Sharks Without Borders

Population Structure in Common Thresher Sharks (*Alopias vulpinus*) in the Northeastern Pacific, and Implications for US/Mexico Bilateral Management

Source: NOAA

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Capstone Project

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Introduction

'Sharks have existed on Earth for over 400 million years,' (Hubbell 1996) —a fact often recited by shark advocates the world over—and for good reason. An animal with such impressive resilience over time, juxtaposed against rapidly declining populations, is compelling; an effective anchor from which to explore shark conservation. But in the reality of an anthropocentric world, we must consider the complexities of animal conservation in terms of resource management. Sharks are biologically and ecologically diverse, widespread, and often highly migratory, with fishing occurring all over the world under highly-disjointed management. It is estimated that one-quarter of the world's sharks and rays are threatened due to overfishing, both targeted and incidental (Dulvy et al. 2014). With slow growth rates and low fecundity, large sharks are particularly vulnerable to overexploitation (Holden 1974; Hoff & Musick, 1990). Further, removing top predators from their environment can negatively impact the greater ecosystem (Stevens et al. 2000). But with different species and different populations facing unique pressures, it is important to consider shark conservation on a species-by-species basis.

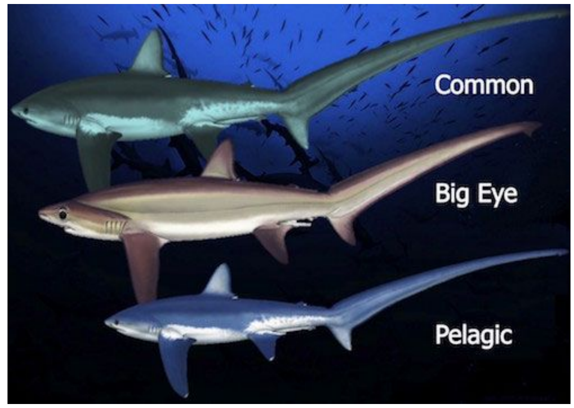
This project focuses on Common Thresher sharks (*Alopias vulpinas*) in the northeastern Pacific (NEP), hereafter referred to as "NEP Common Thresher," exploring genetic relatedness and population structure among Common Thresher sharks found in Baja California, Mexico (BC) and California waters, and considerations for effective bilateral management between the two countries where they are commercially and recreational caught. The US and Mexico manage their Common Thresher shark fisheries independently of each other and there are currently no binational fisheries management plans between the US and Mexico (Teo et al. 2016). While important for managing fish populations that span multiple jurisdictions, bilateral fisheries agreements are uncommon (Caddy & Seijo 2005). Further, there is a particular need for more information of shark populations around the world to inform management efforts (Bradshaw et al. 2008). Although tagging studies provide important information, more research into population structure is needed for many shark species (Ahonen et al. 2009), as well as insights into population genetic health (Frankham 1995; Portnoy et al. 2009).

With the goal of learning more about NEP Common Thresher sharks and their management, I address four research questions in this project: 1) Do these sharks comprise a single, panmictic population? 2) What can genetic identification of sibling relationships tell us about the population(s) response to the international border? 3) What is the effective population size (N_e) for this/these population(s)? 4) What is known about the status of this population; and what are perspectives on efficacy of current management?

Background

Biology and Ecology

There are three known extant species of thresher shark: Common Thresher (*Alopias vulpinus*), Bigeye Thresher (*Alopias superciliosus*), and Pelagic Thresher (*Alopias pelagicus*). Common Thresher sharks are the largest of the three species at an estimated size from about 114-156 cm TL (total length) at birth to over 300 cm TL fully grown (Hixon 1979; Compagno 1984; Moreno et al. 1989).



Source: www.threshercove.com

The Common Thresher shark is a coastal-pelagic shark found in temperate and subtropical waters of the Atlantic, Pacific and Indian Oceans (Compagno 2001; Smith et al. 2008) (Figure 1). In the northeastern Pacific, they inhabit waters from BC to British Columbia, Canada, with the highest concentrations in the Southern California Bight (SCB) and few are found beyond 30 km from shore (Hanan et al. 1993). Research has shown that while migratory, Common Thresher sharks from different areas of world are not emigrating between regions (Moreno et al. 1989, Bedford 1992; Trejo 2005).

Their elongated upper lobe of the caudal fin is used to stun prey, which includes various forage fish and squid (Compagno 2001). Like most large sharks, Common Threshers are slow growing and slow to reproduce (Smith et al. 2008). It is estimated that NEP Common Threshers reach maturity at about 5.3 years of age (Smith et al. 2008) and can live up to 50 years (Cailliet et al. 1983; Smith et al. 1998). Tagging studies in the SCB have shown that sub-adults and adults spend time in deeper offshore waters, while juveniles use shallow waters over the continental shelf as a nursery (Cartamil et al. 2010a; Cartamil et al. 2010b).

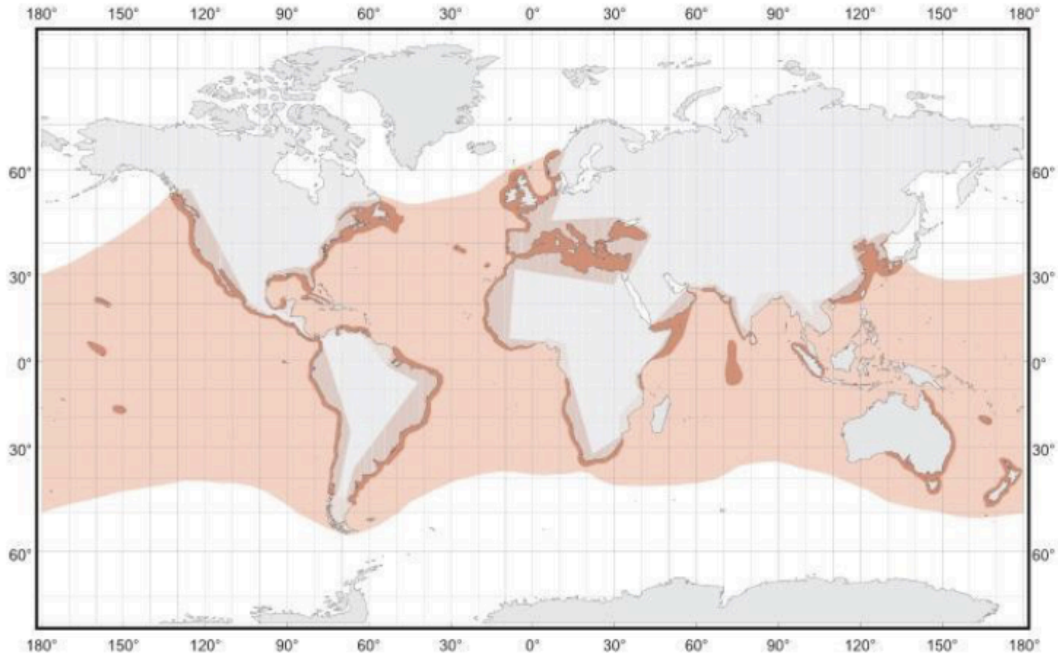


Figure 1: Common Thresher shark distribution. (Source: Compagno 2001)

History and Status of Fishery

In both the US and Mexico, Common Thresher sharks are targeted in commercial and recreational fisheries and considered one of the most important commercially-caught sharks in both areas. In fact, Common Threshers are the most common commercially landed shark in California, targeted secondarily in long-line and purse seine fisheries, caught incidentally in nearshore set gillnets and small-mesh drift gillnets (USSN) fisheries, and targeted in a small recreational fishery in Southern California (USREC) (CDFG 2010). In Mexico, Common Thresher sharks are primarily targeted in near shore gillnet artisanal fisheries along the BC coast (Cartamil et al. 2011; Teo et al. 2016).

Source: nmfs.noaa.gov

United States

The commercial fishery for Thresher sharks in California began in the late 1970s with the creation of the swordfish/shark drift gillnet (USDGN) fishery (CDFG 2010). This was a significant fishery in the early 1980s with an estimated 1,000 metric tons being landed in 1982, followed by a sharp decline in the local population (Goldman 2000). In the 1990s, restrictions were placed on the USDGN fishery with the passage of the Marine Resources Protection Act banning gillnets in the SCB within 3 miles of shore (MRPA 1990). The fishery then shifted to primarily targeting swordfish and seasonal/area closures were implemented by the Pacific Fisheries Management Council (PFMC) (Young et al. 2016). These restrictions continued throughout the late 1990s and 2000s and in 2004 the PFMC implemented a precautionary catch limit through their Highly Migratory Species (HMS) Fisheries Management Plan (FMP) (Young et al. 2016). Currently, under the HMS FMP, precautionary levels are set at 340 metric tons per year for Common Thresher shark catch, and US average annual commercial landings based on 2004-2014 data have been around 115 metric tons per year (PFMC 2016).

Mexico

Common Thresher sharks comprised an important fishery in the late 1980s in the Mexican drift gillnet fishery (MXDGN) in Ensenada, BC, which like the USDGN fishery, primarily targeted swordfish and pelagic sharks (Teo et al. 2016). Since the 1990s, landings of Common Threshers have declined as longlines have replaced drift gillnets for fishing high seas and in 2010 the MXDGN fishery was closed through federal regulation (Teo et al. 2016). However, juvenile Common Threshers are still frequently caught in near-shore artisanal fisheries (Cartamil 2011). Accurate estimates of Common Thresher shark catches from Mexican fisheries are difficult to obtain due to inconsistent and inadequate reporting (Teo et al. 2016). Until 2006, sharks were reported merely as “Tiburon” for large sharks (longer than 150 cm) or “Cazon” for smaller sharks (less than 150 cm), with any thresher species reported as “Tiburon.” Since 2006, species are reported with more discretion but thresher sharks are still only reported as one category, whether they are Common, Pelagic, or Bigeye Thresher sharks. This interjects a certain amount of uncertainty around accuracy of fisheries-dependent data used in assessments of Common Threshers in BC waters.

Genetic Data Analyses

Common Thresher sharks are widely distributed around the world (Compagno 2001), but accurate understanding of distribution patterns of Thresher sharks may be hampered due to misidentification with Bigeye and Pelagic Threshers in some cases (Smith et al. 2008). One study suggests possible genetic differentiation among Thresher sharks across their global range (Trejo 2005), but more research is needed to understand these dynamics. More is known about NEP Common Thresher sharks than other areas (Smith et al. 2008), and this stock is considered the most effectively managed in terms of sustainable fishing (Teo et al. 2016). Cartamil et al. (2010a, b) have researched movements and abundance of NEP Common Threshers using tagging methods and analyses of fisheries catch data, showing adult threshers utilizing off-shore waters while juveniles primarily stay near shore in nursery grounds.

Precautionary management based on relevant science is crucial for the conservation of the species and populations. Sharks can be difficult to study and therefore difficult to manage. Tagging data provides important insight into migration and abundance while fisheries-dependent data from catch reports can also contribute to our understanding of shark populations. However, fisheries catch reporting leaves room for inaccuracies. Genetic analyses of sharks can help provide insight into population health through genetic diversity metrics, information about population structure and movements, and a baseline to which other Common Thresher shark populations might be compared in future studies, as well as for use in future studies of NEP Common Threshers. Further, genetic analyses can tell us about the demographic history of a population. For example, Common Thresher sharks were heavily fished in BC and California during the 1980s and 1990s (PFMC 2003), potentially creating a genetic bottleneck or a sharp reduction in the population size due to outside influences, possibly reducing the genetic diversity and potential adaptability.

For this project, previously-collected genetic data from Common Thresher sharks were analyzed for insight into population structure, genetic relatedness, and effective population size (N_e). The results of this study can be used to support bilateral management of this population.

