Evaluation of stock structure for the Pacific sleeper shark in the Gulf of Alaska and Bering Sea/Aleutian Islands

Beth Matta, Cindy Tribuzio, Ingrid Spies, Sharon Wildes, Wes Larson, Katy Echave, Laura Timm

EXECUTIVE SUMMARY

The stock structure template was first completed for the Shark Stock Complexes for both Fishery Management Plan (FMP) areas in aggregate in 2012 (available at: https://apps-afsc.fisheries.noaa.gov/REFM/Docs/2012/BSAIshark.pdf. Here we present an updated document specifically for the Pacific sleeper shark (*Somniosus pacificus*) for the Bering Sea/Aleutian Islands and Gulf of Alaska FMPs. The purpose of this update is to highlight new species-specific information and inform proposed changes to the assessment of the Pacific sleeper shark. This report applies to the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) FMPs because much of the information is applicable across both FMPs and because region-specific information is limited. We follow the stock structure template recommended by the Stock Structure Working Group and elaborate on each category within this framework. We have added a new section to this stock structure template: Spatial Extent of Catch, where we examine relative changes in the spatial distribution of survey and fishery catches over time.

The Pacific sleeper shark is broadly distributed across the GOA and BSAI and is taken as bycatch, most of which is discarded, in directed groundfish fisheries. There is no evidence to suggest that overfishing is occurring in the GOA or BSAI because the Overfishing Limit (OFL) has not been exceeded. Data are insufficient to determine stock status, but this document utilizes all available information to infer potential stock status. The time series of data available are short relative to the presumed life span of the species, and fishing has been occurring on this species much longer than data are available. Therefore, it is difficult to determine how catch levels relate to stock status. Though data to inform the stock structure of the Pacific sleeper shark in the GOA and BSAI are limited, a number of studies and stock assessments have been completed since the last stock structure evaluation. In this document, we summarize key findings, some of which may be cause for conservation concerns. In particular, fishery and survey catches have declined since the early 2000s, and the area in which Pacific sleeper sharks are caught appears to have substantially decreased over the time series. Sharks generally possess life history characteristics such as high longevity, slow growth, late maturity, and low intrinsic rates of population increase that make them highly vulnerable to depletion. Recent work on closely-related Atlantic congener the Greenland shark (*S. microcephalus*) has suggested an extreme lifespan and late age-at-maturity, and a pilot study on Pacific sleeper sharks suggests a generation time that likely exceeds 50 years. New research suggests no genetically significant stock structure of Pacific sleeper sharks within or between the GOA and BSAI, high dispersal, and relatively low effective population size. Collectively, these characteristics highlight the need for continued study and biologically-based management of this species.

Based on the information presented in this stock structure document, the current management system for Pacific sleeper sharks may need to be reconsidered. Most of the catch in both FMP areas consists of individuals that are likely immature, imparting a greater impact to the population because mortality prior to reproduction will lead to population decline. Examination of survey and catch time series suggests a decline in abundance and a contraction of the spatial distribution of the Pacific sleeper shark in Alaska waters, particularly in the Gulf of Alaska. These concerns coupled with the life history characteristics of this species emphasize the need for improved monitoring and consideration of alternative management measures for Pacific sleeper shark. As a result of the analyses presented in this report, we make the following recommendations:

1) Separate the GOA Acceptable Biological Catch (ABC) for Pacific spiny dogfish from the remainder of the Shark Stock Complex. Spiny dogfish comprise the majority of the Shark Stock Complex catch, and therefore the ABC, in the GOA. Because of the dominance of spiny dogfish, any trends in the remaining components of the complex are muted, and monitoring and managing catch for more at-risk species is not possible. Apportioning the GOA Shark Stock Complex ABC into two groups, Pacific spiny dogfish and all others, would allow for more consistent in-season monitoring of Pacific sleeper shark catch and prevent the potential for inadvertently high fishing pressure on sleeper sharks.
2) Expand fishery-dependent data collections. The single survey that consistently catches sleeper sharks, the International Pacific Halibut Commission (IPHC) survey, only records numbers of sharks and does not collect biological information. Fishery-dependent biological data are therefore critical to improving the stock assessment for Pacific sleeper sharks. Additionally, there are a number of species that occur in Alaska waters, but observers do not have species codes for them. We recommend expanding the list of shark species codes available to observers and that observers record shark length information.
3) Develop fishery-dependent and -independent indices for use in stock assessment models, such as index-based data-limited methods.
4) Continue to expand biological (e.g., age, reproduction, size structure) studies of Pacific sleeper shark to inform the stock assessments.
5) Develop, for future assessments, a unified stock assessment document, so that information is consistent between assessments and promotes efficiency in the review process. The new document would have combined life history, fishery and survey data sections, but models and harvest recommendations would be presented separately for each FMP. This approach would allow the separate groundfish plan teams to review FMP specific models and harvest recommendations, but would also allow for the SSC to only have to review a single document.

Introduction

The last evaluation of shark stock structure was prepared in September 2012 on the Shark Stock Complex as a whole (available at: https://apps-afsc.fisheries.noaa.gov/REFM/Docs/2012/BSAIshark.pdf). Here, we present information specific to the Pacific sleeper shark in response to a request by the Scientific and Statistical Committee (SSC) at the December 2020 North Pacific Fishery Management Council (NPFMC) meeting to prepare a stock structure document in light of the potential for conservation concerns for this species in the GOA and BSAI FMP areas. We follow the Stock Structure template outlined in Spencer et al. (2010) (Table 1).

The Shark Stock Complex in both FMP areas consists of three main species: Pacific spiny dogfish (*Squalus suckleyi*), Pacific sleeper shark (*Somniosus pacificus*), and salmon shark (*Lamna ditropis*). In the GOA, Pacific spiny dogfish is the primary species caught, whereas Pacific sleeper shark is the primary species in the BSAI. The Shark Stock Complex is managed as an aggregate species group in each FMP. The Total Allowable Catch (TAC), Acceptable Biological Catch (ABC), and Overfishing Limits (OFL) for the Shark Stock Complexes are set in aggregate. The aggregate ABC and OFL are the sum of the individual species recommendations, which allows for species-specific stock assessment, if not species-specific catch management.

Included here is a summary of what is known regarding the Pacific sleeper shark in the GOA and BSAI FMP areas relevant to stock structure concern. We also present author recommendations and potential management implications to be considered. The majority of this information is excerpted from the most recent full stock assessments (Tribuzio et al. 2020a, Tribuzio et al. 2020b), a genomic analysis of the subgenus *Somniosus Somniosus* (Timm et al. in review), and a review paper in preparation (Matta et al. in prep). Both the GOA and BSAI Shark Stock Complexes are scheduled for full assessments in 2022.

Distribution

The Pacific sleeper shark is broadly distributed across continental shelves and slopes of the Pacific Ocean, from the Bering Sea to the South Pacific. Its range in the North Pacific extends from Taiwan to Korea, Japan, and Siberia, through the Bering Sea and Gulf of Alaska, and along the west coast of the United States to Baja Mexico (Applegate et al. 1993, Ebert 2003, Grigorov and Orlov 2014, Kang et al. 2015, Orlov and Moiseev 1999, Tanaka et al. 1982, Tribuzio et al. 2020a, Tribuzio et al. 2020b, Wang and Yang 2004). Its distribution north of the Arctic Circle is uncertain; a single specimen was found washed up on a beach in the Chukchi Sea (Benz et al. 2004), which may have drifted northward from the Bering Sea (Love et al. 2005). Genetic analyses have implied that there may be some degree of range overlap and hybridization between the Pacific sleeper shark and a closely-related species, the Greenland shark (*S. microcephalus*) in the Canadian Arctic (Hussey et al. 2015, Walter et al. 2017).

Observations in the South Pacific (Brito et al. 2004, Crovetto et al. 1992, Francis et al. 1988) were previously thought to be a different species (southern sleeper shark, *S. antarcticus*) based on geographic separation and morphometric measurements (Yano et al. 2004), but recent next-generation sequencing has revealed no genetic distinction between Pacific sleeper sharks caught in the Northeastern Pacific and off Taiwan and two individuals considered to be southern sleeper sharks that were caught at high latitudes in the central South Pacific and Tasman Sea (Timm et al. in review). It is unknown whether or to what extent the range of Pacific sleeper shark occurs outside the Pacific Ocean, requiring further genetic analysis in areas such as the South Atlantic and Indian Ocean (Timm et al. in review).

Pacific sleeper sharks have been documented over a wide range of depths, from surface waters to at least 2,000 meters (Compagno 1984, Hulbert et al. 2006, Stevenson et al. 2007). They are generally found in relatively shallow waters at higher latitudes and in deeper waters at lower latitudes (Ebert 2003, Yano et al. 2007). The Pacific sleeper shark has been observed in deep water (~2,000 m) at tropical Pacific latitudes (Becerril-Garcia et al. 2020, Compagno 1984, Lee 2015).

Life History

Little data exist on the life history of Pacific sleeper sharks, with most of the information coming from studies of closely related species of the genus *Somniosus* (in general termed “sleeper sharks”), particularly the Greenland shark. Sleeper sharks of the subgenus *Somniosus* attain large sizes, grow slowly, and are long-lived (Fisk et al. 2002, Nielsen et al. 2016). The largest Pacific sleeper shark with a reliable length measurement (4.65 m total length TL) was captured off the eastern Aleutian Islands, but larger sharks (5 to over 7 m TL) have been photographed in deep water (~2,000 m) (Clark et al. 1990, Compagno et al. 1984, Isaacs and Schwartzlose 1975) and are not encountered during standard fishing or survey operations. There appears to be regional variation in size distributions within the eastern and western North Pacific (Matta et al. in prep., Orlov and Moiseev 1999). Pacific sleeper sharks tend to be larger in the GOA on average than in the BSAI (Figure 1). In the eastern Bering Sea, small individuals are more prominent and there is a noted lack of large, mature sharks (Figure 1). Small animals are observed to some degree in the GOA, British Columbia, and the U.S. West Coast; however, they constitute a smaller proportion of the observations, with larger animals also appearing in the data (Figure 1). Sexual dimorphism in size, with females generally reaching larger sizes than males, has been noted in the Greenland shark (MacNeil et al. 2012, Nielsen 2017) and in Pacific sleeper sharks in the western part of their range (Orlov and Baitalyuk 2014), but differences between size distributions of males and females have been not been observed in the eastern North Pacific (Matta et al. in prep.).

Information on reproduction is limited for the Pacific sleeper shark. The mode of reproduction in sleeper sharks is believed to be lecithotrophic viviparity, in which embryos derive nutrients from yolk and females give birth to live young (Carter and Soma 2020, Ebert 2017). Gestation time, and whether there is a resting time between pregnancies, are both unknown. There are no detailed studies on maturity, but based on the few observations where reproductive status was confirmed, the length at maturity of the Pacific sleeper shark is believed to be around 370 cm TL (Ebert et al. 1987, Yano et al. 2007). However, a larger female (420 cm TL) that was in the process of attaining maturation but not yet fully mature was observed during the 2022 AFSC bottom trawl survey in the Aleutian Islands (J. Hoff pers. comm.), highlighting the need for a more refined estimate of the size at maturity. Litter sizes likely range from 7-10 pups (Ebert et al. 2021 in Augustine et al. 2022), supported by an observation of a pregnant Greenland shark containing 10 near-term embryos (Koefoed 1957). Most of the sharks caught along the west coast of North America (Matta et al. in prep.) and in Russian waters (Orlov 1999, Orlov and Baitalyuk 2014) are probably immature, indicating that adults may occur in habitats that are not well-sampled by surveys or commercial fisheries. The mating and pupping seasons of the Pacific sleeper shark are unknown. Some authors have speculated that pregnant sleeper sharks utilize deepwater habitats of the open ocean (Bjerken 1957, Campana et al. 2015).

Fishery and survey data suggest the presence of small, possibly neonate sharks in the Bering Sea. Size at birth is approximately 40 cm TL (Francis et al. 1988, Yano et al. 2007). A 41 cm TL female was caught by a commercial pelagic trawl vessel in area 521 of the BSAI in July 2008, and a 40 cm TL female was caught during the RACE summer bottom trawl survey in area 630 of the central GOA in 2004. Ebert et al. (1987) noted two 74 cm Pacific sleeper sharks off the coast of California captured at depths of 1300 and 390 m; one of these sharks still had an umbilical scar, suggesting that it may have been relatively young, though the time that umbilical scars persist in this species is unknown. A 117 cm TL female was examined that still retained an umbilical scar (Tribuzio unpublished data), and therefore it may not be a reliable indicator of recent birth. Given that one of the sharks reported in Ebert et al. (1987) no longer had an umbilical scar, we are using that size as a breakpoint for neonates and very young Pacific sleeper sharks. Sharks under 75 cm TL have been caught along the shelf-slope break and in submarine canyons of the Bering Sea and U.S. West Coast (Figure 2). A recent genetics study identified a juvenile sibling pair of similar size (96 cm and 111 cm TL) north of Unalaska Island in the southeastern Bering Sea, caught relatively close to each other 10 days and about 45 km apart, suggesting limited dispersal from what may be an important habitat for the early life stage (Timm et al. in review). Though it is possible that areas identified in Figure 2 may represent important nursery habitats for the Pacific sleeper shark, the data are too scarce to draw any definitive conclusions.

Due to inadequate calcification and a lack of fin spines, sleeper sharks cannot be aged from annulus counts of hard structures. A recent study on the Greenland shark estimated age from analysis of bomb radiocarbon in eye lenses. This study estimated an age at maturity of 156 years and a longevity of 392 years, with high uncertainty (Nielsen et al. 2016). Using similar methodology, a pilot study on the Pacific sleeper shark estimated a growth rate about two times faster than that estimated for the Greenland shark (Tribuzio unpublished data), which still suggests extreme longevity and late maturity. A research proposal to fund a full investigation of Pacific sleeper shark age determination has been submitted to the North Pacific Research Board and is awaiting a decision.

Fishery

There is currently no directed fishing for sharks in either the GOA or BSAI; all catches are incidental, and almost all are discarded. Fisheries catch has been estimated using different methodologies over two distinct time periods: 1997-2002, estimated by staff at the Alaska Fisheries Science Center (AFSC) using the "improved pseudo-blend" approach (Gaichas 2001, 2002) and 2003-present, estimated by the National Marine Fisheries Service (NMFS) Alaska Regional Office's Catch Accounting System (CAS). Species identification improved significantly after 2003; prior to 2003, sharks were often not identified to species. Restructuring of the NMFS North Pacific Observer Program in 2013 resulted in increased observer coverage on vessels under 60 feet in length and vessels participating in the Pacific halibut individual fishing quota (IFQ) fishery. Because a large portion of shark catch originates from these vessels, the catch time series beginning in 2013 may not be comparable to prior catch time series for sharks. It is important to note that because all shark catch is incidental, the description of the fishery is that of a bycatch-only fishery and does not reflect targeted fishing behavior.

