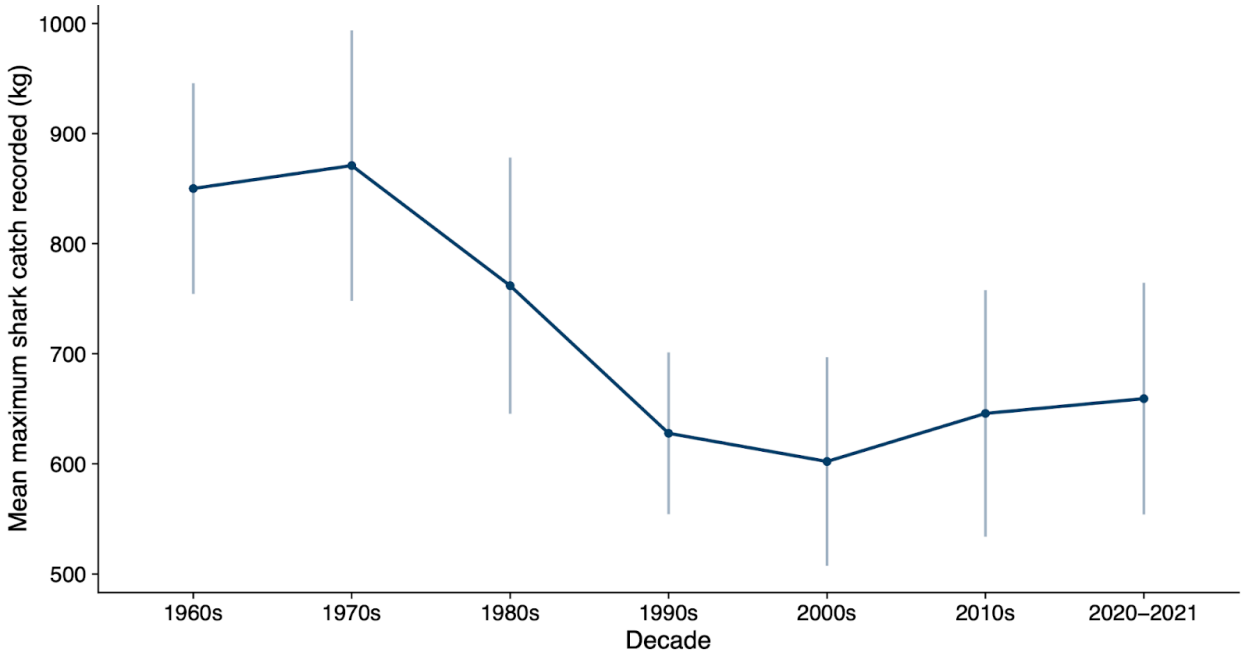


Figure 2. Mean weights (in kg) of the maximum shark catch recorded for fishers across each decade. Points represent means and the vertical lines represent standard deviations.