Methods

Genetics Data

Genetic data were sampled from 549 Common Thresher sharks off the coast of California and BC, from 1997 to 2012. The resulting dataset includes juveniles sampled from two sub-regions: BC (N=55) and Southern California (N=330), and adults sampled from three sub-regions: Northern (N=55) and Southern California (N=54) and BC (N=55). All individuals were genotyped at 11 independent microsatellite loci. Of the individuals of known sex, there was close to a 1:1 sex ratio for both juvenile and adult sharks (50 female adults, 48 male adults, 41 female juveniles, 59 male juveniles).

Summary statistics

We tested for conformity to Hardy-Weinberg equilibrium using the R package StrataG 1.0.5 (Archer et al. 2016). Loci were then analyzed for observed (H_O) and expected heterozygosity (H_E), and allelic richness (A_R) in StrataG.

Population Structure

For insight into population structure, we ran the dataset through StrataG to produce several differentiation metrics using 10,000 permutations. The differentiation metrics analyzed include F_{ST} (Wright's inbreeding coefficient) and G'_{ST} (Nei's coefficient of gene variation). F_{ST} is the most commonly referenced differentiation metric, while G'_{ST} is more appropriate for multi-allelic loci with high heterozygosity (Hedrick 1999). For each differentiation metric, global estimates were calculated as well as pairwise estimates among the five sampled regions.

Sibship analysis

As an additional test for functional separation between Thresher sharks across the US/Mexico border, we looked for sibling relationships based on genotypes using Colony2 version 2.0.6.3 (Wang & Santure 2009). Sharks less than 110 cm FL were considered offspring. We ran offspring (N=382), female (N=50), and male (N=48) genotypes through Colony2 with the following selections: Mating System I=Female Polygamy; Mating System II=With Inbreeding and Without Clone; Species=Dioecious and Diploid; Analysis Method=Full-Likelihood (FL); and for Likelihood Precision, Length of Run, Run Specifications, and Sibship Prior, default settings were used. Marker Type is codominant, and an Error Rate of zero was used.

We used an arbitrary threshold of ≥0.6 probability of sibship, using only those pairings above a 60% likelihood for further analyses. We then calculated the age difference between sibling pairs (see aging in the next section). In R, we calculated the age distribution showing how many sibling pairs differed in age 0-10 years. We also counted the number of sibling pairs that spanned the international border. To test if this was different from random, we randomly paired individuals from our dataset to create the same number of random pairings as found in our sibling dataset and counted how many pairs are divided between BC and California sub-regions. We repeated this calculation 1,000 times to determine the distribution of random cross border pairings and then tested whether the count of true cross-border sibling pairs fell within the 95% percentile of that distribution.

Effective Population Size

Effective population size (N_e) is a is a metric of genetic drift and approximates the number of breeding individuals in the population. Calculation of N_e was performed using a temporal method (Waples 1989) as implemented in the R package NB version 1.0 (Hui & Burt 2015). Calculation of N_e required the dataset be organized into cohorts based on year of birth. The sampled sharks were not aged upon collection. However, fork length (FL) was recorded or estimated for each shark. We used a novel quantitative approach to age each individual shark in our dataset. Using R, we inverted a length-at-age transition matrix, sourced from a recent NOAA Thresher Shark stock assessment (Teo et al. 2016), using a vector containing previously estimated total numbers of individuals per age group (also sourced from the NOAA assessment) to create an age-at-length transition matrix. This provided a matrix of estimated probabilities that a shark of a certain length would be a certain age. We then created a function in R to estimate ages for all sampled sharks using this transition matrix. We then calculated estimated birth years based on age and year of capture, and grouped them into birth-year cohorts.

We created an input dataset of allele counts per cohort year that we ran through NB.estimator in R, along with a vector containing the number of alleles at each locus, and a default lower and upper bound of 50 and 1e+07, respectively. Because the aging is a stochastic process, we ran the whole R script through 1,000 times to obtain a distribution of N_e results. Each run produced an estimate of N_e, lower and upper confidence interval (CI) estimates, and a likelihood estimate. We capped the upper CI at 1x10^7 to ensure the package ran efficiently (an upper CI of 10,000,000 is equivalent to infinity in other programs).

Results

Summary statistics

Deviation from Hardy-Weinberg equilibrium was not detected. Our locus summary statistics (Table 1) show that differences between H_O and H_E are not statistically significant and confirm that our data conforms to Hardy-Weinberg equilibrium. The mean proportion of unique alleles was 0.09 (Table 1), indicating the subpopulations have few unique alleles and therefore relatively high diversity across the loci. H_O estimates ranged from 0.10–0.93 with a mean of 0.74, and H_E estimates ranged from 0.11–0.93 with a mean of 0.76 (Table 1), indicating a relatively high degree of genetic diversity. When compared to estimates for other species (Table 2), our mean H_O and H_E is among the higher estimates, most comparable to lemon sharks (Feldheim, Gruber & Ashley 2001).

Allelic richness (A_R) is a measure of genetic diversity that can indicate how well a population may adapt to future influences. Allelic richness ranged from A_R=0.01-0.05 with a mean A_R of 0.03, indicating low allelic diversity. O'Leary et al. (2015) calculated allelic richness for South African (A_R=9.07) and Northwestern Atlantic (A_R=7.86) White Sharks. Scalloped Hammerhead sharks in the Eastern Pacific and the Gulf of Mexico were shown to have a range of A_R=4.89–6.91 (Daly-Engel et al. 2012). Relative to these estimates, the A_R for the NEP Common Thresher population is low.

Table 1: Locus summary statistics

Locus	A	A_R	Proportion of unique alleles	H_E	H_O
Locus 1	23	0.04	0.04	0.91	0.91
Locus 2	4	0.01	0.50	0.11	0.10
Locus 3	9	0.02	0.11	0.68	0.71
Locus 4	16	0.03	0.00	0.90	0.88
Locus 5	22	0.04	0.09	0.91	0.93
Locus 6	9	0.02	0.00	0.61	0.61
Locus 7	17	0.03	0.00	0.91	0.66
Locus 8	17	0.03	0.00	0.85	0.86
Locus 9	27	0.05	0.07	0.93	0.92
Locus 10	14	0.03	0.07	0.84	0.83
Locus 11	13	0.02	0.15	0.72	0.70
Mean	15.55	0.03	0.09	0.76	0.74

A=number of alleles per locus, A_R=allelic richness, H_E=expected heterozygosity, H_O=observed heterozygosity

Table 2: Examples of heterozygosity estimates from other studies

Species	H_O	Avg. H_O	H_E	Avg. H_E	Reference
Whale shark	0.44–0.85	0.66	0.40–1.00	0.69	Schmidt et al. 2009
Spiny dogfish	0.37–0.84	0.59	0.51–0.81	0.68	McCauley et al. 2004
Zebra shark	0.40–0.97	0.63	0.34–0.92	0.71	Dudgeon et al. 2006
Nurse shark	0.17–0.90	0.55	0.16–0.92	0.54	Heist et al. 2003
Sandtiger shark	0.29–0.75	0.62	0.28–0.73	0.61	Feldheim et al. 2007
White shark	0.45–0.95	0.70	0.51–0.83	0.66	Pardini et al. 2000
Shortfin shark	0.77–0.91	0.86	0.82–0.96	0.89	Schrey & Heist 2002
Blacktip shark	0.10–0.96	0.50	0.09–0.96	0.50	Keeney et al. 2005
Sandbar shark	0.63–1.00	0.87	0.57–0.96	0.85	Portnoy et al. 2006
Spot-tail shark	0.12–0.82	0.50	0.16–0.95	0.54	Ovenden, Street, & Broderick 2006
Australian blacktip	0.44–0.78	0.65	0.54–0.92	0.73	Ovenden, Street, & Broderick 2006

Lemon shark	0.68–0.87	0.77	0.69–0.90	0.78	Feldheim, Gruber & Ashley 2001
Bonnethead shark	0.51–0.87	0.65	0.55–0.96	0.69	Chapman et al. 2004

Population genetic structure

F_{ST} and G'_{ST} are measures of population differentiation or the level of genetic variation between populations. In general, values of zero for either metric indicate complete panmixia wherein the population(s) are interbreeding freely; F_{ST} of 1 indicates there is no shared genetic diversity among the individuals sampled. Our results showed global estimates for F_{ST} and G'_{ST} were both <0.001, indicating no evidence for population structure. Pairwise F_{ST} and G'_{ST} indices did not show significant genetic differentiation among sub-regions (Table 3), further showing no evidence for population structure, indicating one population spanning BC to Northern California.

Table 3: Pairwise population structure results

Sub-regions comparisons	F_{ST}	F_{ST} P-Value	G'_{ST}	G'_{ST} P-Value
MX_A (55) v. MX_J (55)	-0.003	0.950	-0.010	0.950
MX_A (55) v. N_CA (55)	-0.003	0.977	-0.013	0.988
MX_A (55) v. S_CA_A (54)	-0.004	0.999	-0.012	0.999
MX_A (55) v. S_CA_J (330)	-0.002	0.985	-0.006	0.985
MX_J (55) v. N_CA (55)	-0.003	0.979	-0.013	0.989
MX_J (55) v. S_CA_A (54)	-0.002	0.937	-0.010	0.937
MX_J (55) v. S_CA_J (330)	0.000	0.368	-0.004	0.386
N_CA (55) v. S_CA_A (54)	-0.002	0.883	-0.012	0.915
N_CA (55) v. S_CA_J (330)	0.000	0.560	-0.006	0.980
S_CA_A (54) v. S_CA_J (330)	-0.001	0.848	-0.005	0.851

MX_A=Mexico Adults; MX_J=Mexico Juveniles; S_CA_A=Southern California Adults; S_CA_J=Southern California Juveniles; N_CA_A=Northern California Adults

Sibship analysis

Colony2 produced allele matches for 3 full sibling pairs and 487 half sibling relationships. Figure 2 shows the distribution of age separation between siblings, indicating that while most siblings are aged within 0-1 years of one another, some are as far as 10 years apart in age.

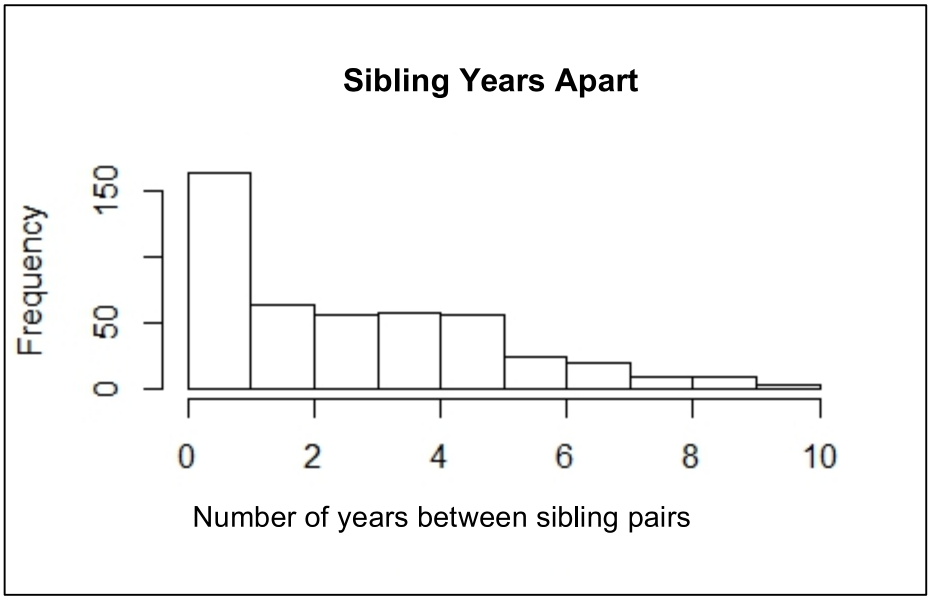


Figure 2: Distribution of number of years between sibling pairs

A random distribution of likelihood of siblings being from the same sub-region (Figure 3) shows the number of random pairings that spanned the border at the time of sampling. The blue line marks the 0.05 lower quantile of the distribution. If the number of siblings that span the border is lower than this, we can assume there are fewer of those siblings than there are randomly throughout the population range. The black line marks the actual count of 118 sibling relationships that span the border calculated from our data. It falls in the middle of the random distribution, indicating that the US/Mexico border is not a boundary for sibship.