There are some concerns about the accuracy of catch estimates. Due to the large size of the species, at-sea observers often cannot weigh sharks, or they are not brought onboard. If the at-sea observer is able to measure the length of a shark, the length measurement can be converted to weight based on a length-to-weight conversion table. The conversion table is based on RACE survey data and likely does not capture the full size range of the species and does not account for natural variability or any possible sexual dimorphism. If the observer is not able to measure the shark, or if the vessel is participating in the fixed-gear electronic monitoring (EM) program, a global average weight is applied. Ongoing research suggests that when a global average is applied, the haul-level average size used for total catch estimates can be underestimated by as much as two thirds, but it is unclear the degree to which it impacts total catch estimates (K. Fuller pers. comm. NOAA Catch Shares funded EM and Large Sharks project with Alaska Pacific University). Of the shark length data that observers take and that are used to convert lengths to weights, none are recorded as part of standard data collections. However, special project requests to the North Pacific Observer Program have resulted in opportunistic collection of length data in concordance with biological tissues, and have demonstrated that length data from the fisheries would be valuable in understanding demographic patterns were these data collections to be expanded.

GOA Fishery

Incidental catch rates of the Pacific sleeper sharks are relatively low in GOA fisheries, and most of the catch (94-100%) is discarded due to its low commercial value (Tribuzio et al. 2020b). Annual catches since 2003 have ranged from 26 to 482 metric tons and have declined 58% between the first five years and the last five years of the time series (Figure 3; Tribuzio et al. 2020b). Catch estimates in numbers of individual sharks are available from 2011 to 2021 (Figure 3); during that time frame, catch numbers ranged from 310 (2011) to 2,533 (2019), but without comparable years to the earlier portion of the time series, it is difficult to interpret those numbers relative to the trends seen in catch weight (Figure 4). The estimated catch in numbers is a new time series, which is being evaluated for use in management. In the GOA, Pacific sleeper sharks are caught primarily in the mixed flatfish (39%, 59 t annually on average), walleye pollock (32%, 49 t annually on average), Pacific halibut (12%, 18 t annually on average), and Pacific cod (11%, 17 t annually on average) fisheries. The mixed flatfish and walleye pollock fisheries are predominantly trawl gear fisheries, and the Pacific halibut and Pacific cod fisheries are predominantly hook-and-line bottom longline gear. Over the past several years, there has been no consistent seasonal pattern in the catch (Figure 5). The spatial extent of the catch has been variable from year to year but has generally become reduced since the beginning of the time series (Figure 6).

Catch of Pacific sleeper sharks occurs in "inside" waters of Alaska as well (Figure 3). These areas are within 3 nm of shore and include Prince William Sound (NMFS area 649) and Southeast Alaska (NMFS area 659). The Alaska Department of Fish and Game (ADFG) does not record or report catch statistics for sharks in ADFG-managed fisheries (e.g., Chatham Strait sablefish in Southeast Alaska). The restructured North Pacific Observer Program extends coverage of vessels participating in federal fisheries within inside waters, such as the Pacific halibut IFQ fishery, providing some catch statistics for inside waters. Catches from federal fisheries in inside waters do not count against the Shark Stock Complex TAC, ABC or OFL, nor are they considered in harvest specifications. Catch estimates from inside waters range from 1 t (2009) to 151 t (2013). Catch numbers are only available from 2011 to 2021, ranging from 3 (2012) to 1,679 (2017). Pacific sleeper sharks are reported from a small number of hauls by at-sea observers or EM-observed hauls each year in inside waters, with very few weight measurements associated with those observations.

BSAI Fishery

The Pacific sleeper shark has generally been the most common shark species caught in BSAI fisheries (48% on average since 2010). Annual catches since 2003 have ranged from 28 to 421 metric tons; similar to the GOA, catches have declined 82% between the first five years and the last five years of the time series (Figure 3; Tribuzio et al. 2020a). The estimated catch in numbers for the BSAI ranges from 1,825 (2018) to 5,804 (2019). Pacific sleeper sharks are caught primarily in the Pacific cod longline fishery (43%, 55 t annually on average) and the walleye pollock trawl fisheries (42% and 54 t annually on average). Comparison of the catch in numbers to the catch in weight suggests that greater numbers of small sharks are caught in the BSAI relative to the GOA (Figure 4). There is a very clear seasonal pattern in Pacific sleeper shark bycatch, where over the past several years, most of the catch has occurred between mid-June and early October (Figure 5). It is unclear if this seasonality may interact with specific life history stages. Given the bycatch nature of this species, the seasonality of the data may be more representative of targeted fishing activity than seasonal abundances (Figure 5). Similarly to the GOA, the spatial extent of the catch has become reduced since the beginning of the time series (Figure 6).

Survey

IPHC Bottom Longline Survey

The International Pacific Halibut Commission (IPHC) bottom longline survey annually samples nearshore and offshore areas of the continental shelf to depths of 500 m in the GOA, eastern Bering Sea (EBS), and Aleutian Islands (AI), as well as waters south of Alaska. This survey provides the most informative abundance index for the Pacific sleeper shark because of its spatial coverage and consistent catch. However, this survey is targeted at Pacific halibut and does not typically record biological information for Pacific sleeper sharks other than the number of sharks caught.

In general, the catch per unit of effort (CPUE) of Pacific sleeper shark in the IPHC survey has been higher in the GOA than in the BSAI, but has declined in both management areas since the beginning of the survey time series in the late 1990s (Figure 7). The spatial extent of Pacific sleeper shark in the IPHC survey has also contracted, with catches occurring at fewer stations since the start of the time series, particularly in the GOA (Figure 8, Figure 9). Historically, survey catches were widely distributed in the GOA, but in recent years have primarily occurred around Kodiak Island, the Kenai Peninsula, and Southeast Alaska (Figure 8). Examination of average catches over the survey time series reveals consistent catch in Shelikof Strait, Prince William Sound, and the inside waters of Southeast Alaska (Figure 8). In the BSAI, Pacific sleeper sharks have been caught consistently along the outer EBS shelf, with a few scattered catches in the Aleutian Islands (Figure 8). Note that the IPHC survey was reduced in 2020 due to the pandemic, and beginning in 2021, substantial differences in the survey sampling design were enacted in the BSAI.

AFSC Bottom Trawl Survey

The efficiency of bottom trawl gear at catching Pacific sleeper sharks is unknown, and biomass estimates are highly uncertain. Pacific sleeper sharks are caught in a small number of hauls (< 4%) on the AFSC GOA bottom trawl survey, which occurs biennially. Biomass estimates in the GOA have fluctuated over the survey time series but have recently decreased to low levels, with zero catch recorded in 2021 (Figure 10).

Pacific sleeper sharks have the highest catch of all shark species caught during the AFSC BSAI bottom trawl surveys. Pacific sleeper sharks are most consistently caught on the EBS slope survey, occurring in up to 14% of hauls annually. Biomass estimates from the EBS slope survey range from 251 to 25,425 t

(Figure 10). Pacific sleeper sharks are rarely encountered in the annual EBS shelf survey (< 2% of hauls), and biomass estimates in this survey range from 0 t to 5,602 t (Figure 10). The AI survey catches Pacific sleeper sharks in < 4% of hauls; biomass estimates have ranged from 0 to 2,926 t but have been under 100 t since the 2006 survey (Figure 10). No Pacific sleeper sharks have been caught during the northern Bering Sea (NBS) trawl survey to date.

AFSC Longline Survey

The AFSC longline survey has a standard series of stations that are fished every year in the GOA and in alternating years in the EBS and eastern Aleutian Islands. The AFSC longline survey has a longer time series than the IPHC survey. However, because this survey primarily samples deep waters along the continental slope, it is not optimal for shark species, and catches of Pacific sleeper sharks are relatively low (Tribuzio et al. 2020b).

ADFG Longline Survey

The Alaska Department of Fish & Game (ADFG) has conducted annual surveys of the inside waters of Southeast Alaska (Chatham Strait and Clarence Strait) since 1998 and routinely catches small numbers of Pacific sleeper sharks. Most of the Pacific sleeper shark catch has been concentrated in Chatham Strait (Tribuzio et al. 2020b). Similar to the IPHC longline survey, Pacific sleeper shark catch rates on the ADFG survey have declined since the mid 2000s (Tribuzio et al. 2020b).

Management

GOA

The Shark Stock Complex has one OFL and ABC set for the entire complex. The complex OFL and ABC are the sums of the individual species' recommended values. Pacific spiny dogfish are managed as a Tier 5 species, and the remaining shark species are managed as Tier 6. Each species' ABC is based on 75% of the OFL. For the Tier 6 species, the OFL is the average historical catch for the years 1997-2007. There is currently no apportionment of the ABC to smaller areas within the GOA. The spiny dogfish, a Tier-5 species, is by far the dominant species in this complex and the majority of the ABC is attributed to that species (~93% on average since 2010). Because of the dominance of spiny dogfish, any trends in the remaining components of the complex are muted, and monitoring and managing catch for more at-risk species is not possible.

One option to better monitor the non-spiny dogfish component of the GOA Shark Stock Complex would be to separate the spiny dogfish ABC from that of the remaining species. On average, Pacific sleeper sharks have comprised 7% of the total GOA Shark Stock Complex catch since 2011, but when spiny dogfish are removed, Pacific sleeper sharks make up 64% of the remaining catch. Setting a separate ABC for spiny dogfish would allow improved in-season monitoring of catch trends for the remaining species. If an ABC were exceeded, the species would be put on prohibited retention status, but since sharks are almost entirely discarded, it has little impact on target fisheries. Based on historical catch data, the ABC would have been exceeded only once since 2011 (Table 2). The OFL would remain the same for the combined full complex, which has never been exceeded.

BSAI

All shark species in the BSAI are Tier 6. Thus, the complex OFL and ABC are based on the sums of the individual species' recommended values, which are based on the maximum historical catch for the years 2003-2015. There is currently no apportionment of the ABC to smaller areas within the BSAI.

Similar to the GOA, separating the ABCs by subset of the Shark Stock Complex species could provide better in-season monitoring of catch. However, in the BSAI FMP, the species composition is more mixed, with Pacific sleeper shark and salmon shark each comprising 44% of the total catch on average since 2011. Spiny dogfish are only about 9% of the catch on average. While separating the Pacific sleeper shark ABC from the remaining species in the BSAI may be an option, the issue is confounded by the Other/Unidentified Sharks group. Past analyses have suggested that the Other/Unidentified sharks are mostly Pacific sleeper sharks, but with high uncertainty. Currently, observers only have five species-code options for sharks: spiny dogfish, Pacific sleeper shark, salmon shark, blue shark, and unidentified sharks. It is impossible to discern between an identifiable shark species (i.e., "other shark") and sharks that are unidentified. While this issue is also present in the GOA, it is much less of an assessment concern due to the large ABC of spiny dogfish. Without resolving the species identification, there is not a clear option for subdividing the ABCs for the BSAI Shark Stock Complex.

Application of Stock Structure Template

To address stock structure concerns, we utilize the existing framework for defining spatial management units introduced by Spencer et al. (2010) (Table 1). In the following sections, we elaborate on the available information used to respond to specific factors and criteria for defining Pacific sleeper shark stock structure.

Harvest and trends

Fishing mortality

Currently, fishing mortality is difficult to estimate for Pacific sleeper sharks due to lack of reliable abundance data and unobserved fishery data. Unobserved fisheries include catch from the Pacific halibut IFQ fleet prior to 2013 and all ADFG managed fisheries. The time series of observed catch (2003-2021) are presented in Figure 3. These catch estimates do not incorporate removals from sources other than federal groundfish fisheries (i.e., research and sport catch) or unobserved fisheries. The estimated catch of Pacific sleeper sharks has declined in both the GOA (since 2000) and BSAI (since 2002).

The stock assessment for Pacific sleeper shark assumes 100% discard mortality. The species is soft bodied, easily damaged, and has scales that easily slough off. Preliminary tagging of Pacific sleeper sharks discarded from trawl vessels has suggested all discards were deceased by the time they were discarded (Tribuzio unpublished data). Pacific sleeper sharks discarded from longline vessels may be more likely to survive if they are cleanly hooked or not entangled in the groundline, otherwise they likely die.

Spatial extent of catch

Examination of IPHC survey and fishery catch data reveal a reduction in the spatial distribution of Pacific sleeper sharks over the length of the available time series (Figure 6, Figure 8, Figure 9, Figure 11). The proportion of fixed stations with Pacific sleeper shark catch in the IPHC survey has decreased over time, especially in the GOA (Figure 9). Trends in the fishery time series data are more variable, but generally indicate a reduction in the spatial extent of the catch (Figure 6, Figure 11). In 2013, the North Pacific Observer Program was restructured, and observer coverage on vessels in the fisheries that typically incidentally catch Pacific sleeper sharks increased. As a result of the restructuring, one would expect that the amount and area of reported Pacific sleeper shark catch would have increased, especially in waters that had previously not been well-observed (e.g., Southeast Alaska). However, comparison of catches prior to and after 2013 indicate a general reduction in not only mean weight in each non-confidential grid cell but also fewer grid cells with any catch (Figure 11). Comparison of the IPHC survey data over the same two time periods indicates a similar trend, with fewer sharks caught in fewer areas in the Aleutians and GOA. Because the IPHC survey data are at fixed stations and are not reflective of changes in fishing behavior, the overall reduction in spatial distribution is considered reliable.

Spatial concentration of fishery relative to abundance

Observed fishery catch and IPHC longline survey data were used to generate spatial distribution maps of Pacific sleeper shark concentrations. An interpolated raster image of the mean survey catch (number of sharks) from 2003-2021 was used to identify long-term patterns in species distribution (Figure 12-Figure 13) and to facilitate comparison with fishery data. It is important to note that the average numbers of observed Pacific sleeper sharks on the IPHC survey are small but ubiquitous, with some areas of predictably higher catch. Aggregated data (mean catch weight) from the North Pacific Observer Program were available in 400 km^2 blocks to satisfy the requirements of confidentiality. From these data, mean fishery catches were calculated by aggregating the observed fishery data in a raster image and converting the centroids of each raster cell to points at a 50 km grid resolution. Observed fishery data were available from 2003-2022.

GOA

Peak survey and fishery abundance of Pacific sleeper sharks coincide in the Shelikof Strait area, with lesser catch occurring along the Alaska Peninsula and along the slope region throughout the GOA (Figure 12). However, it is important to note that much of the fishing effort in the eastern GOA is within the partial observer coverage strata (i.e., there are relatively few observed hauls in the eastern GOA compared to the central and western GOA), and that fishery effort may be more patchy than surveys.

BSAI

The IPHC survey generally catches fewer sharks per station in the BSAI than in the GOA; the mean survey catch in the BSAI is 1-2 sharks per station. The spatial extent of the Pacific sleeper shark IPHC survey catch in the BSAI is concentrated along the EBS outer shelf and slope break and some limited areas near the Pribilof Islands and the eastern Aleutian Islands. The fishery catch generally coincides with the IPHC survey in the EBS but also extends much farther into shallower waters of the Bering shelf region (Figure 13). Fishery catches also occur in relatively small amounts along the Aleutian chain (Figure 13).

Population trends

GOA

The current standardization of the IPHC survey began in 1998, providing the best data for inferring Pacific sleeper shark population trends. Survey CPUE, calculated as the number of sharks divided by the number of effective hooks, was calculated for the IPHC survey for the time period from 1998-2021 (Figure 7). These data are available coastwide, and we present data from Canada and the U.S. West Coast for comparison. Pacific sleeper shark CPUEs have decreased steadily since a peak in 2002, with depressed CPUE from 2008-2021.