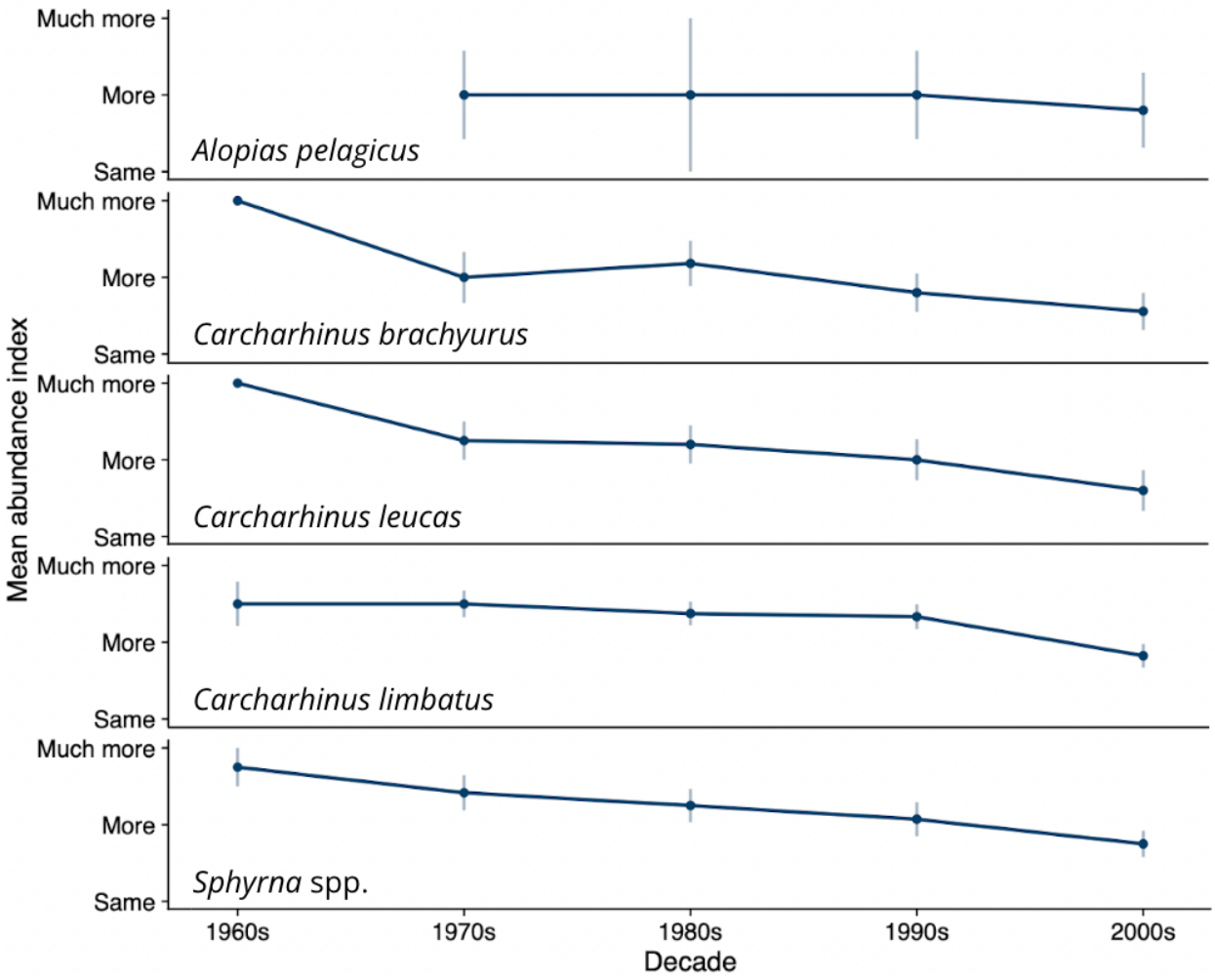


Figure 3. Reported abundance levels for the top five target sharks described near Islas Marías for all decades. Fishers reported relative abundance as 'much more abundant', 'more abundant', 'the same' 'less abundant', or 'much less abundant' compared to present decade (2010-2021) levels for active fishers (or to when a fisher stopped fishing if they were retired). Points represent means and the vertical lines represent standard deviations.

Table 1. Number of fishers interviewed, mean (± SD) age, and mean (± SD) years of fishing experience of all 102 interviewed fishers across the six locations (BAS = Boca de Asadero, BCA = Boca de Camichín, CHA = Chacala, LCH = La Cruz de Huanacaxtle, LPJ = La Peñita de Jaltemba, SB = San Blas).

Location	Total # fishers	Mean age	Mean years of fishing experience
BAS	16	45.2 ± 18.5	30.6 ± 19.7
BCA	16	43.9 ± 19.5	26.0 ± 18.6
CHA	10	59.1 ± 16.5	40.0 ± 15.0
LCH	23	46.6 ± 20.3	29.3 ± 18.2
LPJ	15	46.2 ± 22.3	26.7 ± 16.1
SB	22	47.1 ± 18.4	31.2 ± 17.7

Table 2. Responses for which management strategy on Islas Marías are fishers most in favor of.

Which of the following management strategies would you be most in favor of?	*N*
A: Regulations that protect the islands from most fishing, as they are now	40
B: Regulations that allow fishing at Islas Marías for some species for at least part of the year	6
C: No regulations at all, not even through cooperatives.	8
D: Other: Regulations that allow fishing with permits or concessions	26
D: Other: Regulations that allow fishing with gear restrictions	24
D: Other: Regulations that allow fishing with boat size restrictions	1
D: Other: Regulations that allow fishing with catch limits	1
D: Other: Regulations that allow fishing certain distances from shore or in certain areas	5
D: Other: Regulations that reserve certain areas for recreational diving	1
D: Other: Regulations that allow fishing with size restrictions	1
D: Other: Regulations that respect spawning/breeding seasons	3
D: Other: Reach an agreement either both fishers and tourists allowed or neither	1
D: Other: Regulations that allow at least sport fishing	1
D: Other: Regulations that only allow sport fishing	1
D: Other: Let fishers take refuge or rest on the islands if engine breaks	1
D: Other: Severe consequences for illegal fishing	1

Table 3. Answers to the question ‘do you still fish for sharks?’

Question: Do you still fish for sharks?	*N*
No - stopped in 1970 -1979	5
No - stopped in 1980 -1989	7
No - stopped in 1990 - 1999	8
No - stopped in 2000 - 2009	15
No - stopped in 2010 - 2019	11
No - stopped in unspecified year	11
Yes	36

Table 4 Shark species identified by fishers near Islas Marías and the number of fishers that reported each species. Green cells represent decades where a species was reported and red cells with an 'X' represent decades when a species was not reported by fishers.