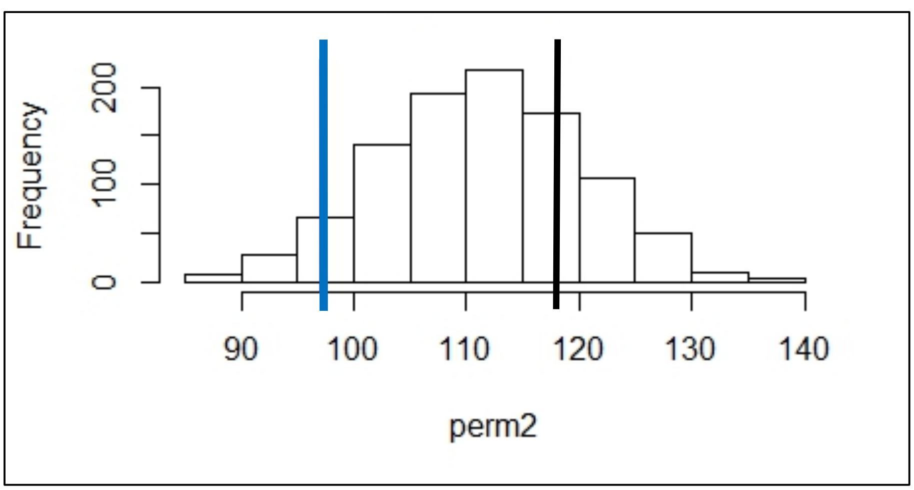


Figure 3: Random distribution of siblings

Effective Population Size

The effective population size (N_e) is a metric of genetic drift, reflecting the number of breeding adults in the population and potential for inbreeding (Lande & Barrowclough 1987). Our results show a mean N_e of 5,240 (Table 4). Figure 4 shows the distribution of 1,000 permutations that were run through NB.

Table 4: Summary statistics for each parameter

	N_e Estimate	Lower CI	Upper CI	Likelihood
Min	3847	1739	209728	-4466
1st Quartile	4853	1967	10000000	-4327
Median	5180	2032	10000000	-4296
Mean	5240	2035	9980581	-4293
3rd Quartile	5567	2099	10000000	-4261
Max	7424	2370	10000000	-4112

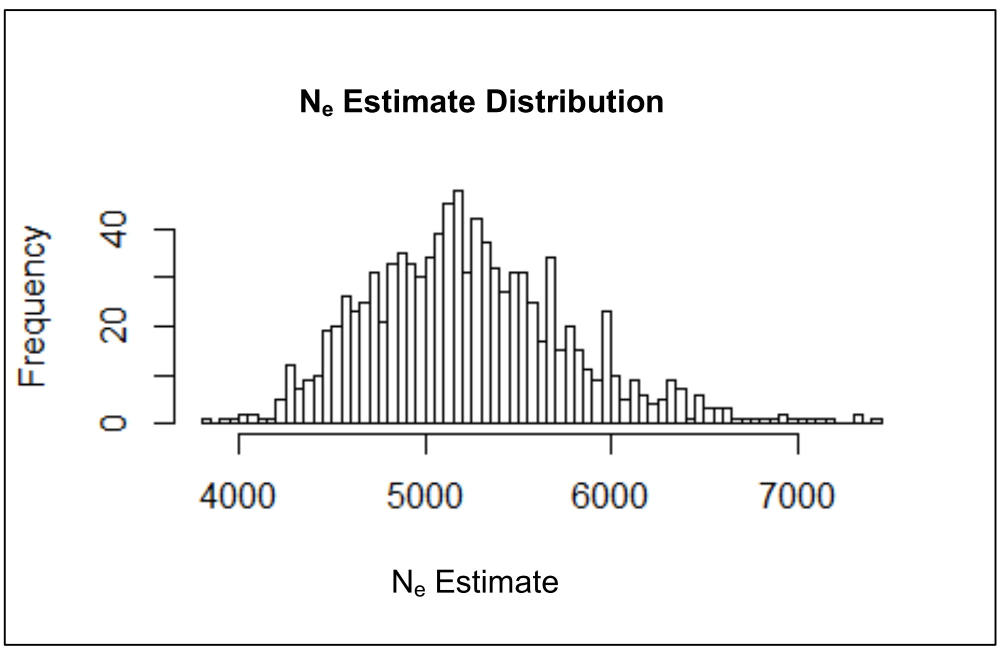


Figure 4: Effective population size (N_e) distribution

Our N_e estimate was then compared with those for other shark populations (Table 5). Here we see that the mean effective population size for the NEP Common Thresher shark population at 5,240 is much lower than some. For example Atlantic Bullsharks, global Soupfin, North Atlanitc Greenland sharks, and Alaska Pacific Sleeper sharks, all have N_e estimates over 90,000, with Bullsharks up to 221,000. It is most comparable to the Atlantic Blue shark and Western Atlantic Sandbar shark estimates.

Table 5: Comparison of effective population sizes across various shark species

Species	Location	N_e Estimate	Reference
Grey Nurse	East Australia	50	Frankham et al. 2002
Grey Nurse	East Australia	126	Tallman et al. 2008
White shark	Northwest Atlantic	23-66	O'Leary et al. 2015
White shark	South Africa	188-1,998	O'Leary et al. 2015
White shark	Australia	1,512	Blower et al. 2012
Sandbar	Western Atlantic (Delaware Bay)	4,890	Portnoy et al. 2009
Sandbar	Western Atlantic (Eastern Shore)	2,709	Portnoy et al. 2009
Blue	Atlantic	4,513	Verissimo et al. 2017
Basking	Global	8,200	Hoelzel et al. 2006
Mako	Eastern Pacific	10,300	Kacev et al. in prep
Soupfin	Africa	46,808	Chabot & Allen 2009
Soupfin	United Kingdom	61,718	Chabot & Allen 2009
Soupfin	South America	63,860	Chabot & Allen 2009
Soupfin	North America	89,545	Chabot & Allen 2009
Soupfin	Global	198,296	Chabot & Allen 2009
Bullshark	South Atlantic	160,000	Karl et al. 2011
Bullshark	North Atlantic	221,000	Karl et al. 2011
Lemon sharks	Global	13-26,000	Schultz et al. 2008
Whale Shark	Global	13-26,000	Castro et al. 2007
Southern sleeper shark	Southern Ocean	46–33,000	Murray et al. 2018
Pacific sleeper shark	Taiwan	73–47,000	Murray et al. 2008
Pacific sleeper shark	Alaska	98–65,500	Murray et al. 2008
Greenland shark	North Atlantic	91–33,300	Murray et al. 2008

Discussion

Overall, we found evidence supporting the hypothesis that NEP Common Thresher sharks comprise one well-mixed population. Genetic diversity between loci was shown to be relatively high, while allelic richness at each locus was relatively low. Our results provide evidence that there is no population structure between the sampled sub-regions, and our sibship analyses support the assertion that there is one juvenile habitat area spanning the US/Mexico border. Estimated distribution of N_e

suggests either a low number of breeding adults or low genetic variability among adults in the population.

Measures of genetic diversity including heterozygosity and allelic richness can be used to address conservation issues related to how genetically healthy a population may be (Caballero & Rodríguez-Ramilo 2010). Heterozygosity is the more commonly used metric for genetic diversity (Toro et al. 2009). High values for heterozygosity indicate high degree of genetic diversity or frequency of alleles across loci, whereas low heterozygosity indicates a low degree of genetic diversity and therefore reduced genetic fitness (Reed & Frankham 2003). The high mean value H_E=0.76 in our results suggests there are a relatively high number of different genes across loci within the population. While high genetic diversity is a positive indication of genetic health, allelic richness showing presence of alleles at each locus can provide further information that can be used for conservation decisions (Greenbaum et al. 2014).

Allelic richness, a measure of different alleles per locus, as opposed to diversity across loci, can provide insight into whether there have been fluctuations in population size in the past (Nei et al. 1975; Luikart et al. 1998). A sharp decline in population size, or genetic bottleneck, in the past could lead to increased rates of inbreeding and loss of genetic variability, leaving the population with less evolutionary potential to adapt (Frankham 1995; Hedrick & Miller 1992). For this we want to address whether the minimal allelic richness is sufficient to retain evolutionary potential. If we consider A_R estimates from other studies, our mean A_R=0.03 is relatively low. Given that catch estimates show a significant increase in catch of Common Thresher sharks in recent decades (PFMC 2016), this could indicate that overfishing events in the 1980s and 1990s caused a genetic bottleneck potentially reducing this population's long-term evolutionary potential.

F_{ST} and G'_{ST} are metrics of genetic differentiation. F_{ST} and G'_{ST} estimates range from 1 to 0, with values at or near zero suggesting little genetic differentiation and therefore no population structure (Nei 1977). Our global estimates for F_{ST} and G'_{ST} were less than zero, indicating no evidence for population structure. Our pairwise F_{ST} and G'_{ST} estimates were not statistically significant between sub regions, further suggesting there is no evidence for differentiation across the population, and therefore no barriers to gene flow and no population structure. This provides evidence for one, well-mixed population.

Next, we looked at sibling relationships within the dataset. Given the large sample size (N=549), the results can provide insight into the size of the population (within bounds) and sibling relationships within a region or across these regions. Our results showed 487 half siblings and 3 full siblings. Further, our results provide evidence that the US/Mexico border is not a barrier for siblings. If the border were a barrier, we would expect to see sibling pairs together on one side of the border or the other. However, we see 118 siblings that span the border. This indicates adult female sharks are contributing to juveniles on both sides of the border and supports the need for cooperative management of juvenile habitat in both the US and Mexico.

Wright (1931) defined N_e as the size of a theoretically ideal population affected by genetic drift at the same rate per generation as the population being studied. The use of a theoretically ideal population standardizes this measurement of genetic drift, allowing comparisons of N_e across different groups of sharks (Hare, Nunney & Schwartz 2011). Assessing the N_e of a species provides an indication of both the breeding population size and of population genetic health (Frankham 1995; Portnoy et al. 2009), making it a potentially invaluable stock evaluation tool for conservation and fisheries management (Luikart et al. 1998; Reed & Frankham 2003). N_e needed to maintain genetic evolutionary potential could be as high as 5,000 (Lande 1995), and according to Franklin & Frankham (1998), an N_e estimate of less than 500 could be considered critically low indicating the population is at risk for loss of genetic variation. From this, our N_e estimate of 5,240 would not be considered critically low. However, in comparison to estimates from other shark populations, it is relatively low. This could suggest that there are relatively few breeding adults in the population, or alternatively, it could suggest adults in this population are genetically similar and therefore there is low genetic variability. Low genetic variability can leave the population vulnerable to future pressures (Nei 1975; Franklin & Frankham 1998) like climate change or overfishing.

Survey

In addition to the genetic analyses, I conducted a survey to explore perspectives and knowledge related to bilateral shark management and NEP Common Thresher sharks. I distributed an online questionnaire to experts in shark and highly migratory species management. The survey results are not intended for publication, but instead are a means to inform the conclusions of this paper based on trends, themes, and new insights.