The NMFS bottom trawl surveys have occurred biennially in the GOA since 1984, providing the longest time series of data (Figure 10). These surveys may not sample Pacific sleeper sharks well, and biomass estimates are likely unreliable. The total number of Pacific sleeper sharks encountered by the GOA trawl survey has decreased from a high of 28 animals to only 1 in 2017 and 2019 (Tribuzio et al. 2020b), therefore estimates of biomass are being made with reduced observations and increasing uncertainty. Trend information may be inferred but should be considered with caution. Pacific sleeper shark biomass estimates increased until 2005, declined until 2011, rose again until 2015 (with the greatest uncertainty), and then sharply decreased; no sharks were caught on the 2021 survey (Figure 10).

BSAI

The CPUEs calculated from the IPHC survey data from 1998 to present in the Bering Sea suggest that abundance of the Pacific sleeper shark has been consistently low since 2004 (Figure 7). The CPUE was greatest in 2000 but also the most uncertain. The index has declined steadily since 2004 and has remained low since. This trend is more apparent when the CPUE is weighted by the survey area (see Fig 19.13 in Tribuzio et al. 2020a). Due to non-standarized changes in the sampling design of the IPHC survey, data after 2019 should be considered a different time series. Population trends cannot be inferred from the various NMFS bottom trawl surveys in the BSAI, as Pacific sleeper sharks are not caught reliably on the EBS shelf and AI surveys, and the EBS slope has not been sampled consistently.

Barriers and phenotypic characters

Generation time

Generation time is a characteristic of a species that reflects longevity and reproductive output, with long generation times indicating increased time required to rebuild overfished stocks. Generation time of the Pacific sleeper shark is unknown. Sharks are generally slow growing, long lived, and late maturing, which are characteristics linked to a long generation time. Using growth parameters from the congener Greenland shark (Nielsen et al. 2016), generation time was estimated at 144 years. Based on a pilot study in which ages of Pacific sleeper sharks were estimated from eye lens radiocarbon, this is likely an overestimate for the species (Tribuzio unpublished data); however, the pilot study still suggested extreme generation times (> 50 years), exceeding the time series of catch data available. If this stock were to become overfished, rebuilding time would be extensive, as longer generation times result in slower recovery times (Spies et al. 2015).

Physical limitations

Physical limitations, such as those defined in Table 1, are less likely for this large-bodied species. The Pacific sleeper shark is capable of directed swimming from birth (i.e., not subject to larval drift considerations) and can undertake large scale migrations. Temperature may pose some level of limitation. The species is generally adapted to colder waters and while adults or large juveniles may easily swim to deeper waters to avoid temperature extremes, very young sharks may not be able to do the same due to their smaller size.

Growth differences

Data on Pacific sleeper sharks are insufficient to determine whether there are regional growth differences.

Age/size structure

There are currently no age data available for the Pacific sleeper shark in any part of its range. Because Pacific sleeper sharks are slow growing and have low fecundity and a large size at birth, it is unlikely to detect recruitment events in length frequency data; thus length data were combined over years. Regional variation in size distributions have been reported in the eastern (Matta et al. in prep.) and western (Orlov and Moiseev 1999) parts of the North Pacific. Sharks are on average smaller in the Bering Sea and Aleutian Islands regions than in the Gulf of Alaska (Figure 1; Matta et al. in prep.). The vast majority of the catch is likely immature (Figure 1). Immature sharks under 75 cm TL and a small number of large individuals have also been noted off the U.S. West Coast (Matta et al. in prep.).

Spawning time differences

Data on mating and pupping phenology are extremely limited for Pacific sleeper sharks. To date, no pregnant females have been examined, and there are relatively few records of very small sharks or mature individuals. Size at birth is thought to be around 40 cm (Francis et al. 1988; Yano et al. 2007), and sharks 74 cm TL in length have been noted with umbilical scars (Ebert et al. 1987), though it is unknown how long these scars persist. There are only a handful of observations of Pacific sleeper sharks less than 75 cm TL in Alaska waters (Figure 2), all of which correspond to the summer months; however, due to the general lack of data and presumed slow growth rate of this species, this does not necessarily imply that pupping occurs in summer.

Maturity-at age/length differences

Data on maturity are scant for the Pacific sleeper shark, precluding assessment of regional variation in size at maturity. The best estimate of size at maturity is approximately 370 cm TL, but it is informed by relatively few observations (Ebert et al. 1987, Yano et al. 2007). No age data are currently available for the Pacific sleeper shark.

Morphometrics and Meristics

Regional variation in morphometric measurements or meristics has not been studied for the Pacific sleeper shark. Yano et al. (2004) used morphometrics and meristics to separate the southern sleeper shark from the Pacific sleeper shark. However, recent research suggests that the southern and Pacific sleeper sharks are not genetically distinct (Timm et al. in review). These large-scale morphometric and meristic differences may be indicative of more subtle population structures, on a global scale.

Behavior and movement

Spawning site fidelity

Little is known regarding the mating or pupping habits of the Pacific sleeper shark. Examination of the few observations of small juveniles (< 75 cm TL) available indicates possible nursery areas along the shelf breaks and canyons of the Bering Sea and U.S. West Coast (Figure 2), but the data are insufficient to draw any definitive conclusions. One sibling pair of juvenile sleeper sharks was detected during a recent genetics study (Timm et al. in review), captured about 45 km apart from each other in the southeastern Bering Sea north of Unalaska Island and Akutan Pass, and other small sharks have been captured previously in the same approximate location (Figure 2). More work is needed to determine whether Pacific sleeper sharks exhibit mating or pupping site fidelity, and whether there are critical nursery habitats in Alaska waters.

Mark-recapture data

Satellite tagging data from the GOA suggest that while Pacific sleeper sharks are capable of moving long distances (at least 457 km), they generally are relatively sedentary, with most recoveries occurring within 100 km from tagging locations (Hulbert et al. 2006). It is unknown, however, if they undertake larger-scale migrations over time (satellite tags generally have a less than 1 year battery life), or if recoveries are indicative of some form of cyclic site fidelity (e.g., seasonal migration). Tagging data from the GOA also revealed that Pacific sleeper sharks make regular vertical migrations, spending most of their time at depths between 150 and 450 m (Hulbert et al. 2006).

Natural tags

No studies have investigated hard structure microchemistry or parasites of the Pacific sleeper shark as natural tags in the GOA or BSAI.

Genetics

A genetics study using restriction-associated DNA sequencing (RADseq) completed in 2022 examining phylogeny and stock structure in the three recognized large-bodied *Somniosus* species is now available (Timm et al. in review). In this study, specimens of Pacific sleeper shark were collected broadly from the eastern Bering Sea to northern Baja California, and several specimens were collected from Taiwan. Population genomic analysis indicated that the Pacific sleeper shark is genetically homogeneous throughout the range sampled, including individuals from the Southern Pacific Ocean that previously would have been assigned to southern sleeper shark (Timm et al. in review). This high genetic similarity among individuals suggests persistent gene flow and little to no significant genetic stock structure among individuals of the species included in the study (Timm et al. in review). In other shark species, lack of population genetic structure has been observed in the whale shark *Rhincodon typus*, blacktip shark *Carcharhinus limbatus*, spot-tail shark *Carcharhinus sorrah*, and milk shark *Rhizoprionodon acutus*, and may indicate lack of barriers to gene flow (Spaet et al. 2015, Hardenstine et al. 2022). Conversely, significant population structure and distinct populations have been observed in white sharks *Carcharodon carcharias* and scalloped hammerhead *Sphyrna lewini* (O'Leary et al. 2015, Spaet et al. 2015). When putting these observations in context, it is important to note that relatively few studies describe the genetic diversity of sharks and rays. Currently only about 10% of species have been investigated (Domingues et al. 2018).

Consideration of strict heterozygosity is not emphasized here because differences in the average heterozygosity are expected among different types of molecular markers (Hahn 2018). However, the inbreeding coefficient, F_{IS}, is a useful measure of the level of the heterozygosity of a sample because it normalizes observed heterozygosity (Ho) by the expected heterozygosity (He). It is calculated as F_{IS} = (He-Ho)/He. Therefore, an excess of observed heterozygotes would result in a negative F_{IS} and a deficit of heterozygotes would result in a positive F_{IS}. A population in which individuals have a high level of variability would likely produce an F_{IS} value of 0 or even a negative number. Positive F_{IS} can indicate inbreeding, the Wahlund effect (undetected population structure), or relatedness among individuals. The F_{IS} of 0.186 calculated from Pacific sleeper shark data (Timm et al. in review) is intermediary when compared to two populations of white shark. A population considered stable had an overall F_{IS} value of 0.107, while a population considered in decline had an F_{IS} of 0.247 (O'Leary et al. 2015). Because there was no evidence for stock structure in the Pacific sleeper shark data, the Wahlund effect is an unlikely explanation for the high F_{IS} estimate.

Inbreeding is a possible explanation for the elevated value of $F_{IS} = 0.186$. It is important to distinguish between inbreeding due to 1) small effective population size, in which mating among relatives is inevitable, and 2) positive assortative mating, in which relatives mate with each other more often than would occur by chance. Inbreeding due to the first case is unlikely because it typically results in negative F_{IS}, but the second case could result in positive F_{IS}. Other factors that could result in high F_{IS} are non-random sampling and genotyping errors. In other words, sample collections that include close kin at higher frequencies than occur naturally can affect F_{IS}. We also posit that a population with multiple related individuals would also tend to cause a deficit of heterozygotes and is consistent with the finding of a sibling pair and females producing multiple offspring with high rates of survival, or the possibility of sampling within a nursery area.

Additionally, the effective population size (N_e) identified in Timm et al. (in review) was 967-970. In RADseq data, increasing levels of missing data can reduce the precision of effective population size estimates (Marandel et al. 2020), and linkage among the thousands of markers obtained in RADseq can depress estimates of effective population size (Waples et al. 2016). The effective population size of 967-970 observed for Pacific sleeper shark (Timm et al. in review) is intermediary when compared to two white shark populations that had an effective population size of 1998 for the stable population and 22 for a declining population (O'Leary et al. 2015). The 50:500 rule has often been cited as a general rule for conservation, in which an effective population size of 50 is recommended, and $N_e = 500$ is considered sufficient to retain evolutionary potential in perpetuity (Franklin 1980, Frankham et al. 2014). However, more recent recommendations have revised this rule in favor of a minimum effective population size of 1,000 to retain evolutionary potential (Frankham et al. 2014). In light of these parameters, the effective population size of 967-970 is near the threshold, and future work should monitor for signs of reduction (Franklin 1980, Lande 1994, Frankham et al. 2013).

Finally, given the unusual finding of a full sibling in the Pacific sleeper shark and the Greenland shark datasets, we simulated the potential census population sizes (N) under which the probability of encountering full siblings would be probable, under a range of assumptions of family structure in these species and assuming random sampling (Table 3). Given that sleeper sharks do not mature until late in life, and that an estimate of 10 offspring were present from a single observed pregnancy in Greenland shark (which is assumed to be similar to Pacific sleeper shark, Koefoed 1957), high juvenile survival may be a survival strategy present in sleeper sharks. Therefore, we can assume that nuclear family sizes may be on the order of 10. Assuming a Poisson distribution of family size with a mean of 3, 12, and 20, we performed simulations with the same number of draws as samples drawn without replacement 1,000 times in a population with a mean family size of 3, 12, and 20. We worked through a range of census sizes until the probability (P) of drawing a single set of full siblings was $P > 0.9$. In both Pacific sleeper shark and Greenland shark, higher family size yielded higher estimates of N (census size). A range of 3-20 mean Poisson-distributed family sizes, and census sizes ranging from 10,000-60,000 were estimated for Greenland shark and 45,000-300,000 for Pacific sleeper shark (Table 3).

Factors and criteria specific to genetics of the Pacific sleeper shark are:

Isolation by distance

Not applicable due to lack of genetic structure

Dispersal distance

Dispersal distance is likely high due to high gene flow. Timm et al. (in review) documented a sibling pair of immature sharks in the southeastern Bering Sea, indicating that this region may be a breeding ground and/or nursery habitat.

Pairwise genetic differences

Not applicable as there is no discernable population structure.

Summary and Implications

The management of catch of Pacific sleeper sharks is challenging due to severely limited data informing stock assessments and scant biological information. We are using this stock structure document to highlight considerations for species management and to make recommendations to improve data collections and stock assessments. The key finding of this document is that there are a number of “red flag warnings” which could indicate conservation concerns; however, data are insufficient to confirm. Key findings are summarized below:

Complex management

The Pacific spiny dogfish dominates the catch and therefore the ABC of the Shark Stock Complex in the GOA. Separating the dogfish ABC from that of the other shark species in the GOA would afford greater protection to the rarer species, including Pacific sleeper shark, and provide a more balanced approach to management of the complex as a whole. The Shark Stock Complex OFL would remain at the complex level and the likelihood of restricting target fisheries is small.

A second consideration for both complexes is that there are two similar documents created for each FMP. This creates inefficiencies in the creation of the stock assessment document, allows for inconsistencies and adds to the review burden. A combined stock assessment document, with distinct sections providing FMP specific models and harvest recommendations would greatly reduce stock assessment document production time and alleviate redundant reviews.

Decreasing survey indices

The IPHC survey provides the most reliable information for the Pacific sleeper shark. The CPUE index for this species has declined from a peak in the early 2000s in the BSAI, GOA, and Canadian waters. This trend is consistent with that observed in the AFSC GOA bottom trawl survey and the ADFG Southeast Alaska longline survey (Tribuzio et al. 2020b). The decreasing trend in indices across surveys has been highlighted in previous stock assessments. Given the probable high longevity, small litter size, and late first maturity of this species, it is unlikely that the relatively high abundances in the early 2000s are indicative of recruitment pulses.

Contracting spatial extent

According to fishery and survey data, the areas where Pacific sleeper sharks are caught have been reduced in size from the early 2000s. This suggests a contraction of range, which, coupled with decreases in abundance, presents a conservation concern.

Fishing mortality on vulnerable stage classes

The overwhelming majority of the Pacific sleeper shark catch consists of immature individuals; adults are either unavailable to or are able to elude fishing and survey gear. The fishing mortality rate is unknown but is presumed to be low in the current assessment model because the Pacific sleeper shark is a non-target species. However, due to its life history characteristics, this species may be especially vulnerable to fishing pressure. Based on demographic modeling of low-productivity shark species, fishing pressure concentrated on immature animals is associated with the highest risk of overfishing (e.g., Tribuzio and Kruse 2011, Cortes 2002, Stevens 2000).

Uncertainty of catch data

There are two primary sources of uncertainty in the catch of Pacific sleeper shark: unobserved fisheries and average weight. The restructured North Pacific Observer Program expanded coverage onto previously unobserved vessels beginning in 2013; however, ADFG state-managed fisheries remain unobserved, and catch in state-managed fisheries is undocumented. While catch in state fisheries is not included in the federal assessment or the harvest specification process and therefore does not count against the TAC, the species is transboundary, and catch in state fisheries impacts the species in federal waters.

Catch of Pacific sleeper sharks is estimated in metric tons based on either length-converted weights or an average weight applied to a count per haul. Because large Pacific sleeper sharks are difficult to land and measure accurately, the average weight is generally informed by smaller animals. Total catch estimates are therefore likely underestimated because of the biased average weight (Tribuzio unpublished data). Courtney et al. (2016) demonstrated that uncertainty in catch is the key risk factor for this species.

Genetics

The results of genetic analyses suggest that while the population is not in a declining state, further monitoring is warranted. The finding of a sibling pair, combined with the F_{IS} value, could be consistent with a population with high female offspring survival, family clustering, or samples that were collected from a nursery area. The effective population size is less than but near the desired 1,000 animal threshold, implying that monitoring for further declines in N_e should be considered. Simulations were performed to estimate the census size of the population and family structure that would result in a high probability of drawing a single full sibling pair; however, it is unclear how these estimates relate to stock status within Alaska waters.