Species	Common name	Number of fishers	Decade reported in catch record						
			1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	2020-2021
Alopias pelagicus	Pelagic thresher shark	13	X						
Carcharhinus brachyurus	Copper shark	23							
Carcharhinus falciformis	Silky shark	6	X						
Carcharhinus leucas	Bull shark	29							
Carcharhinus limbatus	Blacktip shark	39							
Carcharhinus obscurus	Dusky shark	10	X						
Galeocerdo cuvier	Tiger shark	17							
Ginglymostoma unami	Pacific nurse shark	8							
Isurus oxyrinchus	Shortfin mako shark	4	X						
Mustelus lunulatus	Sicklefin smooth-hound	5						X	X
Nasolamia velox	Whitenose shark	2	X		X	X	X		
Negaprion brevirostris	Lemon shark	11							
Prionace glauca	Blue shark	7							
Rhizoprionodon longurio	Pacific sharpnose shark	11	X						
Sphyrna spp.	Hammerhead shark species	52							
Triaenodon obesus	Whitetip reef shark	3	X	X		X			

Table 5. The top three most reported targeted shark species for each decade starting in the 1960s.

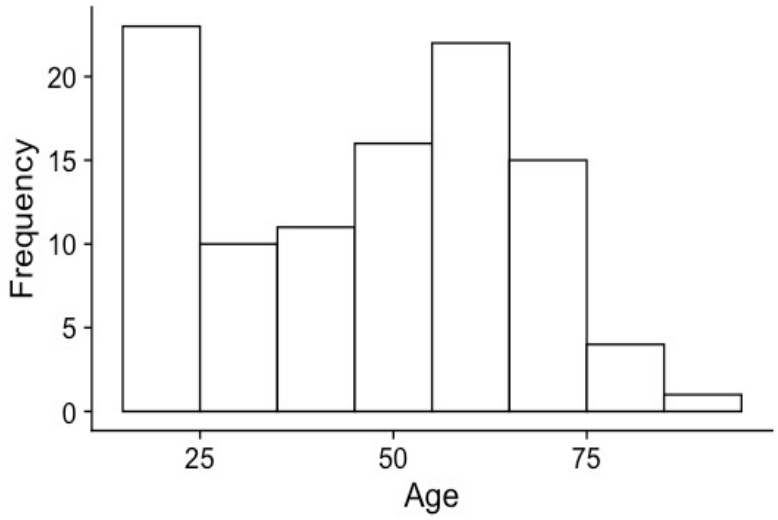
	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	2020-2021
#1 top target shark species	*Carcharhinus limbatus*	*C. limbatus*	*C. limbatus*	*C. limbatus*	*Sphyrna* spp.	*Sphyrna* spp.	*Sphyrna* spp.
#2 top target shark species	*Sphyrna* spp.	*Sphyrna* spp.	*Sphyrna* spp.	*Sphyrna* spp.	*C. limbatus*	*C. limbatus*	*C. limbatus*
#3 top target shark species	*Carcharhinus leucas*	*C. leucas*	*C. leucas*	*Carcharhinus brachyurus*	*C. leucas*	*Alopias pelagicus*	*A. pelagicus*

Supplementary Material

Table S1. Common names in Nayarit and in English of each of the shark species or families described by fishers.

Family	Species	Common name	Common name in Nayarit
Alopiidae	*Alopias pelagicus*	Pelagic thresher shark	Coludo/Zorra/Zorro/Grillo
Carcharhinidae	*Carcharhinus brachyurus*	Copper shark	Colorado/Lobero
Carcharhinidae	*Carcharhinus falciformis*	Silky shark	Atunero/Tunero
Carcharhinidae	*Carcharhinus galapagensis*	Galapagos shark	Barrigona
Carcharhinidae	*Carcharhinus leucas*	Bull shark	Chato/Sapo/Toro
Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	Punta Negra/Volador
Carcharhinidae	*Carcharhinus obscurus*	Dusky shark	Prieto/Zarco
Carcharhinidae	*Galeocerdo cuvier*	Tiger shark	Tigre/Tintorera
Carcharhinidae	*Nasolamia velox*	Whitenose shark	Coyote
Carcharhinidae	*Negaprion brevirostris*	Lemon shark	Bayo/Limón/Maduro
Carcharhinidae	*Prionace glauca*	Blue shark	Aguado/Azul
Carcharhinidae	*Rhizoprionodon longurio*	Pacific sharpnose shark	Coyotillo/Coyotiyo/Platanillo
Carcharhinidae	*Triaenodon obesus*	Whitetip reef shark	Punta Blanca/Aletilla
Ginglymostomatidae	*Ginglymostoma unami*	Pacific nurse shark	Gata
Lamnidae	*Isurus oxyrinchus*	Shortfin mako shark	Mako
Sphyrnidae	*Sphyrna* spp.	Hammerhead shark species	Cornuda/Gorra/Martillo
Squatinidae	*Squatina californica*	Pacific angelshark	Angelito
Triakidae	*Mustelus lunulatus*	Sicklefin smooth-hound	Mamón

Figure S1. Age distribution of all interviewees (n=102).