Methods

Design

The 16-question survey was designed with input from my Capstone Advisory Committee (CAC). Survey design expert Professor Ayelet Gneezy was consulted during the early design phase, and three other individuals with fisheries expertise provided feedback during survey design and testing. The final survey contained four short sections:

- Section 1: "US/Mexico Bilateral Fisheries Management (General Fisheries)" contained three questions related to general fisheries management between the US and Mexico;
- Section 2: "US/Mexico Bilateral Management (Common Thresher Sharks)" asked participants to answer nine questions specific to Common Thresher shark population and juvenile habitat management in the US and Mexico;
- Section 3: "Management and Conservation Strategies" included one general shark management question, two questions related to specific conservation efforts, and one prompt to comment on bilateral management of Common Thresher sharks between the US and Mexico; and,
- Section 4: "Affiliation" asked respondents to select whether they are affiliated with Government (Gov), Fisheries Management (FM), Academia/Scientific Research (AS), Non-Governmental Organization (NGO), or Other, with an option to specify (Other).

Three types of quantitative questions were used: Likert scale, yes-no, and rating. Each question provided a space for comment, although comments were not required. While all questions required an answer to move on, each provided a "Don't know" option. A paragraph at the beginning of the survey provided some background information about the project and goals of the survey. The final version was translated into Spanish using Google Translate and edited by Dr. Dan Cartamil.

Data collection

The survey was distributed over the course of five weeks. An estimated 80-100 emails containing the survey link were sent to various individuals familiar with this topic within government, academia, and non-governmental organization sectors. The survey was anonymous so names or contact information were not collected. Broad affiliations could be detected based on answers in Section 4; distinctions between those who filled out the Spanish or English version; and potentially who received the survey link, although once disseminated I had no way of tracking respondents.

Quantitative results were analyzed through the Survey Monkey website, R, and Excel. Select comments were included in the analysis of results. This selection was somewhat arbitrary but duplicate and/or indirect comments were generally excluded. Comments were selected from both US and Mexico surveys, however because response rates were higher for the US, more comments are incorporated from the US than from Mexico.

Results and Discussion

Forty-five individuals completed the survey; 13 completed the Spanish version, and 32 completed the English version. Spanish responses are assumed to be submitted by individuals from Mexico and English responses are assumed to be submitted by individuals from the US (or Canada but likely only a small percentage). While input from others and preliminary testing helped minimize potential bias, unintentional sampling bias may have occurred in the form of voluntary response bias, leading questions, inherent bias in participant knowledge, and self-selection. However, responses were analyzed with these potential biases in mind; and given the purpose of the study, this should not pose a problem. Of the 45 respondents, roughly half were from the research community, one-quarter affiliated with government, 13% with an NGO, and another 13% chose "other." Various outcomes emerged from both quantitative and comment-based answers and select results are assessed here.

To understand how much is already known about Common Thresher sharks in the NEP among HMS experts, I asked general questions about US/Mexico bilateral fisheries management. Given there are in fact no bilateral fisheries agreements between the two countries, the results can shed light on how many individuals are informed of this. Roughly 50% of the total respondents said they did not know of any bilateral management currently in place, while 27% indicated there *is* currently bilateral management (Appendix Q1). Nearly all (98%) of respondents indicated they feel more action is warranted to jointly manage shared US/Mex fisheries stocks, and comments specifically suggest the need for more research infrastructure, particularly lacking in Mexico; improved data collection methods; and stronger binational agreements (Appendix Q3).

In light of our genetic analyses showing evidence for one large juvenile habitat spanning the US/Mexico border, I wanted to understand expert knowledge and opinions on this topic. Survey results showed 73% of respondents are aware that juvenile habitat exists off the Southern California coast (Appendix Q4), while 63% were aware of the juvenile habitat in Baja California (Appendix Q6). US respondents were slightly more aware of both of these habitats. A total of 76% respondents agree (strongly and somewhat) that if it is shown that juvenile Common Thresher shark habitat exists between the US and Mexico, these areas should be protected. However, comments highlight varied opinions on level and strategy for protection. One comment indicates the need for costs/benefits analyze and feasibility research before making a decision, while another (among the 7% who disagree) points to the large geographic range of habitat to suggest that specific protection for juvenile thresher shark habitat is not practical.

Overexploitation of Common Thresher sharks occurred in US waters in the 1980s and 1990s (Goldman 2000), and Teo et al. (2016) concluded that overfishing by US standards is *not* occurring today. The majority (58%) of respondents were aware that the population was subjected to overfishing in the past (Appendix Q10). However, 25% indicated they thought the population is currently subject to overfishing and about 33% stated they did not know if overfishing was occurring now. Both US and Mexico responses reflect these percentages. While some were aware, this suggests a potential gap in awareness about the population status among both US and Mexico experts. Further, only about half (48%) of respondents knew of the recent stock assessment of Common Thresher sharks published by NOAA in 2016 (Appendix Q9).

When asked if they felt the current level of protection for Common Thresher sharks in the Northeastern Pacific is sufficient, few strongly agreed or strongly disagreed, potentially indicating hesitance to either support or contest efforts to establish a binational plan for this stock. Comments on this question varied but common threads included the need for ongoing collaborative research, consideration for economic and social issues related to fisheries particularly on the Mexican side, and overcoming political barriers to management. Figure 5 shows words frequently used among these comments, further highlighting research, data, and bilateral efforts. The overall results including quantitative trends and insight from comments suggests that data and information about this population is generally more available in the US than in Mexico, but that there are gaps in knowledge among experts from both sides; that there are existing research partnerships between the US and Mexico that should be further supported; and that joint protections for Common Thresher shark juvenile habitat should be considered.

Figure 5: Word cloud generated from Question 15 comments, using www.wordclouds.com.

Management and Future Research Implications

Overall trends from the survey are clear: more should be done to successfully manage shared fisheries resources between the US and Mexico (98% of respondents agree). Specifically, there is the need for:

- More accessible information;
- Research infrastructure, particularly in Mexico;
- Stronger bilateral agreements;
- Continuation and strengthening of existing partnerships particularly in the academic/science world;
- Juvenile shark habitat protections, if it is shown that juvenile Common Thresher shark habitat exists between the US and Mexico (76% respondents agree);
- Pursue practical population-specific management.

Commenters also touched on the need to consider economic and social issues related to fisheries, particularly on the Mexican side; and resource disparities between stakeholders and jurisdictions.

Conclusion

Results from this project validate the need for cooperative, bilateral management of NEP Common Thresher shark. Findings from the genetic analyses show evidence of one, panmictic population with juvenile habitat spanning across the US/Mexico border, and a low number of breeding adults or low genetic variability. Outcomes from the survey provide insights into potential limitations and challenges to bilateral management, but offered encouraging trends.

This study underscores how genetic population research can complement other sources of information such as tagging studies and fisheries catch data for a more complete picture of population health. Further the use of fisheries data in this study promotes research collaborations across academia and fisheries.

The NEP Common Thresher shark is considered to be well managed compared to other Common Thresher shark populations around the world (Teo et al. 2016). However, ongoing efforts to achieve more efficient bilateral management between the US and Mexico are needed. Coastal-pelagic species that traverse political boundaries, and that comprise geographically different populations in various parts of world, need to be managed regionally and bi- or multi-nationally. While there are productive collaborations between US/Mexico scientific institutions (particularly between SIO, NOAA SWFSC, and the Ensenada Center for Scientific Research and Higher Education), efforts to collaborate through MEXUS, and information sharing through the Inter-American Tropical Tuna Commission, there are currently no fisheries binational management measures between the US and Mexico.

Recommendations

The following recommendations are based on the outcomes of this study, in regard to the ongoing management and conservation of the NEP Common Thresher shark, and the science that informs it:

- **Continuation and strengthening of existing US/Mexico partnerships within the academic/science community**
    - Overcome political obstacles to joint management through strong scientific collaborations; US fisheries managers prioritizing science-based management and seeking data from Mexico may provide opportunity for binational studies that can stimulate binational management
    - Prioritize HMS shark research;

- Take into account and highlight successes to encourage participation and interest in conservation.

- **Cost-effective data sharing and research infrastructure**
    - Distribute the responsibility of bringing the data into the fold and collaborating across diverse resource levels; e.g., through an interdisciplinary consortium;
    - Seek practical but creative solutions to data sharing; e.g., online sharing tools;
    - There is a need for a streamlined, mutually accessible data system in which stock assessments can be generated based on both US and Mexican fisheries and scientific data.
- **Prioritize improvement to fisheries reporting in Baja**
    - More education may be needed to ensure species can be properly identified;
    - Reporting methods should be improved.
- **Monitor and consider future protections for sensitive shark juvenile habitat in Baja**
    - While the most recent Common Thresher shark assessment asserts that catch of this stock is sustainable (Teo et al. 2016), many Baja elasmobranch fisheries have historically not been sustainable (Walker 1998), and catch is mainly comprised of juveniles in these areas (Cartamil et al., 2011);
    - Conduct a cost/benefit analysis for insight into how similar seasonal area closures to those currently instituted in the US would impact Baja shark fisheries

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Appendix

Survey: Quantitative results and select comments by questions (Q1-16)

Q1: To the extent that you know, there currently exists binational fisheries management between the US and Mexico.

Quantitative results:

	Yes	No	Don't know
US Results	31.3% (10)	53.1% (17)	15.6% (5)
Mexico Results	15.4% (2)	46.2% (6)	38.5% (5)
Combined US/Mexico Results	26.7% (12)	51.1% (23)	22.2% (10)

Results per affiliation:

	Yes	No	Don't know
US Government	28.6% (2)	37.5% (6)	0.0% (0)
US Science/Academia	42.9% (3)	25.0% (4)	80.0% (4)
US NGO	14.2% (1)	18.8% (3)	0.0% (0)
US Other	14.2% (1)	12.5% (2)	20.0% (1)
Mexico Government	0.0% (0)	60.0% (3)	0.0% (0)
Mexico Science/Academia	50.0% (1)	40.0% (2)	100.0% (4)
Mexico NGO	50.0% (1)	0.0% (0)	0.0% (0)
Mexico Other	0.0% (0)	0.0% (0)	0.0% (0)

Select comments:

Answer	Affiliations	Comment
No	US/AS	My understanding is that there is very little coordination between Mexico and U.S. along the west coast regarding any fisheries.
No	US/AS	There is cooperation between US and Mexican entities, but not a binational agreement.
No	US/Gov	US and Mexico fisheries officials meet regularly to discuss bilateral fisheries interests. However, in my opinion these discussions are currently insufficient for fisheries management. For example, I don't believe joint stock-wide assessments are done for shared fisheries resources. There are also multilateral arrangements, such as the Inter-American Tropical Tuna Commission, but its issues span the entire eastern Pacific and issues of wider interest than the US and Mexico.
No	US/Gov	The domestic regulation is not coordinated between the two countries. There are some general international measures (Inter-American Tropical Tina Commission), not specific to threshers, that apply generally to sharks encountered in tuna fisheries. The laws of both countries should implement those, but beyond that I am not aware of any coordinated management.
No	US/Gov	There are attempts. There is MEXUS. But I don't think it can be called a binational fisheries management
Don't know	Mex/AS	I think there are gaps and agreements between the fishing sector and academia. It should be sought to implement a greater dissemination of the