Fishery-dependent data collection improvements

The North Pacific Observer Program uses a statistically rigorous sampling design to monitor groundfish fisheries. Due to the high volume and diversity of fisheries monitored, sampling objectives are prioritized by target fishery. This prioritization can result in limited biological information being collected for lower priority species, which often includes sharks and other rarely caught species. In the case of Pacific sleeper sharks, at-sea observers often measure shark body lengths to convert to weights, but do not record the lengths in the database. If those lengths were recorded, it would provide stock assessors with a critical data stream that can be used to improve the assessment model. The most reliable survey index, the IPHC survey, cannot measure Pacific sleeper sharks due to the longline gear and small vessel sizes that preclude landing sharks onboard; therefore observer data are the only available source of size data.

Further, observers are limited by the number of species codes they have available for sharks. This limitation creates a situation in which species that may be identifiable are pooled with unidentifiable sharks.

Manage by numbers

The current assessment model does not account for the species biology, nor the fact that much of the catch is occurring on immature Pacific sleeper sharks. Examination of estimated catch in numbers suggests that a large number of small sharks are being caught, as opposed to the current assumption that only a small number of large sharks are caught each year. This assumption can be a critical error in the assessment model because fishing mortality on large numbers of immature animals removes them from the population before they can reproduce. If biological data cannot be collected to inform the stock assessment, assessing the species by numbers may be necessary. The Alaska Regional Office has updated total catch estimates by numbers, and analyses of these data are underway as part of a larger project.

Recommendations

Taken together, the above key findings suggest that there is no clear urgent conservation concern at the current time. However, these findings do suggest a potential for concern, and thus expanded monitoring and improved assessments are needed. To address these needs, we make the following recommendations:

1) Separate Pacific spiny dogfish ABC from that of the other shark species in the GOA.
2) Reduce uncertainty in catch of Pacific sleeper sharks. Retain observer at-sea length measurements and explore numbers as an alternative to weight for management. Expand list of shark species codes available for observers.
3) Develop indices to more accurately track catch and abundance of Pacific sleeper sharks and improve the stock assessment.
4) Support research efforts to generate or improve estimates of Pacific sleeper shark life history parameters.
5) Develop a combined shark stock assessment document.

Research Priorities

1) Improve assessments:
    a) Develop a model to estimate historic Pacific sleeper shark IPHC survey catch and hindcast the time series prior to 1998. The extended time series would allow for better interpretation of current stock status and allow for exploration of more data-limited assessment methods.
    b) Explore fishery-dependent indices. While this species is not commercially desirable, it is not necessarily avoided, therefore fishery-dependent indices may provide valuable information for the assessment.
    c) Data-limited methods have advanced dramatically over recent years. Explore the use of data-limited methods based on improved catch and survey indices and life history parameters.
2) Expand fishery-dependent data collections:

    a) Fishery length composition data are critical to improving the stock assessment. Length data are often taken by observers but are not reported prior to estimation of weights based on a conversion table. We propose that observers record lengths as well as calculated weights. Special projects within the North Pacific Observer Program have demonstrated that observers can estimate size ranges of captured Pacific sleeper sharks even when not brought onboard (e.g., in longline fisheries).
    b) Develop machine learning tools to estimate lengths, and therefore weights, of sharks from EM video.
3) Conduct biological research:
    a) Life history parameters are largely unknown for this species. Investigate age, maturity, natural mortality, and habitat use to better inform assessments.

Acknowledgements

We are grateful to research scientists and fisheries observers who have collected data and biological specimens to contribute to our understanding of Pacific sleeper sharks. The International Pacific Halibut Commission and Alaska Department of Fish and Game graciously shared their survey data with us. We thank Cara Rodgveller for a thoughtful review of an earlier draft of this document.

References

Applegate, S. P., F. Soltelo-Macias, and L. Espinosa-Arrubarrena. 1993. An overview of Mexican shark fisheries, with suggestions for shark conservation in Mexico. *In* Branstetter S. (ed.) Conservation Biology of Elasmobranchs, NOAA Technical Report NMFS vol. 115. U.S. Department of Commerce, pp 31-37.

Augustine, S., K. Lika, and S. A. L. M. Kooijman. 2022. The comparative energetics of the chondrichthyans reveals universal links between respiration, reproduction and lifespan. Journal of Sea Research 185.

Becerril-Garcia, E. E., E. M. Hoyos-Padilla, B. Henning, and P. Salinas-De Leon.2020. Sharks, rays, and chimaeras of the Revillagigedo National Park: An update of new and confirmed records. J Fish Biol 97:1228-1232.

Benz, G. W., R. Hocking, A. Kowunna Sr., S. A. Bullard, and J.C. George. 2004. A second species of Arctic shark: Pacific sleeper shark *Somniosus pacificus* from Point Hope, Alaska. Polar Biol. 27:250-252.

Bjerken, P. 1957. The reproduction problem of the Greenland shark. Report on Norwegian Fishery and Marine Investigations vol. 11, no. 10.

Brito, J. L. 2004. Record of *Somniosus pacificus* Bigelow & Schroeder, 1944 (Squaliformes: Squalidae) in San Antonio, central Chile. Investigaciones marinas 32:137-139.

Campana, S. E., A. T. Fisk, and A. P. Klimley. 2015. Movements of Arctic and northwest Atlantic Greenland sharks (*Somniosus microcephalus*) monitored with archival satellite pop-up tags suggest long-range migrations. Deep-Sea Research Pt. II 115:109-115.

Carter, A. M., and H. Soma. 2020. Viviparity in the longest-living vertebrate, the Greenland shark (*Somniosus microcephalus*). Placenta 97:26-28.

Clark, E., D. Doubilet, and E. Kristof. 1990. Suruga Bay: In the shadow of Mount Fuji. National Geographic, vol 178, issue 4.

Compagno, L. J. V. 1984. FAO species catalogue vol 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1. Hexanchiformes to Lamniformes. FAO Fish. Synop. (125) Vol 4, Pt. 1, 249 p.

Cortes, E. 2002. Incorporating uncertainty into demographic modeling: Application to shark populations and their conservation. Conservation Biology 16:1048-1062.

Courtney, D. L., M. D. Adkison, and M. F. Sigler. 2016. Risk analysis of plausible incidental exploitation rates for the Pacific sleeper shark, a data-poor species in the Gulf of Alaska. North American Journal of Fisheries Management 36:523-548.

Crovetto, A., J. Lamilla, and G. Pequeno. 1992 *Lissodelphis peronii,* Lacepede 1804 (Delphinidae, Cetacea) within the stomach contents of a sleeping shark, *Somniosus* cf. *pacificus*, Bigelow and Schroeder 1944, in Chilean waters. Marine Mammal Science 8:312-314.

Domingues, R.R., A.W.S. Hilsdorf, and O.B.F. Gadig. 2018. The importance of considering genetic diversity in shark and ray conservation policies. Conservation Genetics 19:501-525.

Ebert, D. A., L. J. V. Compagno, and L. J. Natanson. 1987. Biological notes on the Pacific sleeper shark, *Somniosus pacificus (*Chondrichthyes: Squalidae). Calif. Fish and Game 73(2):117-123.

Ebert, D. A. 2003. Sharks, rays, and chimaeras of California. University of California Press, Berkeley, CA.

Ebert, D. A., J. S. Bigman, and J. M. Lawson. 2017. Biodiversity, life history, and conservation of northeastern Pacific chondrichthyans. *In* Northeast Pacific Shark Biology, Research, and Conservation (S. E. Larson, and D. Lowry, eds.). Elsevier, p. 9-78.

Fisk, A. T., S. A. Panache, and J. L. Nordstrom. 2002. Using anthropogenic contaminants and stable isotopes to assess the feeding ecology of Greenland sharks. Ecology 83: 2162-2172.

Francis, M. P., J. D. Stevens, and P. R. Last. 1988. New records of *Somniosus* (Elasmobranchii: Squalidae) from Australasia, with comments on the taxonomy of the genus. New Zealand Journal of Marine and Freshwater Research 22:401-409.

Frankham, R., B. W. Brook, C. J. Bradshaw, L W. Traill, and D. Spielman. 2013. 50/500 rule and minimum viable populations: response to Jamieson and Allendorf. Trends in Ecology and Evolution 28:187-188.

Frankham, R., C. J. Bradshaw, and B. W. Brook. 2014. Genetics in conservation management: revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. Biological Conservation 170:56-63.

Franklin, I. R. 1980. Evolutionary change in small populations. *In* Conservation biology: an evolutionary ecological perspective (M. E. Soule, and B. A. Wilcox, eds.), p. 135-149. Sinauer Associates, Sunderland, MA.

Gaichas, S. K. 2001. Squid and other species in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands for 2002. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Gaichas, S. K. 2002. Squid and other species in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands for 2003. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Grigorov I. V., and A. M. Orlov. 2014. Species diversity and conservation status of cartilaginous fishes (Chondrichthyes) of Russian waters. Journal of Ichthyology 53:923-936.

Hahn, M. 2018. Molecular Population Genetics. Sinauer Publishing.

Hardenstine, R.S., S. He, J. E. Cochran, C. D. Braun, E. F. Cagua, S. J. Pierce, C. E. Prebble, C. A. Rohner, P. Saenz-Agudelo, T. H. Sinclair-Taylor, and G. B. Skomal, 2022. Pieces in a global puzzle: Population genetics at two whale shark aggregations in the western Indian Ocean. Ecology and Evolution 12(1):e8492.

Hulbert, L. B., Sigler, M. F., and Lunsford, C. R. 2006. Depth and movement behaviour of the Pacific sleeper shark in the northeast Pacific Ocean. Journal of Fish Biology 69(2): 406-425.

Hussey, N. E., A. Cosandey-Godin, R. P. Walter, K. J. Hedges, M. VanGerwen-Toyne, A. N. Barkley, S. T. Kessel, and A. T. Fisk. 2015. Juvenile Greenland sharks *Somniosus microcephalus* (Bloch & Schneider, 1801) in the Canadian Arctic. Polar Biol 38:493-504.

Isaacs, J. D., and R. A. Schwartzlose. 1975. Active animals of the deep-sea floor. Scientific American 233:85-91.

Kang, C. B., W. J. Lee, J. K. Kim, and H. G. Jung. 2015. New record of the Pacific sleeper shark, *Somniosus pacificus* (Squaliformes: Somniosidae) from the western margin of the East Sea, Korea. Korean Journal of Ichthyology 27:45-49.

Koefoed, E. 1957. A uterine fetus and the uterus from a Greenland shark. Report on Norwegian Fishery and Marine Investigations vol. 11, no. 10.

Lande, R. 1994. Risk of population extinction from fixation of new deleterious mutations. Evolution 48:1460-1469.

Lee, J. J. 2015. Sleeper shark pops up in unexpected place. National Geographic, July 15, 2015.

Love, M. S., C. W. Mecklenburg, T. A. Mecklenburg, and L. K. Thorsteinson. 2005. Resource inventory of marine and estuarine fishes of the West Coast and Alaska: A checklist of North Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon border. US Department of the Interior, US Geological Survey, Biological Resources Division, Seattle, WA.

MacNeil, M. A., B. C. McMeans, N. E. Hussey, P. Vecsei, J. Svavarsson, K. M. Kovacs, C. Lydersen, M. A. Treble, G. B. Skomal, M. Ramsey, and A. T. Fisk. 2012. Biology of the Greenland shark *Somniosus microcephalu*s. Journal of Fish Biology 80:991-1018.

Marandel, F., G. Charrier, J. B. Lamy, S. Le Cam, P. Lorance, and V. M. Trenkel. 2020. Estimating effective population size using RADseq: Effects of SNP selection and sample size. Ecology and Evolution 10(4):1929-1937.

Matta, M. E., C. A. Tribuzio, and K. Fuller. In prep. Biology of the Pacific sleeper shark: a review.

Nielsen, J., R. B. Hedeholm, J. Heinemeier, P. G. Bushnell, J. S. Christiansen, J. Olsen, C. B. Ramsey, R. W. Brill, M. Simon, K. F. Steffensen, and J. F. Steffensen. 2016. Eye lens radiocarbon reveals centuries of longevity in the Greenland shark (*Somniosus microcephalus*). Science 353:702-704.

Nielsen, J. 2017. The Greenland shark (*Somniosus microcephalus*): diet, tracking, and radiocarbon age estimates reveal the world's oldest vertebrate. PhD, University of Copenhagen.

O'Leary, S. J., K. A. Feldheim, A. T. Fields, L. J. Natanson, S. Wintner, N. Hussey, M. S. Shivji, and D. D. Chapman. 2015. Genetic diversity of white sharks, *Carcharodon carcharias*, in the Northwest Atlantic and Southern Africa. Journal of Heredity 106(3):258-265.

Orlov, A. M. 1999. Capture of especially large sleeper shark *Somniosus pacificus* (Squalidae) with some notes on its ecology in Northwestern Pacific. Journal of Ichthyology 39:548-553.

Orlov, A. M., and S. I. Moiseev. 1999. Some biological features of Pacific sleeper shark, *Somniosus pacificus* (Bigelow et Schroeder 1944) (Squalidae) in the Northwestern Pacific Ocean. Oceanological Studies. 28: 3-16.

Orlov, A. M., and A. A. Baitalyuk. 2014. Spatial distribution and features of biology of Pacific sleeper shark *Somniosus pacificus* in the North Pacific. Journal of Ichthyology 54:526-546.

Seitz, J. C., and G. R. Poulakis. 2006. Anthropogenic effects on the smalltooth sawfish (*Pristis pectinata*) in the United States. Marine Pollution Bulletin 52(11):1533-40.

Spaet, J. L.Y., R. W. Jabado, A. C. Henderson, A. B. M. Moore, and M. L. Berumen. 2015. Population genetics of four heavily exploited shark species around the Arabian Peninsula. Ecology and Evolution 5(12):2317-2332.

Spencer, P., M. Canino, J. DiCosimo, M. Dorn, A. J. Gharrett, D. Hanselman, K. Palof, and M. Sigler. 2010. Guidelines for determination of spatial management units for exploited populations in Alaskan fishery groundfish management plans. Paper prepared for the September 2010 NPFMC Plan Team meeting.

Spies, I., P. D. Spencer, and A. E. Punt. 2015. Where do we draw the line? A simulation approach for evaluating management of marine fish stocks with isolation-by-distance stock structure. Canadian Journal of Fisheries and Aquatic Sciences 72(7):968-982.

Stevens, J. D., R. Bonfil, N. K. Dulvy, and P. A. Walker. 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES Journal of Marine Science 57:476-494.

Stevenson, D. E., J. W. Orr., G. R. Hoff, and J. D. McEachran. 2007. Field guide to sharks, skates, and ratfish of Alaska, Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, Alaska.

Tanaka, S., K. Yano, and T. Ichihara. 1982. Notes on a Pacific sleeper shark, *Somniosus pacificus*, from Suruga Bay, Japan. Journal of the College of Marine Science and Technology, Tokai University 15:345-358.

Timm, L. E., C. Tribuzio, R. Walter, W. A. Larson, B. Murray, N. E. Hussey, and S. Wildes. In review. Molecular ecology of the sleeper shark subgenus *Somniosus Somniosus*. Journal of Heredity.