Appendix A: Interview Guide

Birth Year: Year fisher was born

Age: Fisher's age

Background Questions

What year did you begin fishing?

Are you still actively fishing?

- Yes
- No What year did you stop fishing?

What year did you begin fishing near Islas Marías?

- Year
- Never fished near Islas Marías

How often do you fish near Islas Marías in present day?

- Never
- Once
- Occasionally
- Regularly

Are you still actively fishing near Islas Marías?

- Yes
- No What year did you stop fishing?

Current General Fishing

How frequently do you fish (#days/week)?

How many months do you fish at sea each year?

Shark Fishing

Have you ever intentionally fished for sharks? (does not count if sharks were bycatch)

- Yes
- No

If yes to the above questions, what year did you start fishing for sharks?

If yes to the above question, do you still fish for sharks?

- Yes
- No What year did you stop fishing?

If no to the above question, why did you stop fishing for sharks?

In your memory, is there a specific year when people began fishing for sharks off Nayarit or near Islas Marías, or have people here always been fishing for sharks?

- Year
- Always

How often, if ever, do you encounter sharks while fishing for sharks or other species?

- 1-2 days/week
- 3-4 days/week
- 5-6 days/week
- Every day
- Once every two weeks
- Once a month
- Once every 2-3 months
- Never

What percentage of the fishing vessels in your fishing cooperative or community take part in shark fishing for at least some part of the year?

- None
- A few (less than 10%)
- Some (10-50%)
- About half (50%)
- More than half (50-90%)
- Most (90% or more)

How many of those days do you typically catch sharks?

- 1-2
- 3-4
- 5-6
- Everyday

Timeline Questions

Your #1 most important target shark species for each decade

Your #2 most important target shark species for each decade

Your #3 most important target shark species for each decade

Most you caught (kg) for unspecified top 3 target shark species for each decade

Most you caught (kg) for #1 most important target shark species for each decade

Most you caught (kg) for #2 most important target shark species for each decade

Most you caught (kg) for #3 most important target shark species for each decade

If your top target shark species changed over time, why?

If the most you caught (kg) changed over time, why?

What type of gear did you use for your #1 most important target species for each decade?

What type of gear did you use for your #2 most important target species for each decade?

What type of gear did you use for your #3 most important target species for each decade?

If the type of gear changed over time, why?

For each decade, do you think the abundance of your #1 most important target shark species has changed compared to the present decade (2010-2021) (or compared to the decade you stopped fishing if retired)?

- Much more abundant than present
- More abundant than present
- The same as present
- Less abundant than present
- Much less abundant than present

For each decade, do you think the abundance of your #2 most important target shark species has changed compared to the present decade (2010-2021) (or compared to the decade you stopped fishing if retired)?

- Much more abundant than present
- More abundant than present
- The same as present
- Less abundant than present
- Much less abundant than present

For each decade, do you think the abundance of your #3 most important target shark species has changed compared to the present decade (2010-2021) (or compared to the decade you stopped fishing if retired)?

- Much more abundant than present
- More abundant than present
- The same as present
- Less abundant than present
- Much less abundant than present

If abundance changed over time, why?

Were there areas where you frequently observed shark aggregation near Islas Marías for each decade? Identification on the map, add any notes on shark species, key habitats, nursery areas, etc.

What percentage of your total catch production depends on Islas Marías?

Are there any places near Islas Marías that were once productive fishing grounds but are now depleted?

- Yes Where?
- No
- I do not know

Are you concerned about the number of sharks in the area possibly declining?

- Concerned
- Not concerned

Do you think fishing will be a valuable source of income in the future?

- Yes
- No

Which of the following management strategies would you be most in favor of?

- Regulations that protect the islands from most fishing, as they are now

- Regulations that allow fishing at Islas Marías for some species for at least part of the year
- Regulations that allow cooperatives to grant use rights of certain areas to fishermen in the community
- Other cooperative-regulated management
- No regulations at all, not even through cooperatives.
- Other:

Do you support or oppose the current restrictions on *commercial* fishing around the islands?

- Support
- Oppose

Do you support or oppose the current restrictions on *recreational* fishing around the islands?

- Support
- Oppose