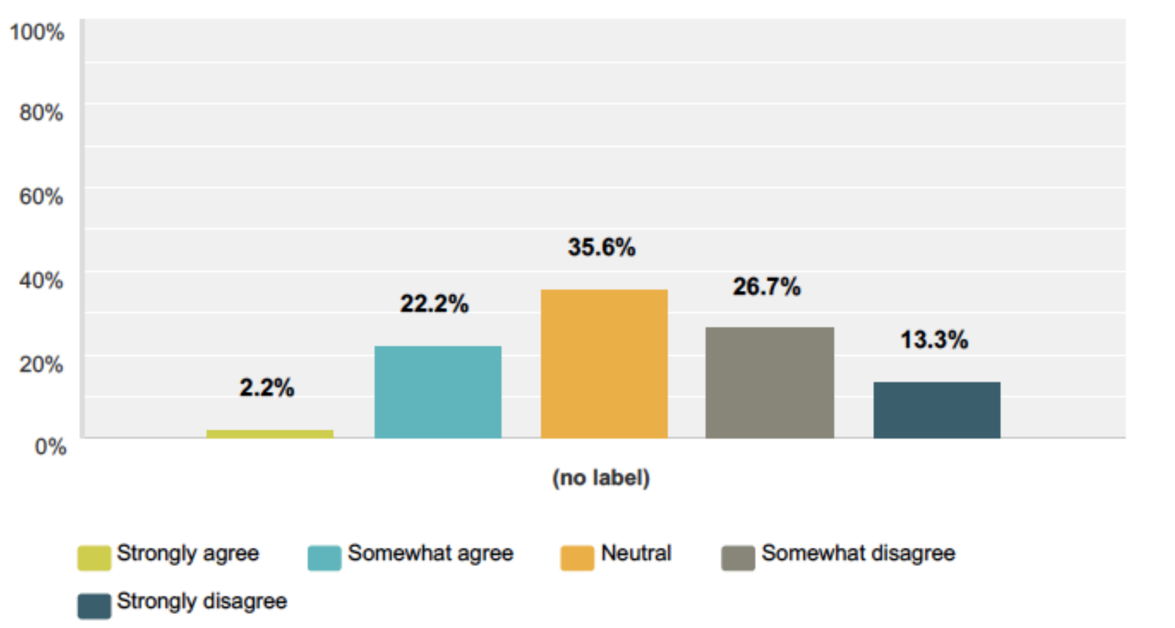
		activities of the Mexican institutions responsible for protecting natural marine resources, inform fishermen, researchers and interested and / or affected individuals.
Don't know	Mex/AS	I come from a family of marine fish taxidermists and I do not remember a single binational agreement to stop their capture in sport or export as trophies for the USA or the rest of the world.
No	Mex/Gov	Fisheries that involve some fishing resources that share Mexico with other nations like the U.S. Are only carried out within the so-called Regional Fishery Management Organizations (RFMOs) such as the IATTC and the ISC. The management recommendations emanating from these RFMOs are applied in Mexican fisheries. It is not my understanding that there are joint fisheries management agreements or programs between the U.S. And Mexico.

Q2: Fisheries management efforts between the US and Mexico are successful in managing intended fish populations.

Quantitative results:

	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
US Results	0.0% (0)	18.8% (6)	37.5% (12)	28.1% (9)	15.6% (5)
Mexico Results	7.7% (1)	30.8% (4)	30.8% (4)	23.1% (3)	7.7% (1)

Combined US/Mexico Results



Select comments:

Answer	Affiliations	Comment

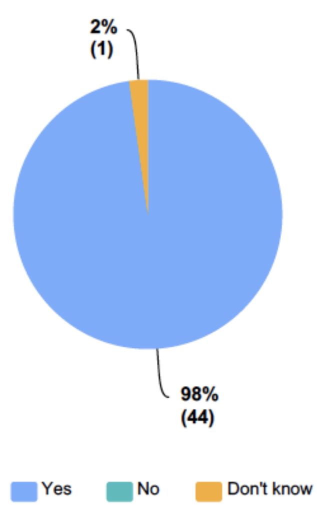
Somewhat disagree	US/AS	The recreational fishery is not well managed as many US boats exploit Mexican stocks and in some cases exploit the Mexican stocks more than the Mexicans (US win, Mexico lose)
Neutral	US/Gov	The answer to this question probably depends on the populations at issue and how you define success. It would be useful for the US and Mexico to have more dedicated discussions to define stocks of common interest, data needs and management objectives, but to my knowledge bilateral fisheries discussions are more ad hoc and don't get into these issues systematically.
Somewhat agree	Mex/AS	Most efforts do not go beyond the desk, unless they represent a restrictive measure of trade. Totoaba Case, Tuna-Dolphin; Trawl bed.
Somewhat agree	Mex/NGO	The economic needs and therefore fishing between the two countries are very distant, so that the management measures cannot always be homogenized.

Q3: In your opinion, more could be done to successfully manage shared fisheries resources between the US and Mexico.

Quantitative results:

	Yes	No	Don't know
US Results	97.0% (31)	0.0% (0)	3.0% (1)
Mexico Results	100.0% (0)	0.0% (0)	0.0% (0)

Combined US/Mexico Results



Select comments:

Answer	Affiliations	Comment

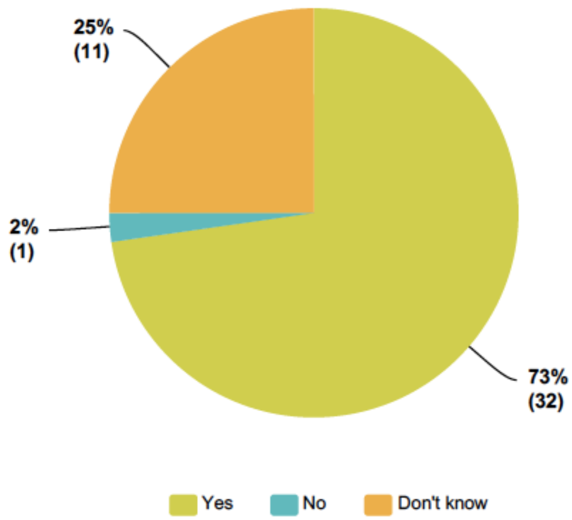
Yes	US/AS	Better agreements between the countries in which Mexico gains more from the collaborations. At present it appears (from the outside at least) that the money Mexico makes from binational agreements benefits very few people (high-end managers / government) and does not account for social well-being of local Mexicans that could be part of the money-making
Yes	US/Gov	So much more could be done but I think the political situation in Mexico doesn't allow much space for serious collaboration. It's unfortunate because Mexico has great scientists and people who really believe in working together.
Yes	US/NGO	Gill nets are having a serious impact on untargeted species.
Yes	US/Gov	There is a lot we don't know. Improving data collection (both fisheries dependent and fisheries independent) and data sharing would be a good first step toward eventually conducting joint assessments and defining shared management objectives.
Yes	US/AS	A more accurate assessment of MX catch rates is needed for improved management
Yes	Mex/AS	I am fully convinced that in the case of action, both from the various points of attention (scientific, academic, industrial, social, governmental, etc.) by the two nations, can lead to good administration. As long as each party delineates its capabilities, benefits, purposes, sponsored under an agreement and follow-up on both sides.
Yes	Mex/Gov	Mexico has for more than 10 years a number of measures and fisheries regulations that apply to directed and non-directed fisheries for sharks and rays in the Pacific. Among the measures that may be helping the population of Alopias vulpinus is the elimination since 2009 of the use of driftnets in medium height vessels and a total ban of 90 days during summer. However, I believe that there are spaces of binational cooperation, fundamentally in the subject of fisheries research applied to management. U.S.A. Have a greater and better research infrastructure that can greatly help improve the quality of Mexican fisheries research, age and growth studies, migration patterns such as conventional and electronic tagging, habitat use studies, trophic ecology studies, among others.
Yes	Mex/AS	Yes, in the case of common thresher may be a binational management could give more reasonable results for a robust management approach.

Q4: To the extent that you know, there is juvenile Common Thresher shark habitat located off of Southern California.

Quantitative results:

	Yes	No	Don’t know
US Results	84.0% (26)	3.0% (1)	13.0% (4)
Mexico Results	46.0% (6)	0.0% (0)	54.0% (7)

Combined US/Mexico Results



Select comments:

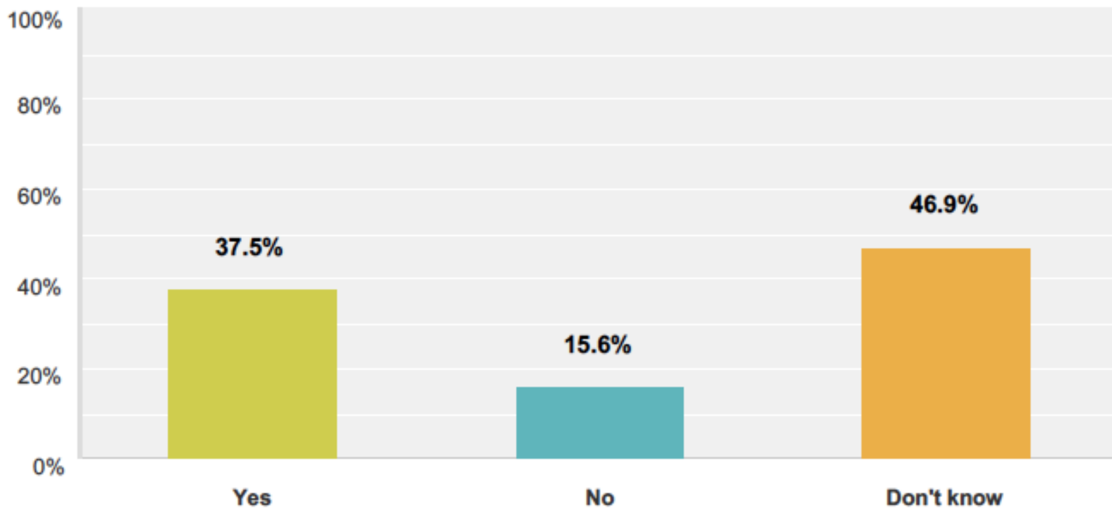
Answer	Affiliations	Comment
Yes	US/Other	Yes, juvenile, Thresher sharks are found throughout the year from Punta Eugenia throughout the Southern California bight
Yes	US/AS	I would assume yes, but have no evidence.
Yes	US/Gov	The HMS Fishery Management Plan has management measures with the explicit purpose of protecting juvenile Common Thresher shark habitat.
Yes	Mex/AS	Yes, in certain coastal areas
Yes	Mex/NGO	In my experience, there are areas in Baja California, mainly on the threshold of the continental slope or areas of thermal brakes where fox sharks are usually added. Detecting these areas through satellite imagery is a strategy that Mexico's fishing fleet uses.

Q5: (If answered 'Yes' to Question 4) This juvenile Common Thresher shark habitat is considered when establishing management goals for Northeastern Pacific Common Thresher shark population.

Quantitative results:

	Yes	No	Don't know
US Results	42.3% (11)	11.5% (3)	46.2% (12)
Mexico Results	16.7% (1)	33.3% (2)	50.0% (3)

Combined US/Mexico Results



Select comments:

Answer	Affiliations	Comment
No	US/Other	I do not believe so, further the extent of juvenile harvest is somewhat minimal compared to previous exploitation on larger individuals in the DGN fishery
No	Mex/Gov	I believe that the management measures of Mexico protect to some extent this zone of juveniles of A. vulpinus. A stock assessment of Alopias vulpinus between NMFS and CICESE (binational) presented + or evidences that the population of this species has not been overexploited.

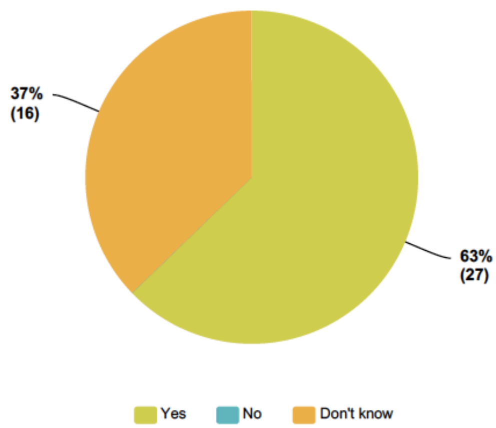
Q6: To the extent that you know, there is juvenile Common Thresher shark habitat located off of Baja California, Mexico.