Tribuzio, C. A., and G. H. Kruse. 2011. Demographic and risk analyses of spiny dogfish (*Squalus suckleyi*) in the Gulf of Alaska using age-and stage-based population models. Marine and Freshwater Research 62:1395-1406.

Tribuzio, C. A., M. E. Matta, K. Echave, and C. Rodgveller. 2020a. Assessment of the shark stock complex in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands for 2021. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Tribuzio, C. A., M. E. Matta, K. Echave, and C. Rodgveller. 2020b. Assessment of the shark stock complex in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska for 2021. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Walter, R. P., D. Roy, N. E. Hussey, B. Stelbrink, K. M. Kovics, et al. 2017. Origins of the Greenland shark (*Somniosus microcephalus*): Impacts of ice-olation and introgression. Ecology and Evolution 7:8113-8125.

Wang, J. Y., and S. C. Yang. 2004. First records of Pacific sleeper sharks (*Somniosus pacificus* Bigelow and Schroeder, 1944) in the subtropical waters of eastern Taiwan. Bull Mar Sci 74:229-235.

Waples, R. K., W. A. Larson, and R. S. Waples. 2016. Estimating contemporary effective population size in non-model species using linkage disequilibrium across thousands of loci. Heredity 117(4):233-240.

Yano, K., J. D. Stevens, and L. J. V. Compagno. 2004. A review of the systematics of the sleeper shark genus *Somniosus* with redescriptions of *Somniosus* (*Somniosus*) *antarcticus* and *Somniosus* (*Rhinoscymnus*) *longus* (Squaliformes: Somniosidae). Ichthyol Res. 51:360-373.

Yano, K., J. D. Stevens, and L. J. V. Compagno. 2007. Distribution, reproduction and feeding of the Greenland shark *Somniosus (Somniosus) microcephalus*, with notes on two other sleeper sharks, *Somniosus (Somniosus) pacificus* and *Somniosus (Somniosus) antarcticus.* Journal of Fish Biology 70: 374-390.

Tables and Figures

Table 1. Summary of available data on stock structure evaluation of the GOA and BSAI Pacific sleeper shark (*Somniosus pacificus*) stocks. Adapted from template of Spencer et al. (2010).

Factor and criterion	Justification	Findings
Harvest and trends		
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	If this value is low, then conservation concern is low	Unable to determine
Spatial extent of the catch (changes in areas of catch over time)	If fishing is focused on very small areas due to patchiness or convenience, localized depletion could be a problem.	The total area in which the species is caught has reduced in both FMPs, while the footprint of the fisheries is unchanged. Suggests the species range has contracted
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Differing population trends reflect demographic independence that could be caused by different productivities, adaptive selection, differing fishing pressure, or better recruitment conditions	Fishing appears to be distributed similar to survey abundance and distribution when all years are combined. There are likely annual variations.
Population trends (Different areas show different trend directions)	If this value is low, then conservation concern is low	Overall population trends from multiple surveys appear to have declined. No evidence of different trends among areas
Barriers and phenotypic characters		
Generation time (e.g., >10 years)	If generation time is long, the population recovery from overharvest will be increased.	Generation time is unknown but likely long (>50 years).
Physical limitations (Clear physical inhibitors to movement)	Sessile organism; physical barriers to dispersal such as strong oceanographic currents or fjord stocks	No physical limitations known. Temperature may pose some level of limitation to this cold-adapted species.
Growth differences (Significantly different LAA, WAA, or LW parameters)	Temporally stable differences in growth could be a result of either short term genetic selection from fishing, local environmental influences, or longer-term adaptive genetic change.	Unknown
Age/size-structure (Significantly different size/age compositions)	Differing recruitment by area could manifest in different age/size compositions. This could be caused by different spawning times, local conditions, or a phenotypic response to genetic adaptation.	Average size is smaller in BSAI than other areas, and fisheries select for smaller/younger animals, which results in a high risk of overfishing.

Table 1. Continued

Factor and criterion	Justification	Findings
Barriers and phenotypic characters		
Spawning time differences (Significantly different mean time of spawning)	Differences in spawning time could be a result of local environmental conditions, but indicate isolated spawning stocks.	No known differences in pupping or mating timing within the GOA or BSAI
Morphometrics (Field identifiable characters)	Identifiable physical attributes may indicate underlying genotypic variation or adaptive selection. Mixed stocks w/ different reproductive timing would need to be field identified to quantify abundance and catch	No significant regional variation within Alaska waters
Meristics (Minimally overlapping differences in counts)	Differences in counts such as gillrakers suggest different environments during early life stages.	No significant regional variation within Alaska waters
Behavior & movement		
Spawning site fidelity (Spawning individuals occur in same location consistently)	Primary indicator of limited dispersal or homing	Unknown
Mark-recapture data (Tagging data may show limited movement)	If tag returns indicate large movements and spawning of fish among spawning grounds, this would suggest panmixia	Pacific sleeper sharks are capable of migrations of at least several hundred kilometers but generally appear to move small (< 100 km) distances.
Natural tags (Acquired tags may show movement smaller than management areas)	Otolith microchemistry and parasites can indicate natal origins, showing amount of dispersal	Unknown
Genetics		
Inbreeding coefficient (F_{IS})	Indicator of stability of population	0.186
Effective population size (Ne)	Estimate of number of breeding adults in an idealized population that would lose heterozygosity (due to inbreeding or genetic drift) at a rate equal to the observed population)	967-970, just below the recommended threshold, suggesting monitoring for further decreases should be considered
Isolation by distance (Significant regression)	Indicator of limited dispersal within a continuous population	Not applicable due to lack of genetic structure
Dispersal distance (<<Management areas)	Genetic data can be used to corroborate or refute movement from tagging data. If conflicting, resolution between sources is needed.	Likely high due to high gene flow
Pairwise genetic differences (Significant differences between geographically distinct collections)	Indicates reproductive isolation.	Not applicable as there is no discernable population structure

Table 2. Catch history (metric tons) for the Shark Stock Complexes in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI). Catch for component species or species groups are shown with example acceptable biological catches (ABCs) for that species or group for comparison. Catch estimates are current as of 9/12/2022.

	GOA					
	Shark Stock Complex		Spiny dogfish		Non-dogfish	
Year	Catch	ABC	Catch	Example ABC	Catch	Example ABC
2011	523	6,197	486	5,766	37	431
2012	701	6,028	459	5,600	242	428
2013	2,156	6,028	2,050	5,600	106	428
2014	1,582	5,989	1,335	5,562	247	428
2015	1,389	5,989	947	5,562	442	428
2016	1,951	4,514	1,782	4,087	170	428
2017	1,772	4,514	1,609	4,087	163	428
2018	3,410	4,514	3,129	4,087	280	428
2019	1,989	8,184	1,868	7,757	122	428
2020	1,358	8,184	1,217	7,757	141	428
2021	1,864	3,755	1,710	3,327	155	428

	BSAI									
	Shark Stock Complex		Pacific sleeper shark		Salmon shark		Spiny dogfish		Other sharks	
Year	Catch	ABC	Catch	Example ABC	Catch	Example ABC	Catch	Example ABC	Catch	Example ABC
2011	107	1,020	47	629	47	149	8	13	5	351
2012	96	1,020	48	629	26	149	20	13	3	351
2013	119	1,020	68	629	25	149	24	13	2	351
2014	138	1,022	63	629	54	149	19	13	2	351
2015	109	1,022	61	629	36	149	8	13	3	351
2016	135	1,022	81	629	48	149	6	13	1	351
2017	143	517	56	315	75	149	10	18	2	229
2018	103	517	40	315	51	149	10	18	2	229
2019	151	517	53	315	92	149	4	18	1	229
2020	180	517	68	315	106	149	4	18	2	229
2021	221	517	78	315	141	149	2	18	1	229

Table 3. Estimated census population sizes (*N*) based on the finding of full siblings or mother-offspring pairs in Pacific sleeper shark (*Somniosus pacificus*) and Greenland shark (*S. microcephalus*).

Pacific sleeper shark				
# Draws	*P*	Mean max family sizes sampled	Mean family size	*N*
170	0.94	1.6	20	300,000
170	0.999	1.7	12	175,000
170	0.98	1.6	3	45,000
Greenland shark				
# Draws	P	Mean max family sizes sampled	Mean family size	N
80	0.96	1.6	20	60,000
80	0.94	1.6	12	40,000
80	0.95	1.6	3	10,000

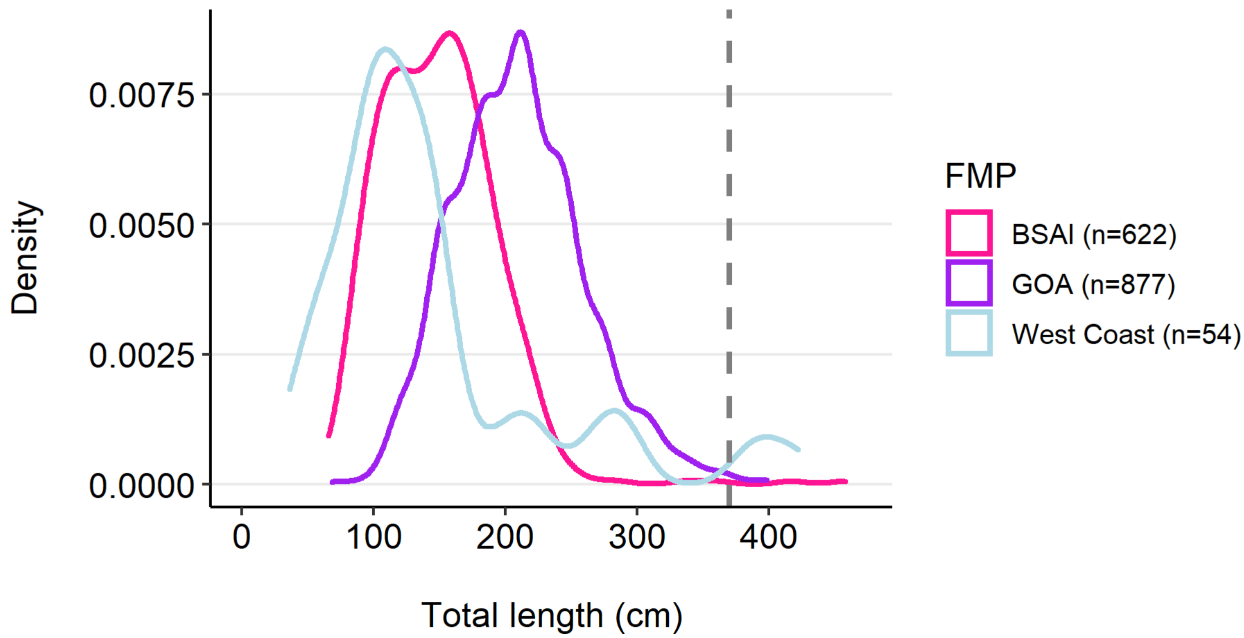


Figure 1. Length distributions of Pacific sleeper sharks (*Somniosus pacificus*) caught from various sources (opportunistic fishery-dependent and survey sampling) in Alaska Fishery Management Plan (FMP) areas (BSAI=Bering Sea/Aleutian Islands, GOA=Gulf of Alaska) and the U.S. West Coast. Note that all years of data were combined in each FMP area. Vertical dashed line indicates the best estimate of the size at maturity (370 cm TL, from Ebert et al. 1987 and Yano et al. 2007).

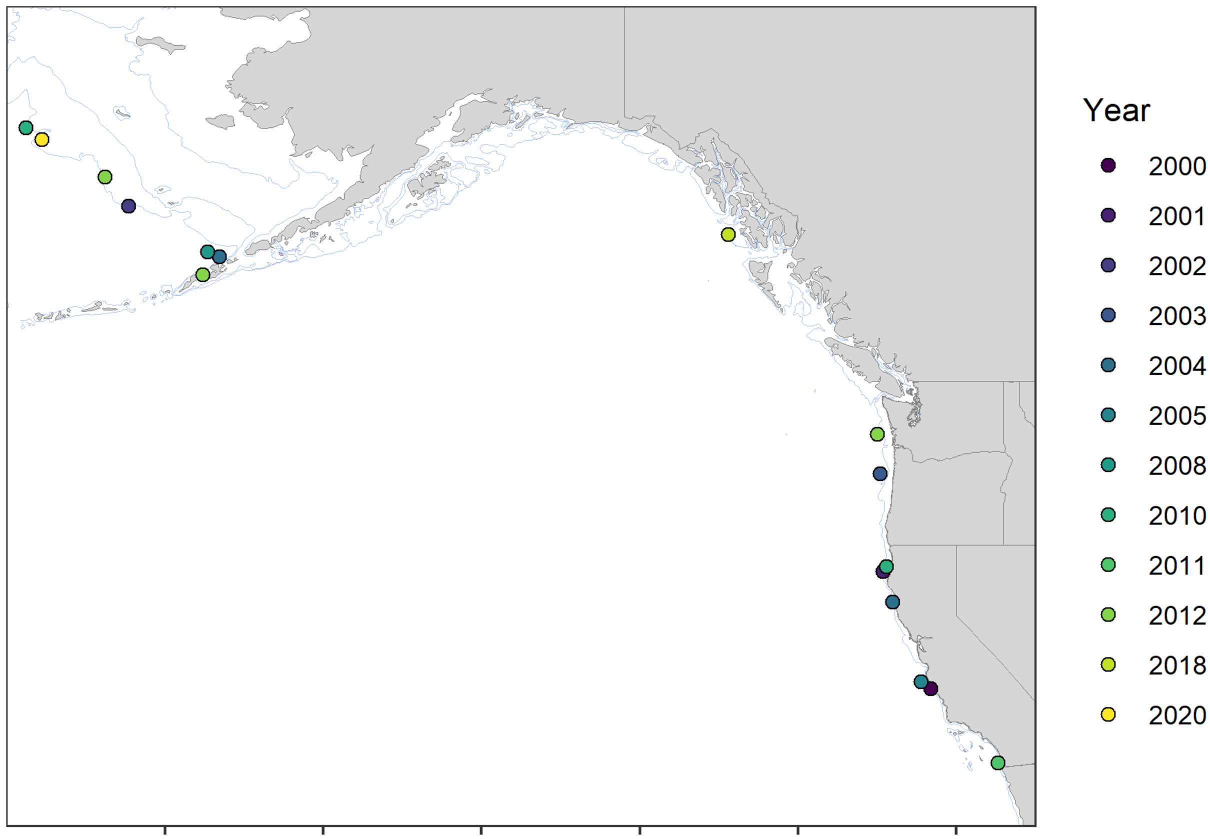


Figure 2. Capture locations of juvenile Pacific sleeper sharks (*Somniosus pacificus*) under 75 cm total length in the eastern North Pacific Ocean. Data sources include NMFS bottom trawl surveys and non-confidential fishery-dependent collections.