Quantitative results:

	Yes	No	Don't know
US Results	71.0% (22)	0.0% (0)	29.0% (9)
Mexico Results	42.0% (5)	0.0% (0)	58.0% (7)

Combined US/Mexico Results

Select comments:



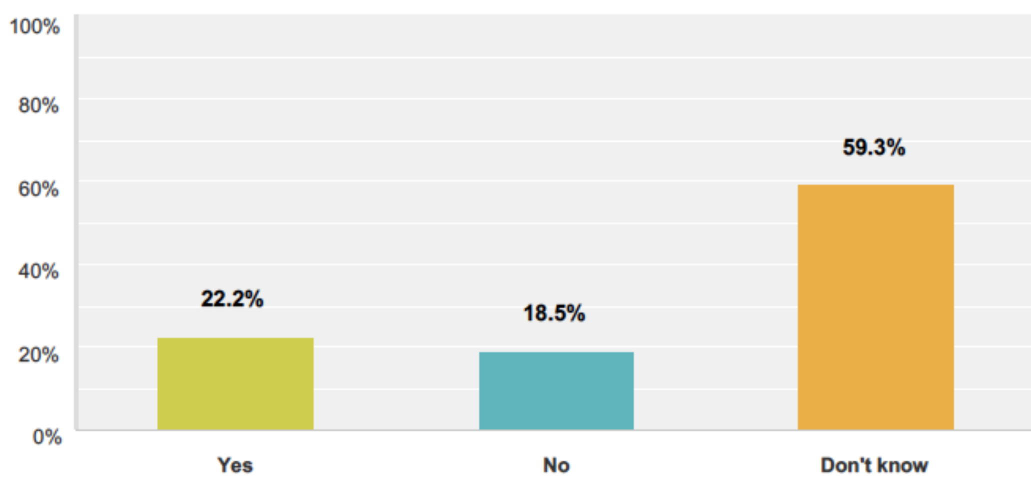
Answer	Affiliations	Comment
Yes	US/AS	I would assume yes, but have no evidence.
Yes	US/AS	I assume so as I know that some local recreational boats have landed sharks in Mexican waters, just south of the border
Yes	Mex/Gov	Probably based on the information that has been published. But I think that more data is needed in order to define breeding areas for this species.
Yes	Mex/AS	Even there is not a binational management, we assessed the population recently with a binational team using information from both sides of the border

Q7: (If answered 'Yes' to Question 6) This juvenile Common Thresher shark habitat is considered when establishing management goals for the Northeastern Pacific Common Thresher shark population.

Quantitative results:

	Yes	No	Don't know
US Results	22.7% (5)	13.6% (3)	63.6% (14)
Mexico Results	20.0% (1)	40.0% (2)	40.0% (2)

Combined US/Mexico Results



Select comments:

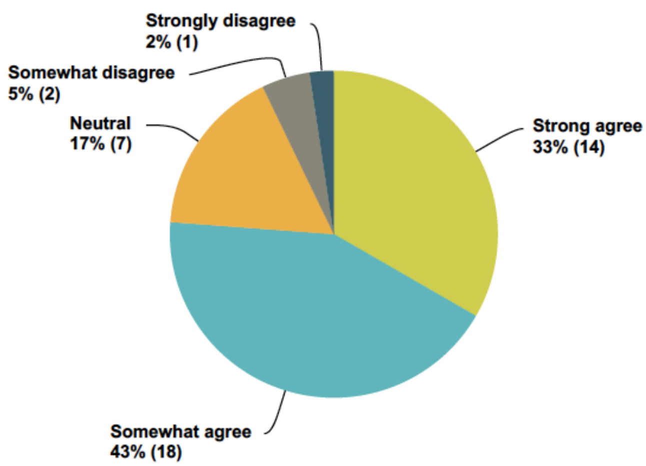
Answer	Affiliations	Comment
No	Mex/AS	Not if no one has located their areas of reproduction much less the distribution
No	Mex/Gov	In a very personal opinion, I consider that it is not necessary at present to establish a binational fishing management program for this species, as mentioned in previous questions. I believe that further joint fisheries research should be developed and more training provided to Mexican scientists. I think that's the way to go.

Q8: If it is shown that juvenile Common Thresher shark habitat exists along the California and Baja Mexico coasts, these areas should be protected.

Quantitative results:

	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
US Results	30.0% (9)	43.0% (13)	17.0% (5)	7.0% (2)	3.0% (1)
Mexico Results	41.7% (5)	41.7% (5)	16.7% (2)	0.0% (0)	0.0% (0)

Combined US/Mexico Results



Select comments:

Answer	Affiliations	Comment
Somewhat disagree	US/AS	Thresher shark habitat encompasses a large geographic area; it would not be practical to designate specific protection for juvenile thresher shark habitat areas.
Somewhat agree	US/Gov	They should be properly managed. Protected suggests a closure which would not be warranted given the status of the population

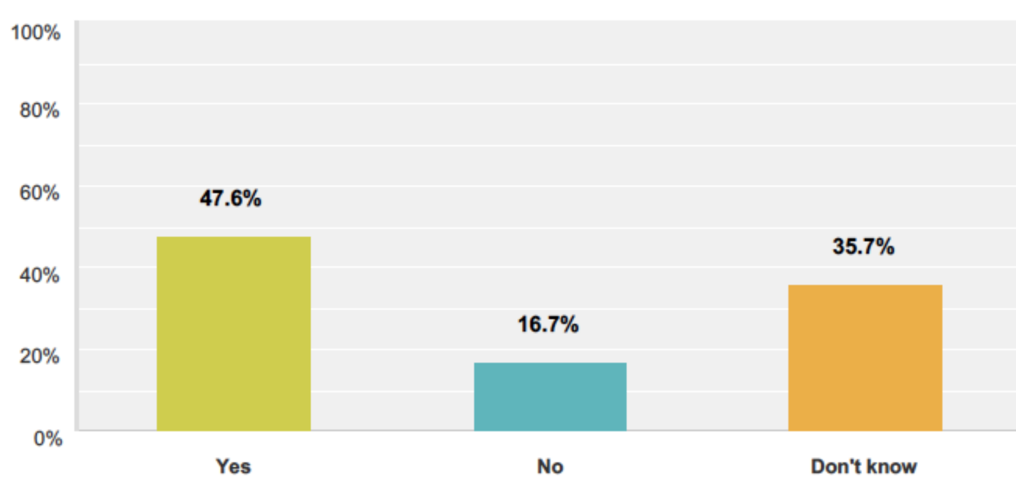
Somewhat agree	US/Other	Single species management is always a bit tricky. If they are common juvenile habitat for other sharks species or for some other benefit, maybe that is an easier sell, but establishing a time-area closure for a species like Threshers could be a touch slog. Should there be some protection? Probably, but the critical question is what type of protection can be both effective and politically viable.
Neutral	US/Gov	I would agree with this statement if the status of the stock indicates some protection / management action is warranted. Assuming management actions are needed, a suite of potential measures should be considered to determine which are most likely to result in the desired effects, including an evaluation of costs and benefits of each, political barriers, feasibility, etc.
Strongly agree	Mex/AS	If I fully agree, but I also agree to ensure proper management in the areas of exploitation. Curious case and similar is the gray whale.
Somewhat agree	Mex/Gov	In my opinion there is already a degree of protection to these juveniles of A. vulpinus. My opinion is to do more research to prove if these measures are sufficient on the Mexican side. In my opinion fishing mortality is limited and only to artisanal fishing, which with the 3-month ban has been reduced further.

Q9: To the extent that you know, a stock assessment of Northeastern Pacific Common Thresher sharks has been completed to date.

Quantitative results:

	Yes	No	Don't know
US Results	50.0% (15)	13.3% (4)	36.7% (11)
Mexico Results	41.7% (5)	25.0% (3)	33.3% (4)

Combined US/Mexico Results



Select comments:

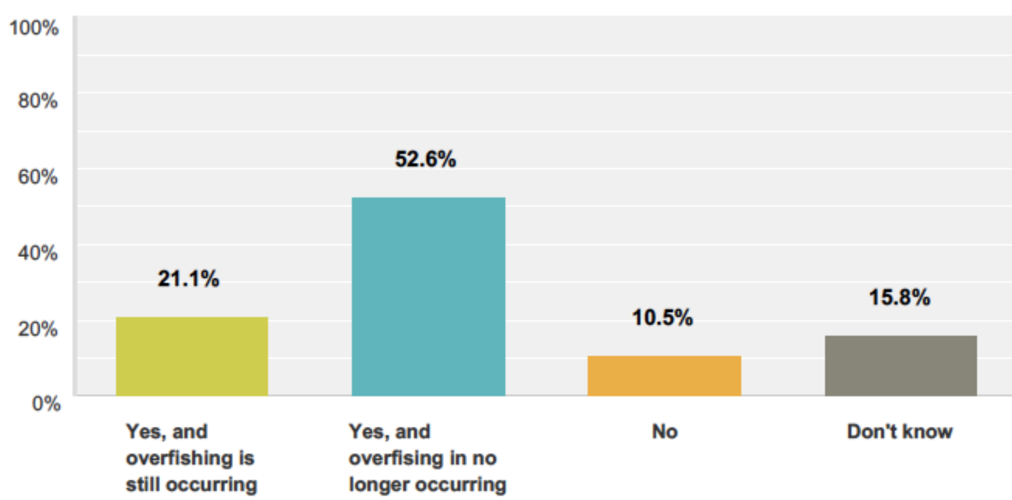
Answer	Affiliations	Comment
Yes	US/Other	Yes, I do not believe that it is complete, however there was a working group effort focused on the common thresher shark that entailed collaborators from Mexico and the Southwest Center
Yes	US/AS	Pretty sure it has, but I think the results were ambiguous due to lack of trend data.
Yes	Mex/AS	I was part of the assessment team, and the population seems to be in a stable and good level.
Yes	Mex/Gov	A year or two, 2015-2016, the Southwest Fisheries Science Center of La Jolla of NOAA and CICESE conducted a stock assessment. I know the report of the same that was published.

Q10: (If answered 'Yes' to Question 9) In this stock assessment, Common Thresher sharks were found to be historically overfished.

Quantitative results:

	Yes, and overfishing is still occurring	Yes, and overfishing in no longer occurring	No	Don't know
US Results	21.4% (3)	57.1% (8)	7.1% (1)	14.3% (2)
Mexico Results	20.0% (1)	40.0% (2)	20.0% (1)	20.0% (1)

Combined US/Mexico Results



Select comments:

Answer	Affiliations	Comment

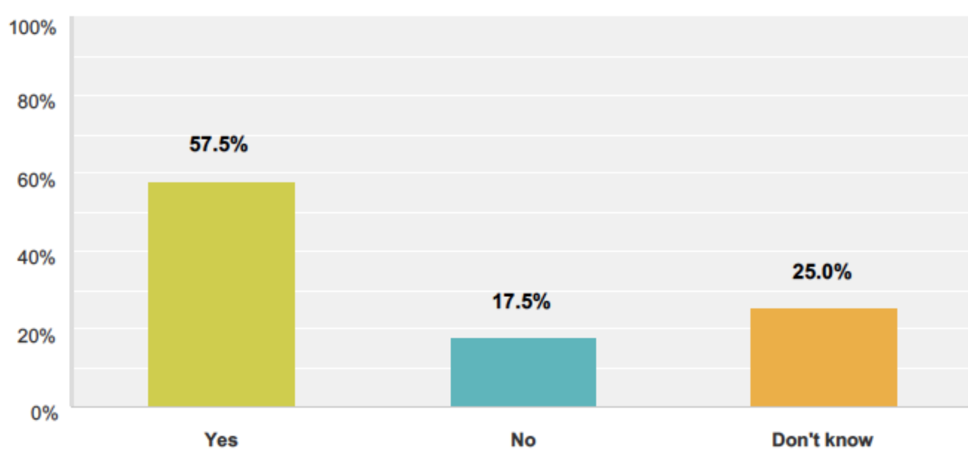
Yes, and overfishing in no longer occurring	US/Gov	The Kobe plot in the assessment documents a period of overfishing in the late-1970s through the 1980s which led to a historic period when the stock was overfished. However, subsequent reductions in fishing pressure have resulted in rebuilding of the stock.
Yes, and overfishing in no longer occurring	US/Other	I believe it was somewhat well excepted that heavy exploitation in the 1980s coupled with fishing on pregnant females led to a decline in the population.
Yes, and overfishing in no longer occurring	US/Gov	They were overfished at a point but are currently far from being in an overfished state

Q11: To the extent that you know, Common Thresher sharks in the Northeastern Pacific are historically overfished.

Quantitative results:

	Yes	No	Don't know
US Results	57.1% (16)	17.9% (5)	25.0% (7)
Mexico Results	58.0% (7)	17.0% (2)	25.0% (3)

Combined US/Mexico Results



Select comments:

Answer	Affiliations	Comment
No	US/AS	I am under the impression, through hearsay (generally) that the Thresher shark fishery is one of the few sustainable shark fisheries - this is based on no real evidence other than what I have heard.

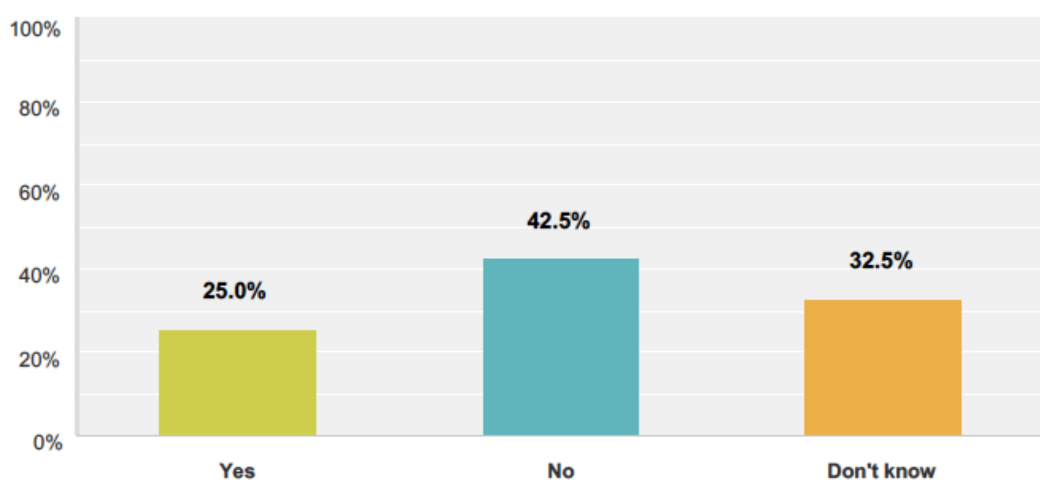
Yes	Mex/AS	We are currently analyzing the fishery in southern Mexico, off the coast of Chiapas. Records over a decade, despite not being the common fox shark but a related species, show a drastic decrease in its population. In addition it is reflected in the fishing effort, of the same area, invested in its capture.
Yes	Mex/NGO	They were over-exploited while the driftnet in Mexico was authorized. This fishing earring has been banned for several years now and I would expect the fox shark population to be rapidly recovering. There are still catches of this species during artisanal fishing activities, but these catches are not significant compared to the ones that driftnet fishing was doing.

Q12: To the extent that you know, Common Thresher sharks in the Northeastern Pacific are currently subject to overfishing.

Quantitative results:

	Yes	No	Don't know
US Results	25.0% (7)	42.9% (12)	32.1% (9)
Mexico Results	25.0% (3)	41.7% (5)	33.3% (4)

Combined US/Mexico Results



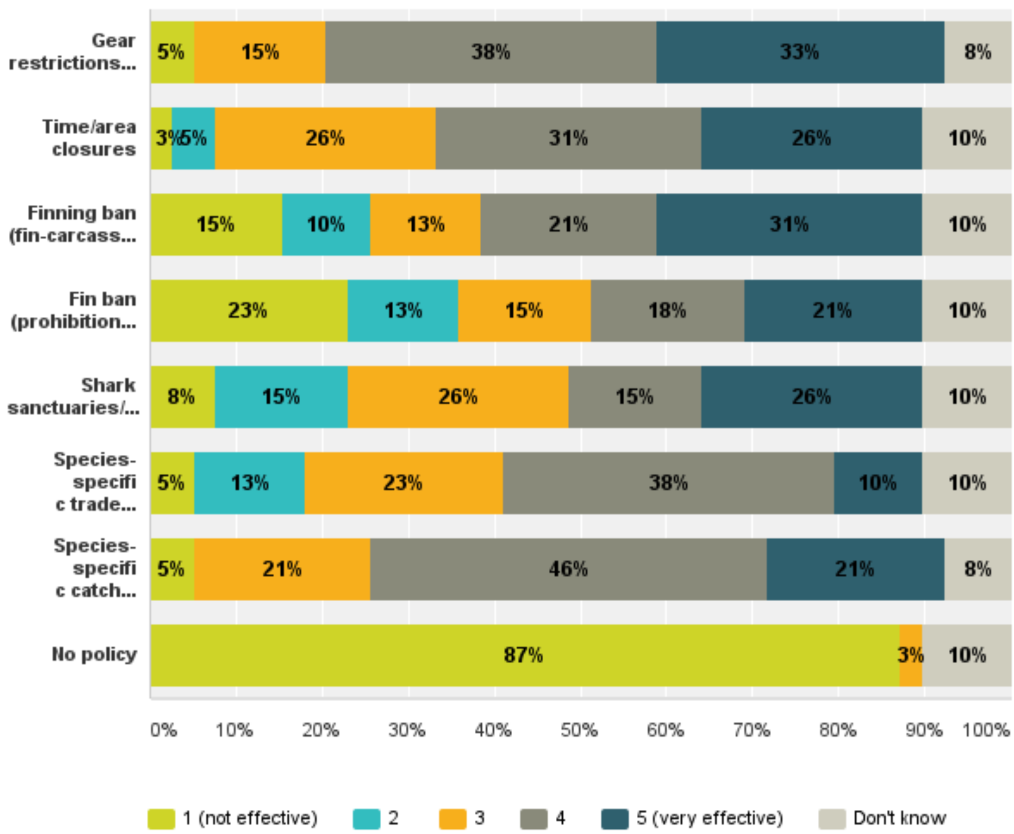
Select comments:

Answer	Affiliations	Comment
Yes	US/Gov	They say no, but I think the population is not rebounding how they say. We don't have complete info.
No	US/Gov	I don't believe they are currently subject to overfishing.
Don't know	Mex/AS	At present, they must inform us about the current state and health of the populations, not only in regions. Globally.

Q13: Rate the effectiveness of the following strategies as they pertain to conservation of sharks in general,1 being not effective and 5 being very effective:

Quantitative results:

Combined US/Mexico Results



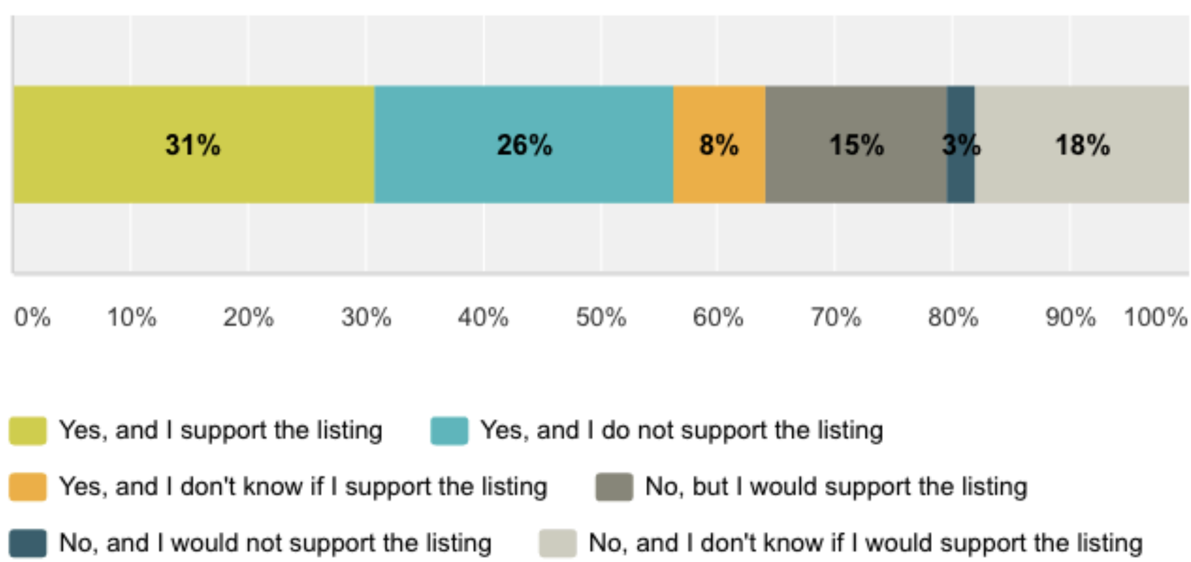
Affiliations	Comment
US/Other	I don't think that the way this question is worded is useful. These strategies can work well in theory, but occur in complex social-ecological contexts that heavily influence their success. So, I'm not comfortable giving a blanket response for each. My answer for each would be "it depends."
US/Gov	So much more could be done but I think the political situation in Mexico doesn't allow much space for serious collaboration. It's unfortunate because Mexico has great scientists and people who really believe in working together.
Mex/AS	With regard to Mexico, it is necessary to clarify and collate previous measures and policies. In order to be able to compare the results, in case of being favorable and unsuccessful, to follow or modify. However, the poor implementation of policies and regulations in Mexico on the extraction and exploitation of chondrichthyos is notorious. Issues of marine regionalization, ecology and species biology should be addressed for appropriate legislation.
Mex/Gov	The best means of fishing management in sharks, in my opinion, are the restrictions on fishing equipment and the temporary closure of fishing zones and seasons. Measures that restrict the marketing of fishery resources in a country like Mexico, with little surveillance and high corruption, are not very effective.
Mex/AS	In Mexico we have a season ban of shark fishing during May 1st to July 31 in whole Pacific coast. We do not need to prohibit finning because we eat all sharks meat. In Mexico the whole

	shark is used, so to sell fins is the common. We have a 100% ban for certain species as white shark, whale shark and basking shark.
Mex/NGO	In the case of shark fins, those of thresher shark are those that have less economic value or rather, they are the ones of lower quality; This because they have almost no cartilaginous fibers used for the fin soup. For this reason, neither the prohibition of fins or the banning of the commercialization of their fins could have an effect on the conservation of this species. The economic value of this species is meat but only if it is fresh or if it has just been caught, which is unfeasible in artisanal fishing; However when this species is caught by the long liners commercial fleet, it is when its value is high because it does not last more than 6 hours in the water after being captured and after being cleaned (remove flies and fins) Is trimmed and stored.

Q14: Are you aware of the recent CITES listing of Bigeye Thresher sharks, and subsequently Common Thresher sharks, under Appendix II?