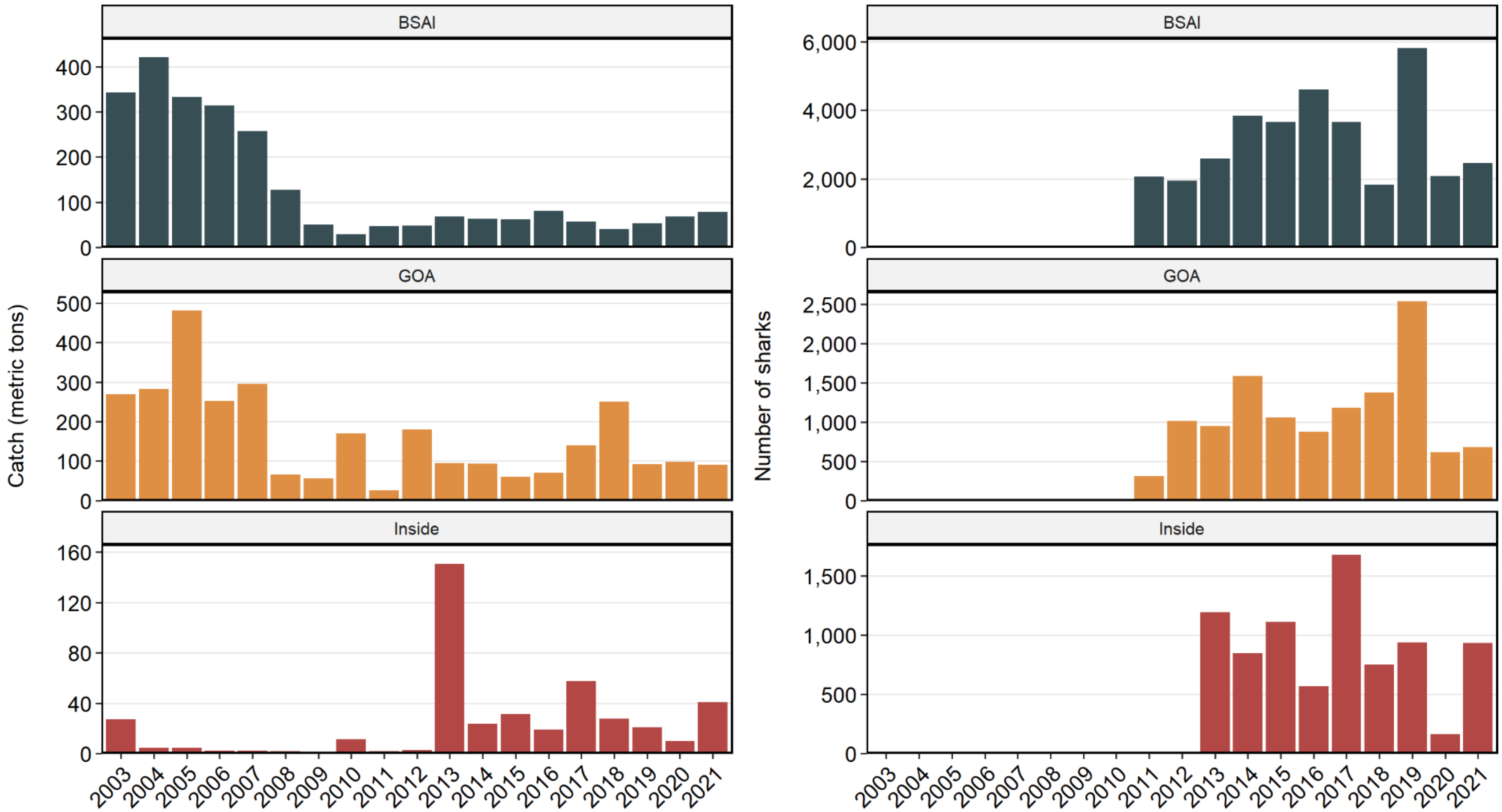


Figure 3. Total fisheries catch in weight (left) and numbers (right) of Pacific sleeper sharks (*Somniosus pacificus*) in the Bering Sea/Aleutian Islands (BSAI), Gulf of Alaska (GOA), and Inside Waters of the GOA (NMFS areas 649 and 659 within 3 nm of shore). Catch data were obtained from the Alaska Regional Office's Catch Accounting System.

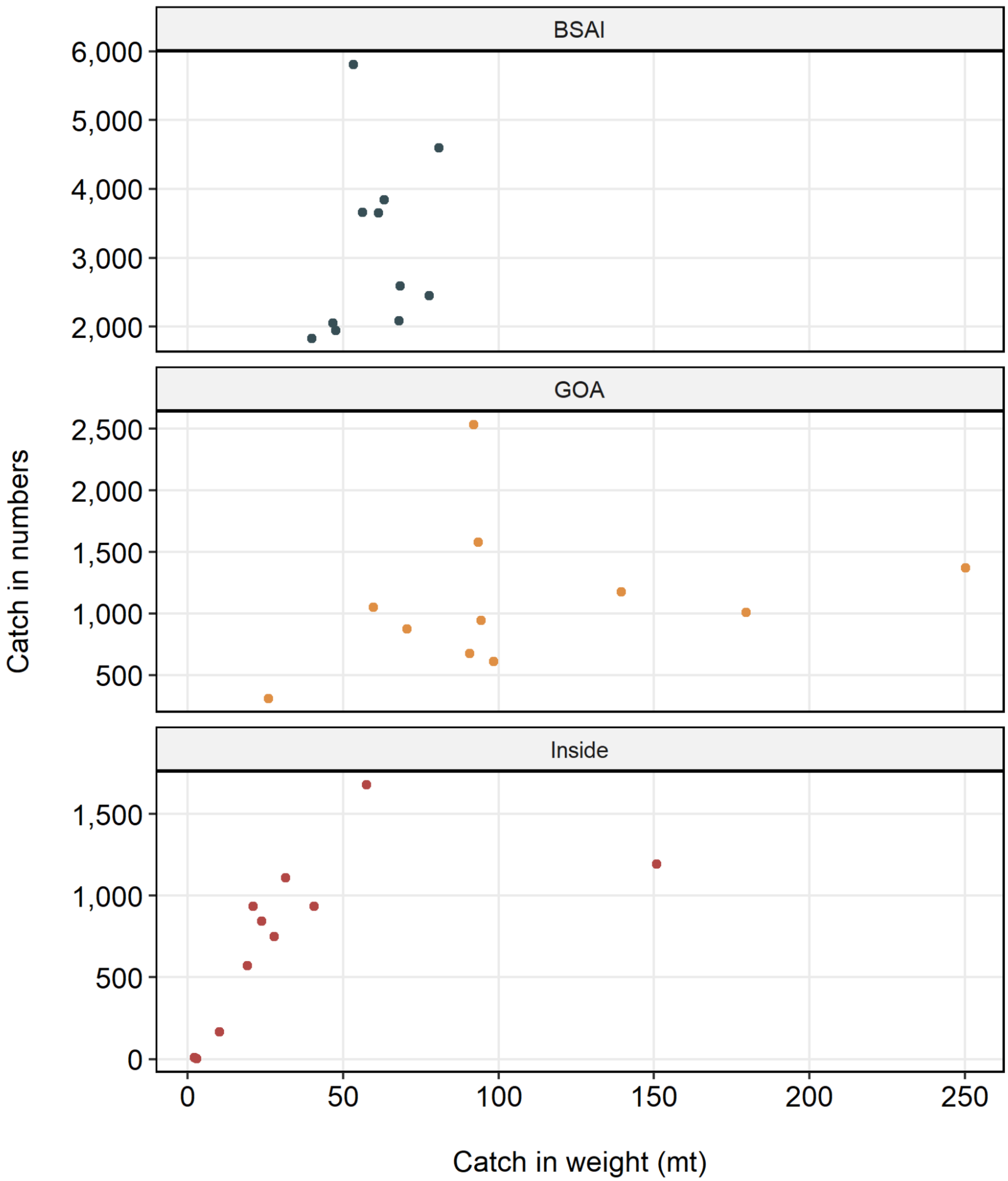


Figure 4. Relationship of estimated catch numbers to catch weight (metric tons) of Pacific sleeper sharks (*Somniosus pacificus*) in the Bering Sea/Aleutian Islands (BSAI), Gulf of Alaska (GOA), and Inside Waters of the GOA (NMFS areas 649 and 659 within 3 nm of shore) from 2011-2021. Catch data were obtained from the Alaska Regional Office's Catch Accounting System.

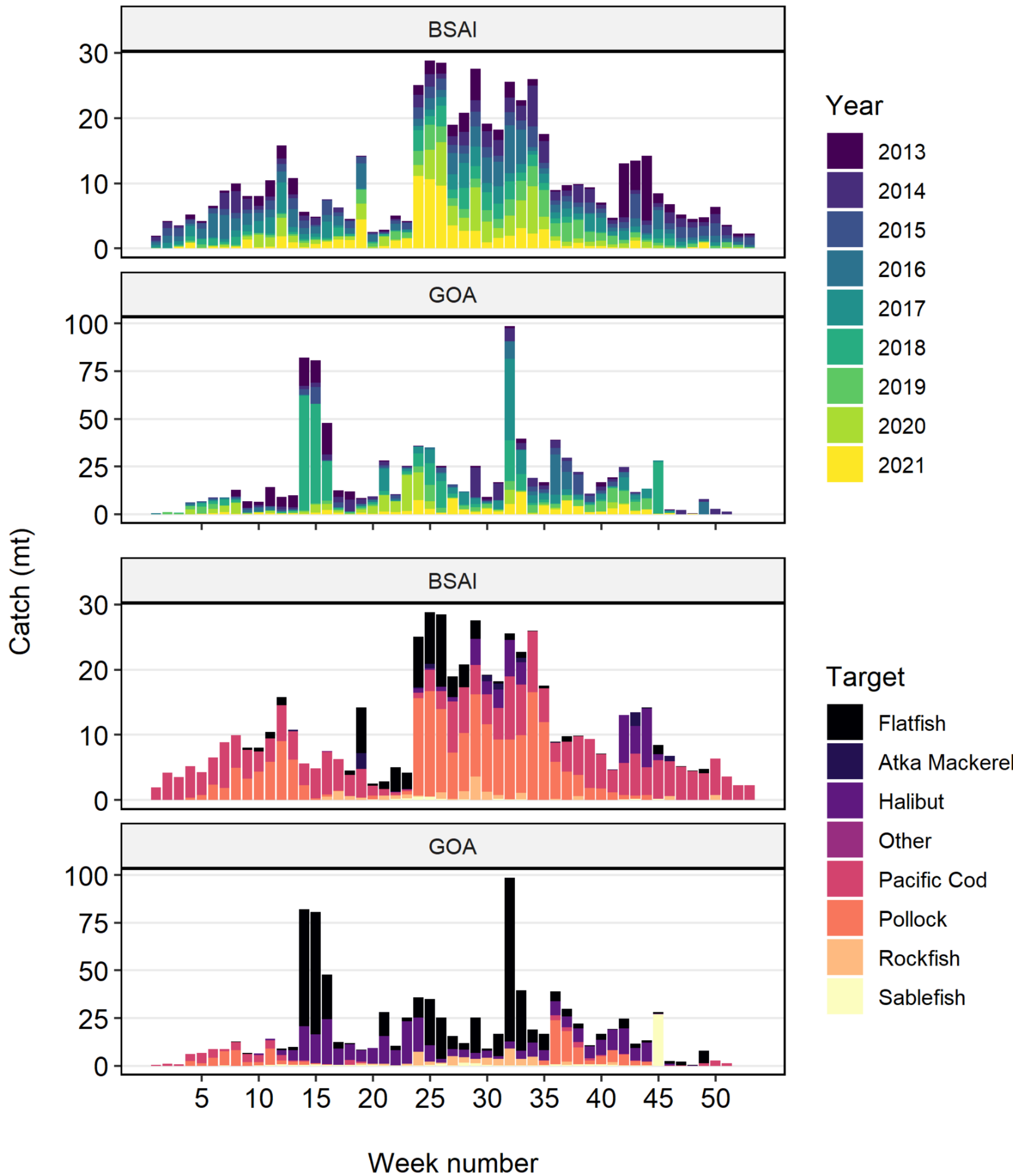


Figure 5. Weekly cumulative catches (metric tons) of Pacific sleeper sharks (*Somniosus pacificus*) in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas from 2013-2021, shaded by year (top) and target species group (bottom). Does not include Inside Waters of the GOA (NMFS Areas 649 and 659). Catch data were obtained from the Alaska Regional Office's Catch Accounting System.

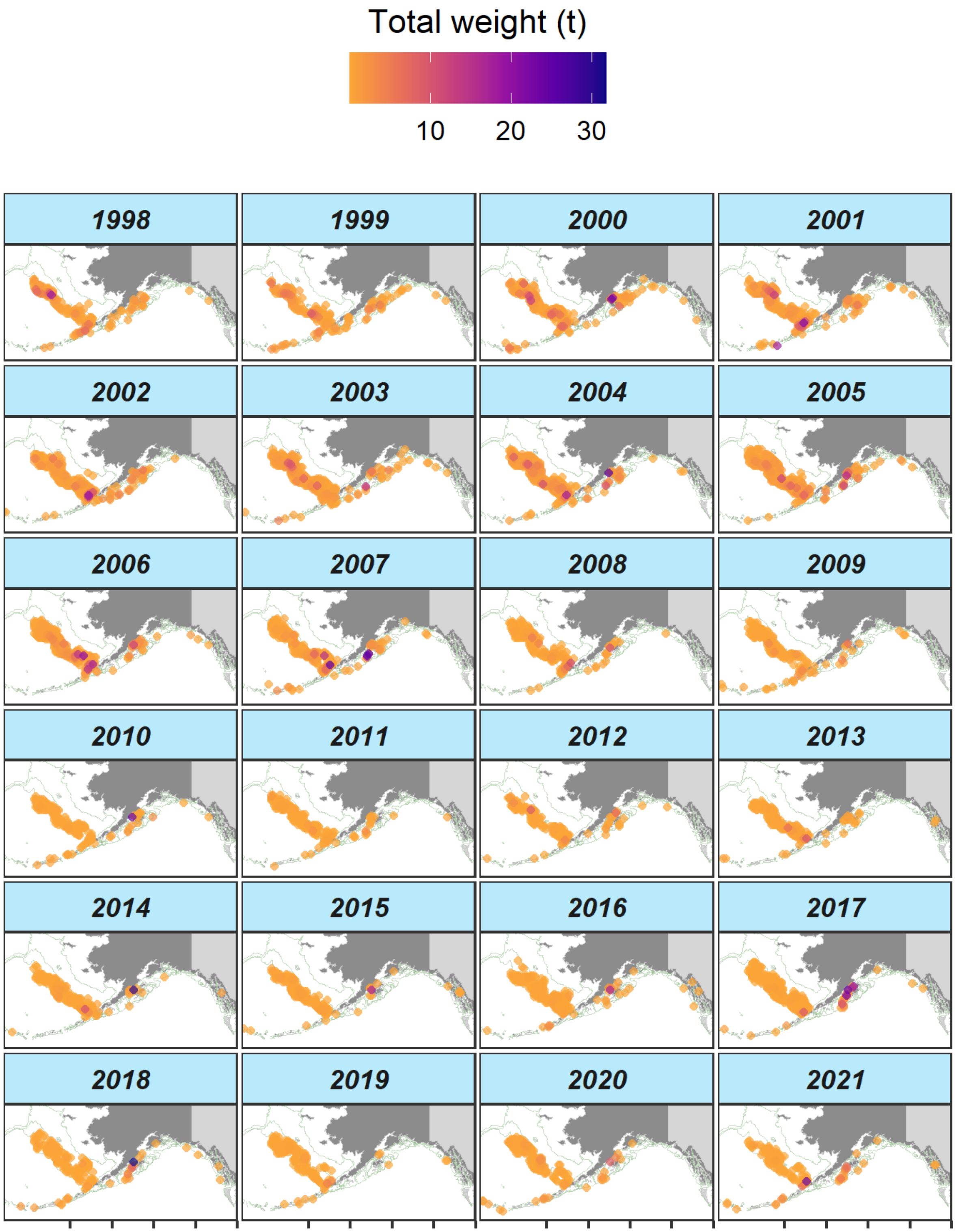


Figure 6. Observed fishery bycatch (metric tons) of Pacific sleeper sharks (*Somniosus pacificus*) in Alaska waters from 1998-2021 (all fisheries combined). Data are nonconfidential and aggregated to 400 km^2 grid cells, and were obtained from [https://www.fisheries.noaa.gov/resource/map/spatial-data-collected-groundfish-observers-alaska.](https://www.fisheries.noaa.gov/resource/map/spatial-data-collected-groundfish-observers-alaska)

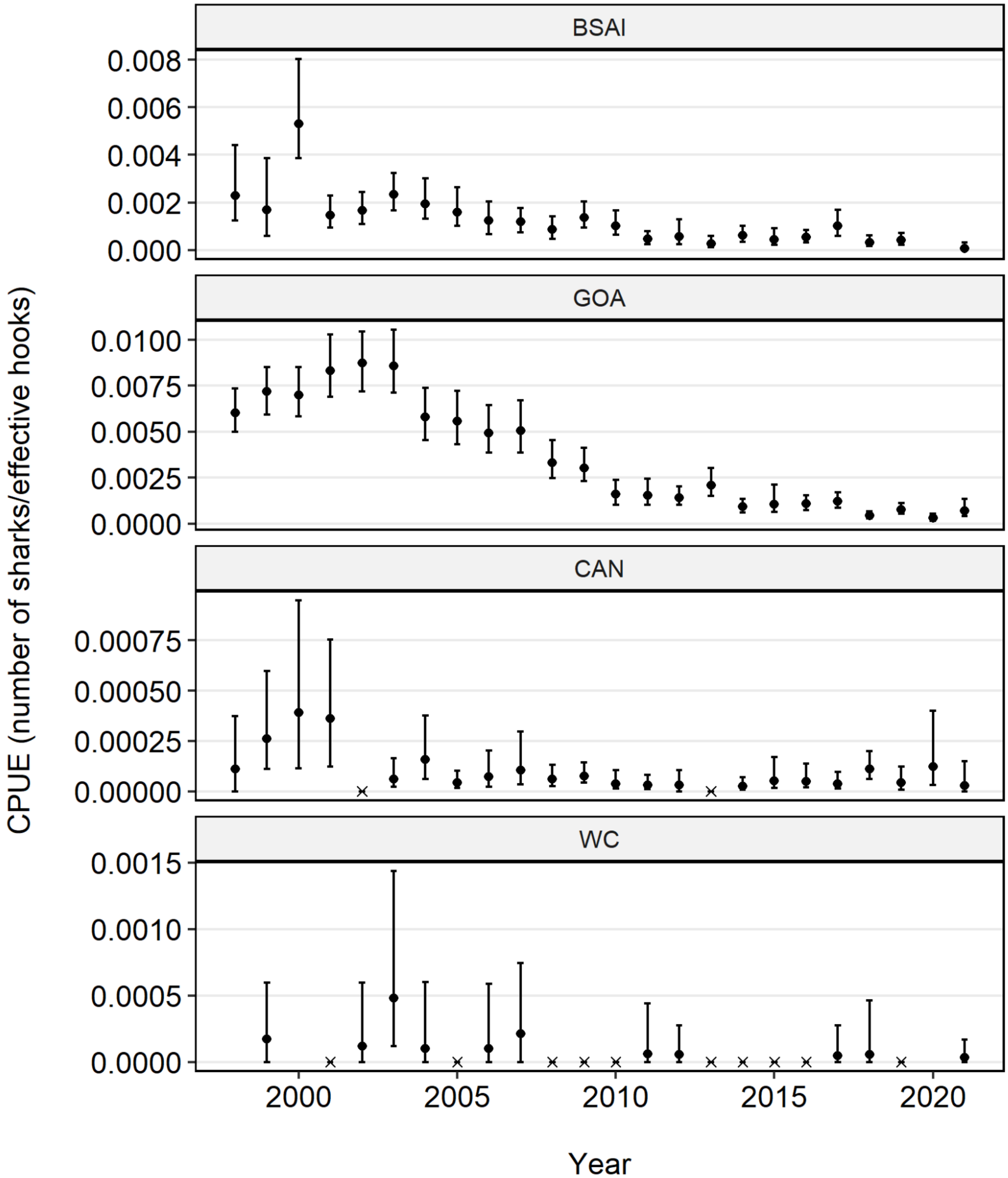


Figure 7. Trends in International Pacific Halibut Commission (IPHC) longline survey estimates of Pacific sleeper shark (*Somniosus pacificus*) catch per unit effort (CPUE) reported here as an index of relative abundance for Alaska Fishery Management Plan areas (BSAI = Bering Sea/Aleutian Islands, GOA = Gulf of Alaska), British Columbia (CAN) and the U.S. West Coast (WC). Years with zero catch are denoted by "×". Error bars represent bootstrapped 95% confidence intervals. Note that y-axis scales differ among panels. Updated through 2021.

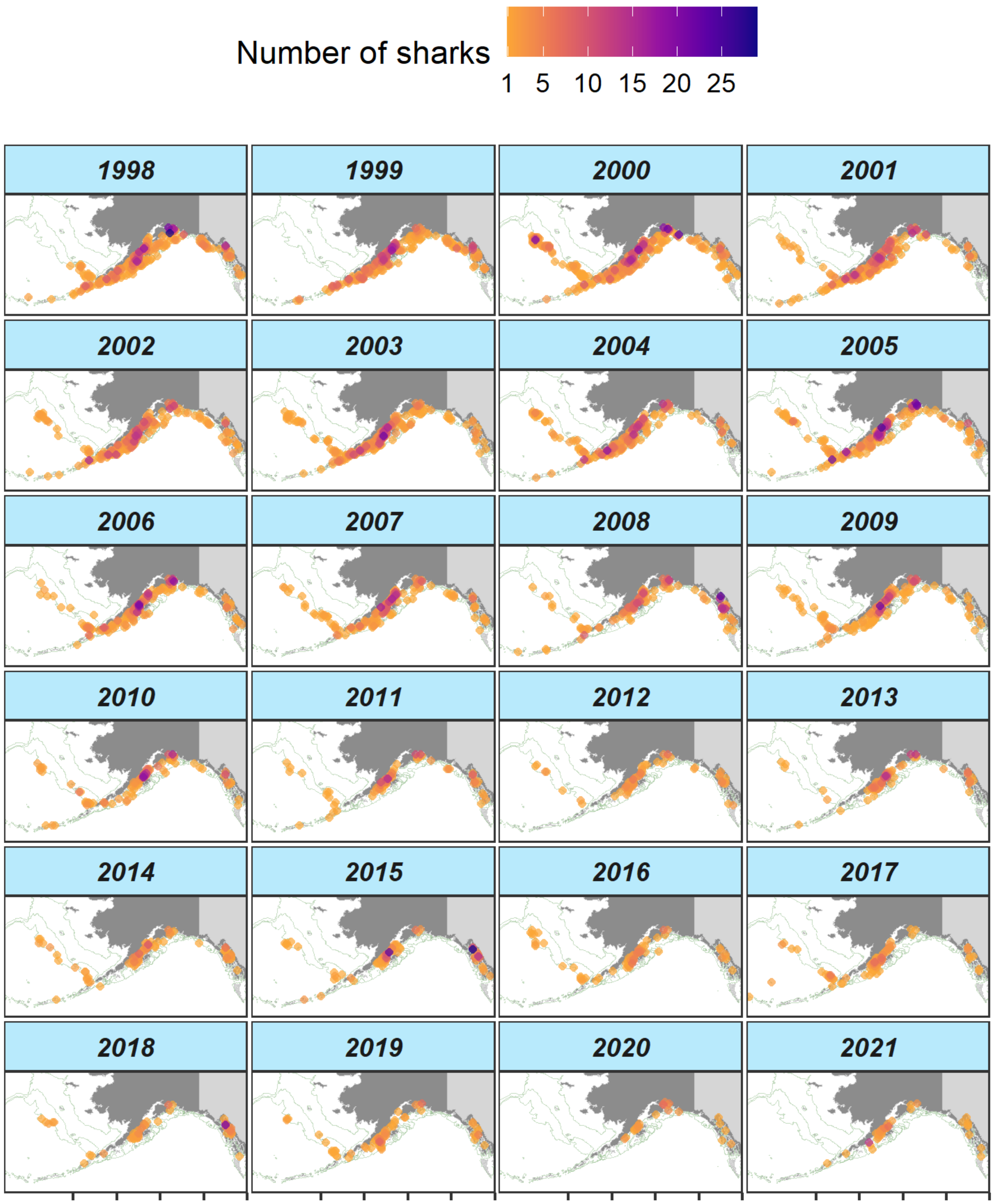


Figure 8. Spatial distribution of the Pacific sleeper shark (*Somniosus pacificus*) catch during annual International Pacific Halibut Commission (IPHC) longline surveys. Colors represent the number of sharks observed and each point represents one survey haul. Hauls with zero catch were removed for clarity.

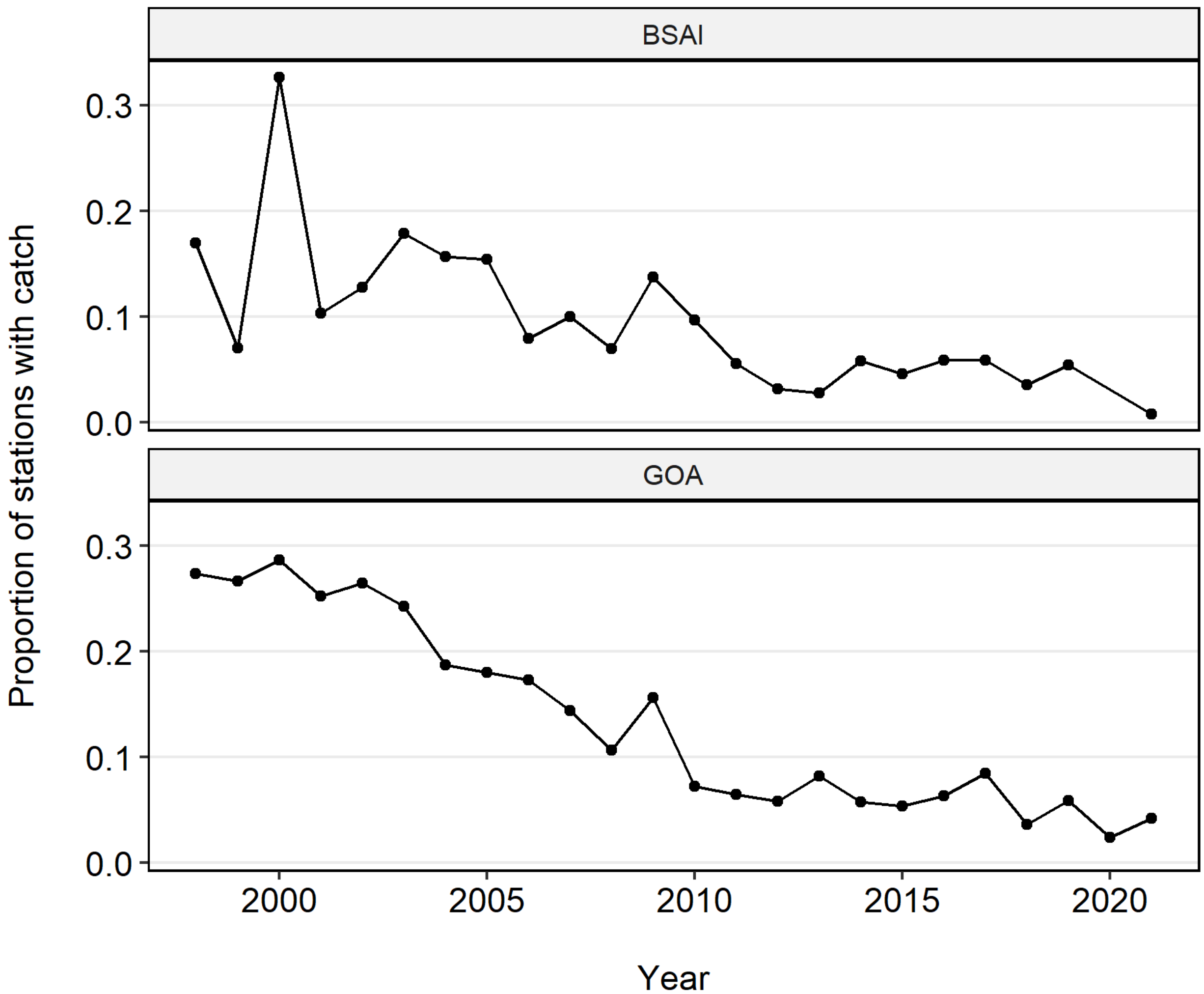


Figure 9. Proportion of fixed International Pacific Halibut Commission (IPHC) longline survey stations with Pacific sleeper shark (*Somniosus pacificus*) catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas.

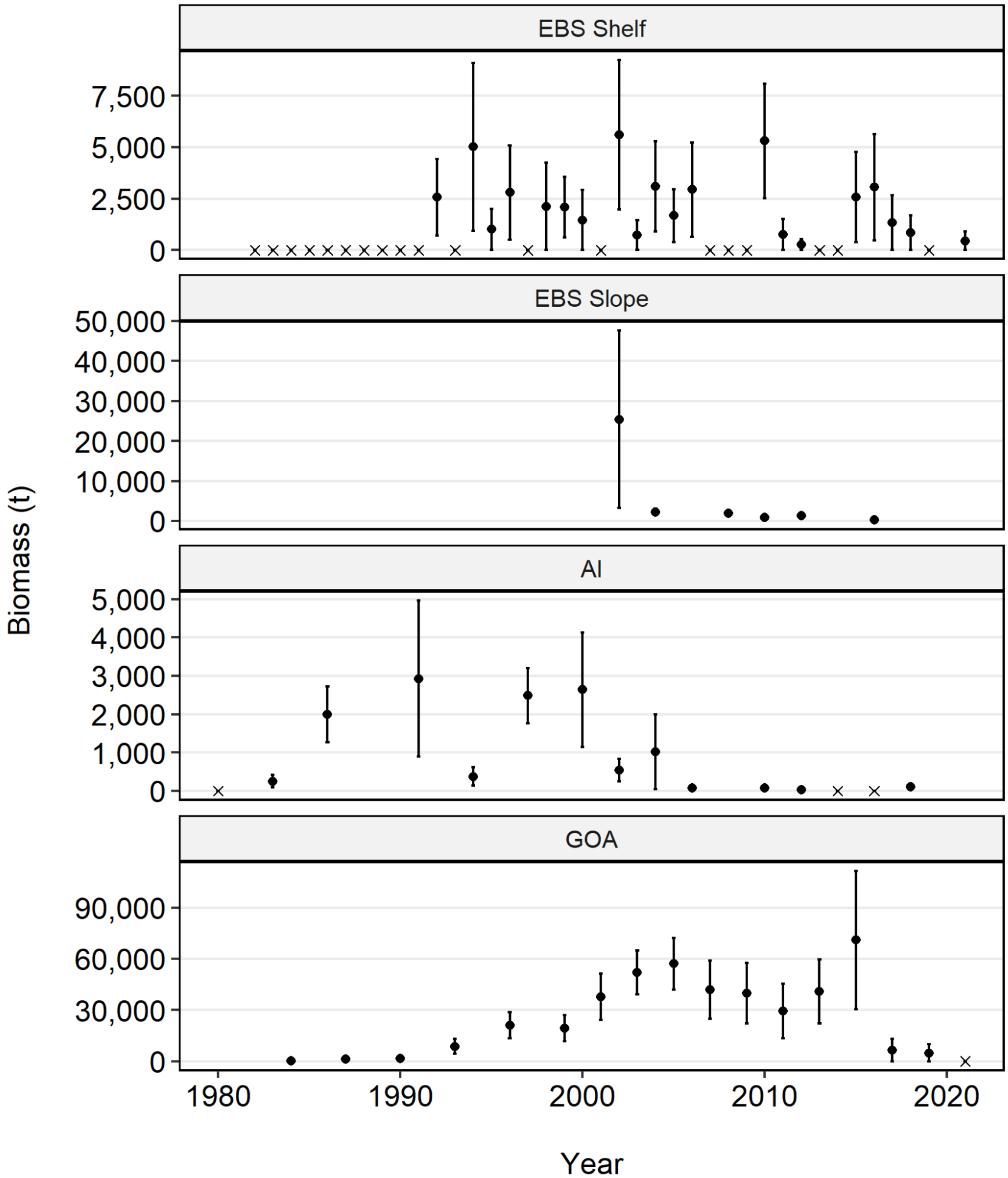


Figure 10. Trends in Alaska Fisheries Science Center (AFSC) bottom trawl survey estimates of Pacific sleeper shark (*Somniosus pacificus*) total biomass (metric tons), reported here as an index of relative abundance. Error bars represent 1 standard error. Note that y-axis scales differ among survey areas (EBS = eastern Bering Sea, AI = Aleutian Islands, GOA = Gulf of Alaska). Years with zero catch are denoted by "×". Updated through 2021.

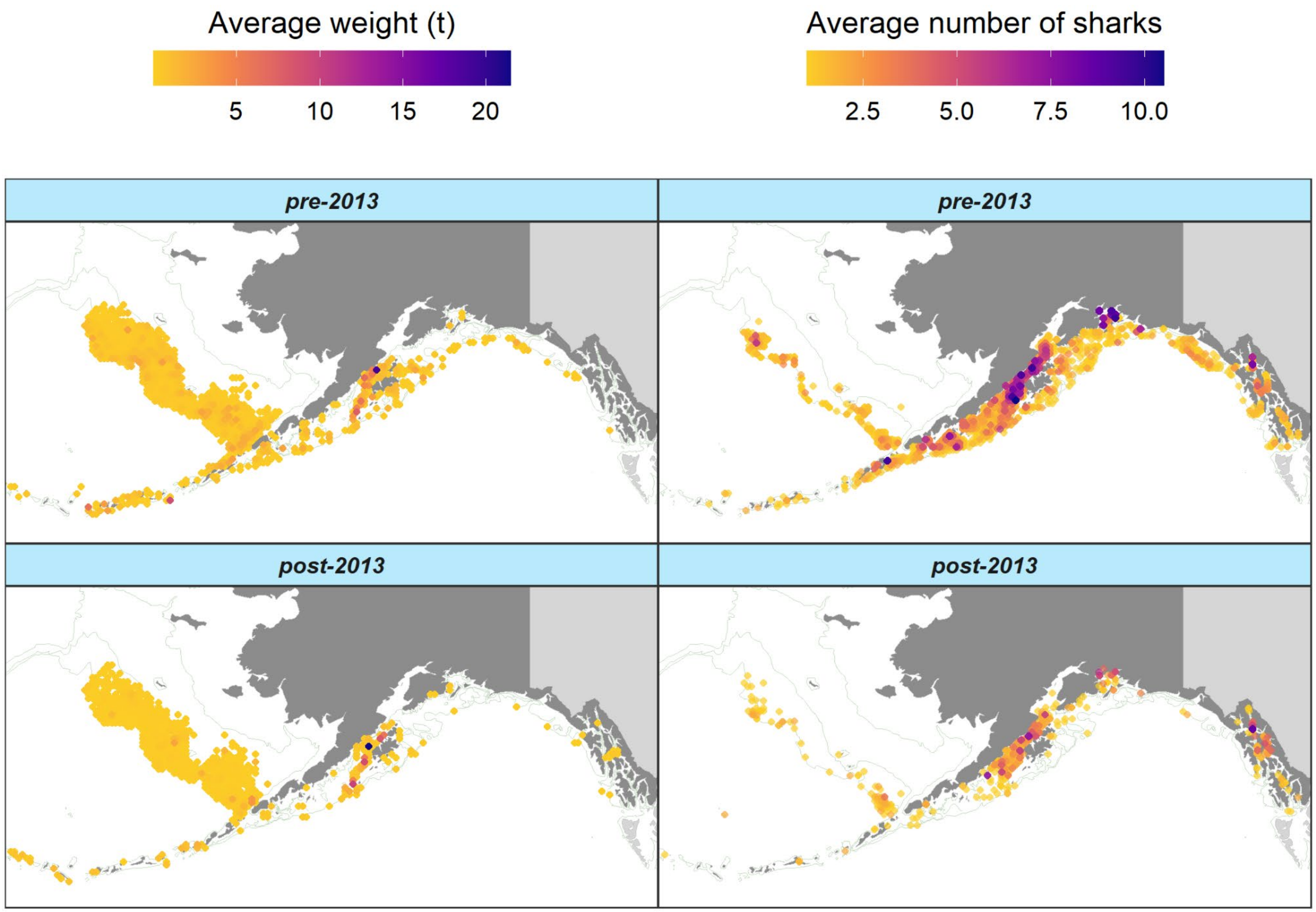


Figure 11. Spatial trends in nonconfidential observed fishery and survey catches of Pacific sleeper sharks (*Somniosus pacificus*) over recent (2013-2021) and historic (1998-2012) time periods. Left panels show the fishery average weight (metric tons) per nonconfidential grid cell before and after restructuring of the North Pacific Observer Program that occurred in 2013. Right panels show the International Pacific Halibut Commission (IPHC) longline survey average number of sharks per station (zero catches removed).

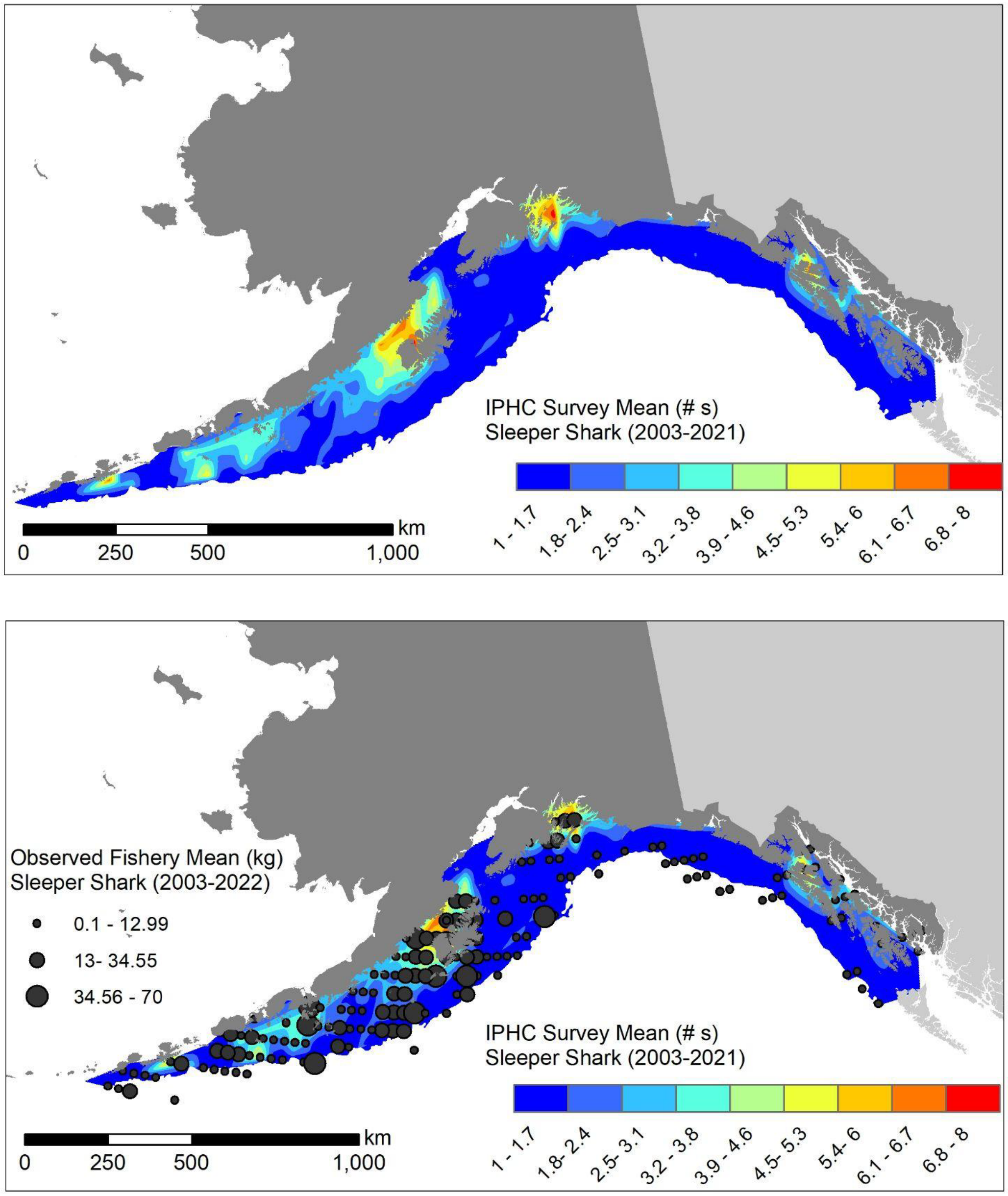
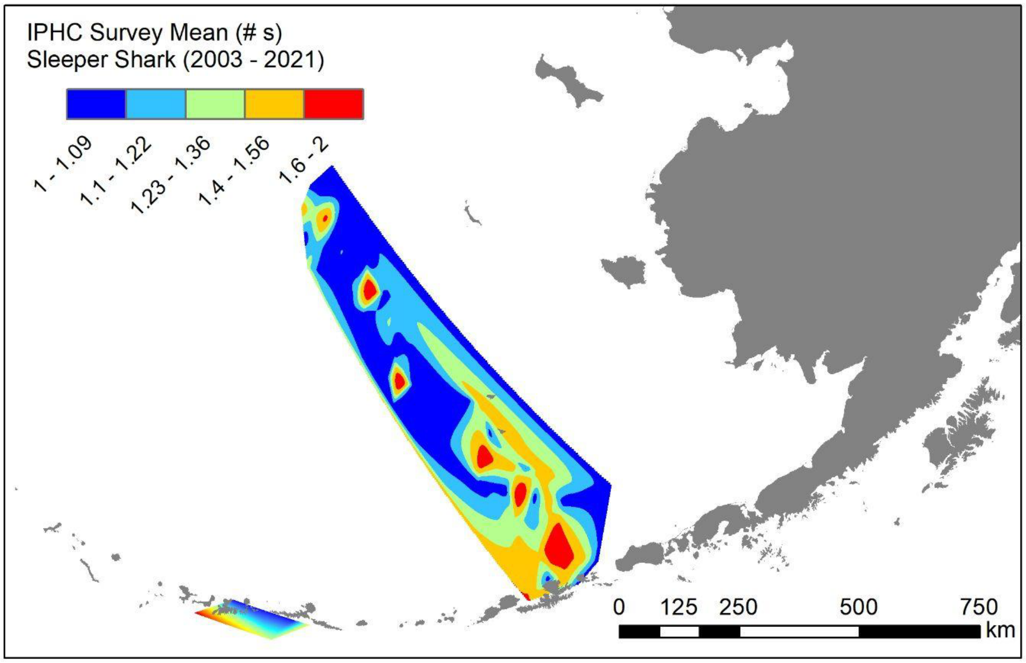


Figure 12. Comparison of the spatial distribution of Pacific sleeper sharks (*Somniosus pacificus*) based on mean (2003-2021) International Pacific Halibut Commission (IPHC) survey conditions with the spatial distribution of the mean (2003-2022) fishery catch in the Gulf of Alaska. Top panel shows the IPHC mean conditions and bottom panel shows the overlay of the fishery mean on the IPHC mean.



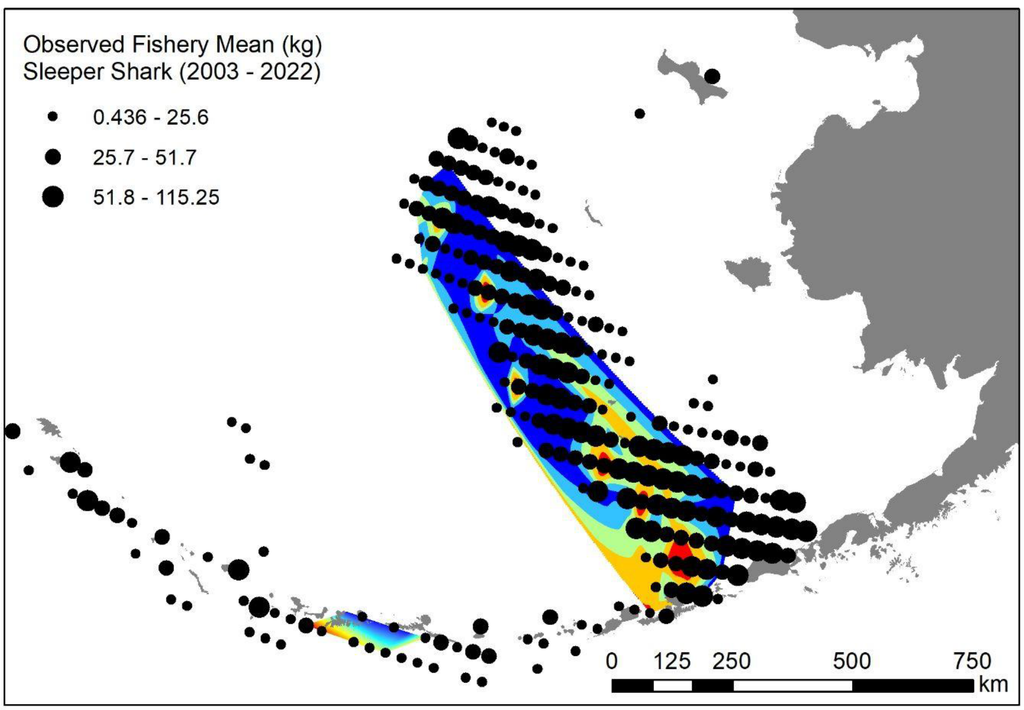


Figure 13. Comparison of the spatial distribution of Pacific sleeper sharks (*Somniosus pacificus*) based on mean (2003-2021) International Pacific Halibut Commission (IPHC) survey conditions with the spatial distribution of the mean (2003-2022) fishery catch in the Bering Sea/Aleutian Islands. Top panel shows the IPHC mean conditions and bottom panel shows the overlay of the fishery mean on the IPHC mean. Note the different scales between the two data sources, in particular the IPHC survey in the BSAI catches a small number of Pacific sleeper sharks and ranges on average between 1-2 animals.