Quantitative results:

Combined US/Mexico Results



Combined US/Mexico Results by Affiliation

	Yes, and I support the listing	Yes, and I do not support the listing	Yes, and I don't know if I support the listing	No, but I would support the listing	No, and I would not support the listing	No, and I don't know if I would support the listing
Government	0.0% (0)	60.0% (6)	66.6% (2)	12.5% (1)	0.0% (0)	25.0% (2)
Science/Academia	77.8% (7)	30.0% (3)	0.0% (0)	75.0% (6)	0.0% (0)	12.5% (1)

NGO	22.2% (2)	0.0% (0)	0.0% (0)	12.5% (1)	0.0% (0)	12.5% (1)
Other	0.0% (0)	10% (1)	33.3% (1)	0.0% (0)	0.0% (0)	37.5% (3)

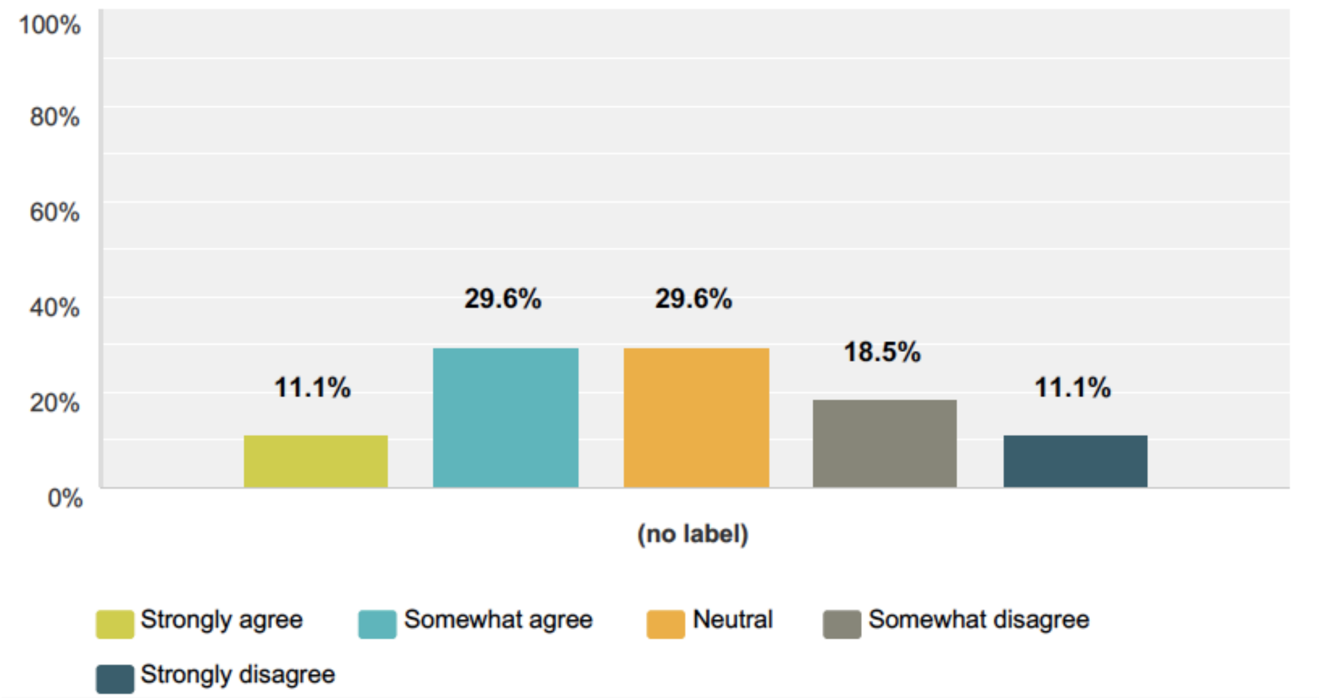
Select comments:

Answer	Affiliations	Comment
Yes, and I don't know if I support the listing	US/Gov	My understanding is that CITES tries to establish population status on a global scale, which may be inappropriate for characterizing the status of distinct population segments such as CTS in the Northeastern Pacific.
Yes, and I do not support the listing	US/Other	I do not support the listing for the north eastern Pacific population
Yes, and I support the listing	US/AS	Tracking and understanding the amount of trade of the sharks is an important information gathering mechanism. But CITES listings do not always lead directly to implementation of protections or changes in trade practices, so there are challenges.
Yes, and I do not support the listing	Mex/Gov	Placing CITES Appendix II on a species or species of sharks does not solve the problem of overfishing occurring in different regions of the world. It is the fisheries management measures that have the greatest impact on overexploited stocks.
Yes, and I do not support the listing	Mex/AS	I do not support the inclusion of common thresher into CITE's A II. I agree with the inclusion of bigeye thresher and pelagic thresher.

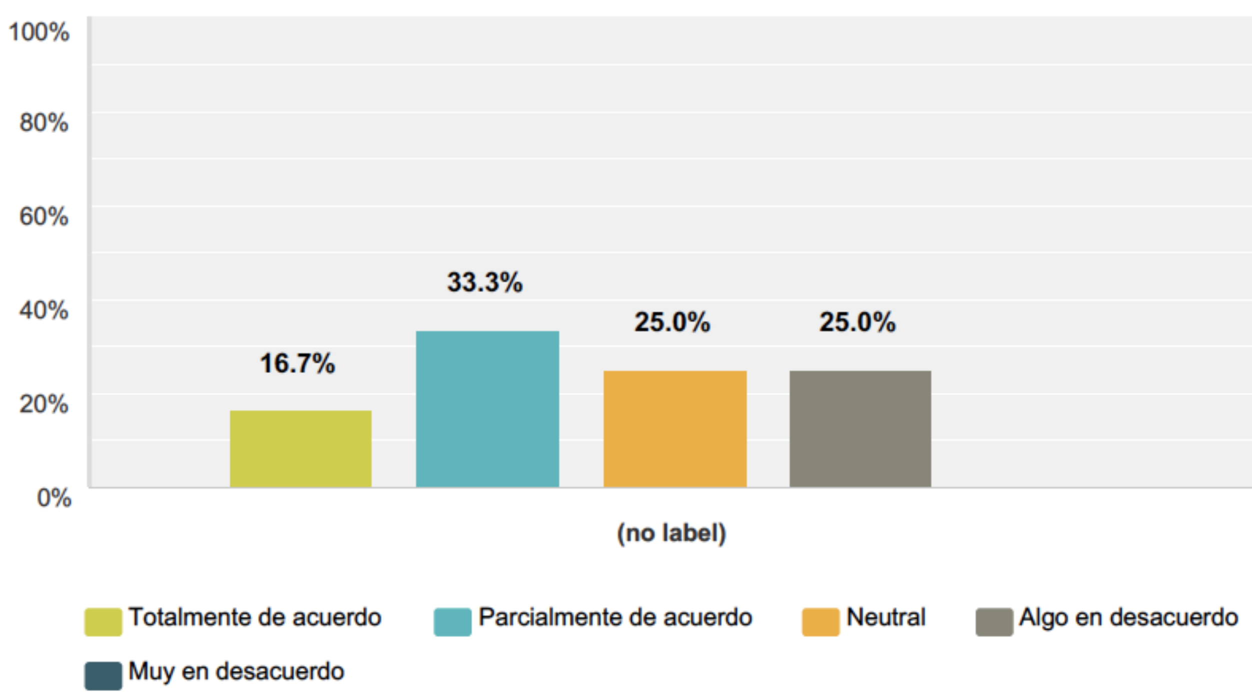
Q15: The current level of protection for Common Thresher sharks in the Northeastern Pacific is sufficient.

Quantitative results:

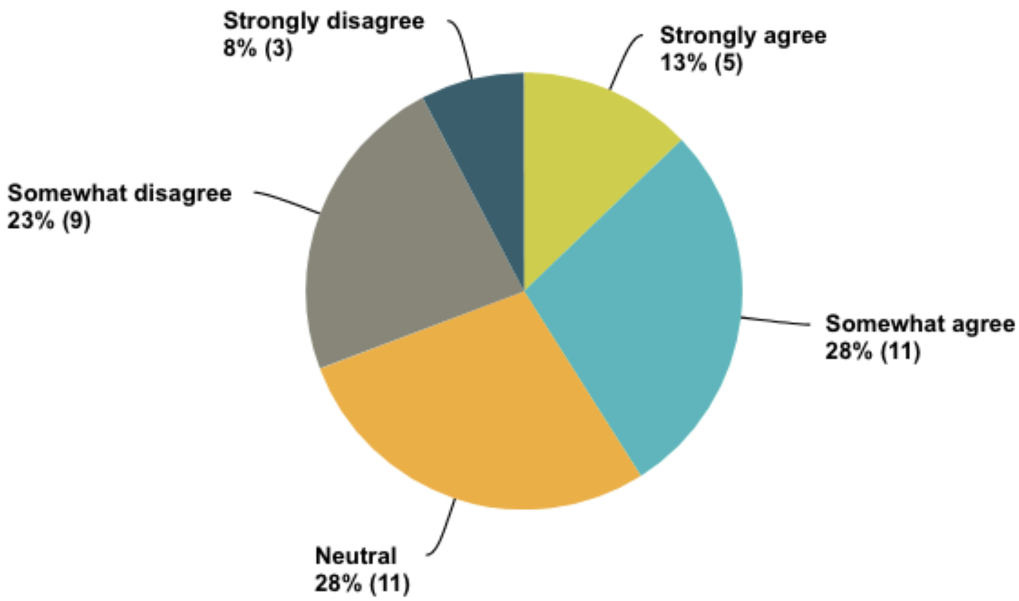
<u>US Results</u>



Mexico Results



Combined US/Mexico Results



Following Question 15, respondents were prompted to comments with: Please comment on specific strategies you feel could improve bilateral management of Common Thresher sharks between the US and Mexico:

Comments from US respondents
Scientist from both sides collaborating on the research
Use shark tourism as an economic alternative to fishermen
Bi-lateral management must occur with closer relationships and collaborations between fisheries and conservation sectors who share borders.
It's difficult to say. It needs a change of mentality that is very difficult to bring about.
Finding a shared political motivation and commitment to coordination is a big one. After that, given the nature of the fisheries that tend to catch threshers, the capacity to adequately monitor, sample and ultimately to enforce any bilaterally agreed goals would be critical to the viability of any such plans.
It would be great if bilateral management of common thresher sharks was part of a broader bilateral partnership on fisheries research and management between the US and Mexico. These would include understanding socioeconomic drivers behind the ebb and flow of specific fisheries, monitoring, data sharing, and research planning. One of the biggest challenges might be defining common management objectives given the two countries have different legal frameworks.
More info needed for thresher catch (all Alopias spp.) in MX waters
As far as I'm aware the two countries have no governmental process for cooperative fisheries management. Nor is there an NGO working in that space.
Further measures to address IUU fishing in US and Mexican waters, including strengthened measures related to shark finning.
Recognizing that the principle set forth in MSA National Standard 3 is still applicable to transboundary fisheries and establishing a dialogue to coordinate CTS management could be a place to start. I'm also not sure off the top of my head whether the IATTC has a role in managing CTS between

the US and Mexico, but coordinating management through the RFMO process could be worth exploring if it is not already in place.
Seasonal closures, gear restrictions and eliminating gill nets, stronger enforcement.
It would be good to have a better understanding of Mexico's production, the size it first maturity and some better estimates of species specific catch. With size and sex data

Comments from Mexico respondents
That they be regularly disseminated at the level of the fishing fields, in addition to the centers of collection in cities.
Educate the public and fishermen. Establish a regulated market, legal, with high prices for certain products, so that the fisherman does not need to overdraw to have an adequate standard of living. That is to say, to improve the living conditions of people, and their concept of the importance of species, is the best way to protect, in general, the natural communities.
Mexico needs to be more severe in the practice of fishery normatives. The economical and technological gap between Mexican and USA fisheries needs to be address, to achieve a proper management of shared natural resources
Improve scientific cooperation on fisheries issues such as the stock assessment, improve fishery statistics, improve the scientific observer program, improve the research capabilities of Mexican scientific groups (INAPESCA, CICESE, UABC, among others).
Because there is already a robust analysis of the population of common thresher sharks and are currently caught incidentally, it would propose a catch quota for thresher
To keep monitoring and collecting fisheries data in order to update the assessment to see if further changes are need.
The common shark meat that is of high quality and has a high economic value goes directly to the United States, so the management of this species could be controlled at any given time if the EU market reduces or controls demand.

Q 16: Which of the following groups do you affiliate with?

Combined results: