IOTC-2023-WPEB19-32

19. Assessment of the Shark Stock Complex in the Bering Sea/Aleutian Islands and Gulf of Alaska

Cindy A. Tribuzio, Mary Elizabeth Matta, Katy B. Echave, Cara Rodgveller, Garrett Dunne and Keith Fuller

November 2022

EXECUTIVE SUMMARY

This document presents the assessment for the shark stock complex (Pacific spiny dogfish, Pacific sleeper shark, salmon shark and other/unidentified sharks) in both the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan (FMP) areas. While advice remains separate by FMP, recent tagging and genetic studies suggest that the stocks are shared between these areas. We combined the assessments here to streamline the presentation of data that are in common (e.g., life history, data summaries, etc.) and to harmonize advice and management recommendations between regions.

For the BSAI, the SSC has placed this complex within Tier 6 of the FMP. This means the OFL is based on the maximum historical catch between the years 2003-2015, and the ABC is 75% of OFL. For the GOA, the complex is managed as a combination of Tier 5 (for spiny dogfish) and Tier 6 species (for all other sharks). The OFL and ABC for the GOA complex sums over these tiers. The GOA spiny dogfish assessment uses the random effects while the remaining components (Tier 6) are based on species-specific average catches from 1997-2007.

BSAI - Summary of Changes in Assessment Inputs

Changes to the input data

1. Total catch for BSAI sharks is updated for 2003-2022 (as of Oct 8, 2022)

Changes in assessment methodology

We proposed changes for how 3 of the 4 BSAI shark species categories are treated. For Pacific sleeper sharks, we evaluated stock status based on a catch-only model; for the other two, we illustrate results from a modified Tier 6 approach where the 90th percentile of the catch series is used instead of the maximum. The ABC/OFL recommendation from the salmon shark component of the complex would remain the same.

BSAI - Summary of Results

There is no evidence to suggest that overfishing is occurring for any shark species in the BSAI because the OFL has not been exceeded. Total shark catch in 2021 was 221 t, and catch in 2022 was 123 t, as of October 8, 2022. On average, 12% of the total annual catch occurs after October 1st each year.

For 2023-2024 we **recommend the maximum allowable ABC of 293 t and an OFL of 391 t for the shark stock complex in the BSAI**. The recommended ABC/OFL are a 43% decrease from the previous assessment and are due to the recommended model changes. Current catches are below the recommended ABC and have been below the recommended ABC over the last 15 years. It is unlikely that shark catches would increase such that the ABC would be reached. There are currently no directed commercial fisheries for shark species in the BSAI, and most incidental catch is discarded.

ABC and OFL calculations and Tier 6 recommendations for BSAI, 2023-2024.

Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
Tier	6	6	6	6
OFL (t)	689	689	**391**	391
maxABC (t)	517	517	293	293
ABC (t)	517	517	**293**	293
Status	As determined *last* year for: 2020	2021	As determined *this* year for: 2021	2022
Overfishing	No	n/a	No	n/a

BSAI - Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Shark Stock Complex	2021	NA	689	517	200	221
	2022	NA	689	517	500	123
	2023	NA	391	293		
	2024	NA	391	293		

[1]The shark stock complex in the BSAI is a Tier 6 complex with no reliable estimates of biomass.
[2]Catch as of October 8, 2022

GOA - Summary of Changes in Assessment Inputs

Changes to the input data

1. Total catch of GOA sharks from 2003-2022 has been updated (as of October 8, 2022).
2. All survey indices have been updated where data are available:
   a. National Marine Fisheries Service (NMFS) bottom trawl through 2021
   b. International Pacific Halibut Commission (IPHC) longline through 2021

Changes in assessment methodology

We recommend two changes for how components of the GOA shark complex are treated. As for the BSAI, we recommend that Pacific sleeper shark in the GOA use a catch-only assessment method. Also, as with the BSAI, the other/unidentified sharks component is set to the 90th percentile of the 1997-2007 catch time series of catch for the OFL.

GOA - Summary of Results

There is no evidence to suggest that overfishing is occurring for any shark species in the GOA because the OFL has not been exceeded. Total shark catch in 2021 was 1,917 t and catch in 2022 was 1,550t as of October 8, 2022. On average, 33% of the total annual catch occurs after October 1st each year.

For 2023-2024 we recommend that for the shark stock complex the spiny dogfish be managed as a Tier 5 species using status quo Model 15.3A and the remaining sharks as Tier 6 species adopting the alternative models for Pacific sleeper shark (PSS22.0) and other/unidentified sharks (OU22.0). **The recommended ABC is 4,756 t and OFL is 6,341 t for the shark stock complex.** This is a 27% increase from the previous assessment. There was a decrease in the Tier 6 ABCs due to the recommended model changes, but the Tier 5 recommendations were increased due to an increase in the spiny dogfish trawl survey biomass. There are currently no directed commercial fisheries for shark species in federal or state managed waters of the GOA, and most incidental catch is discarded.

ABC and OFL calculations and Tier 5 recommendations for GOA spiny dogfish for 2023-2024. Here the OFL is based on the random effects estimated exploitable biomass (31,243 t) divided by catchability (q = 0.21) to equal an adjusted biomass of 148,776 t, which is then multiplied by the *F* rate of 0.04.

Spiny Dogfish Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
M (natural mortality rate)	0.097	0.097	0.097	0.097
Tier	5	5	5	5
Biomass (t)	23,289	23,289	31,243	31,243
F_{OFL}	0.04	0.04	0.04	0.04
$maxF_{ABC}$	0.03	0.03	0.03	0.03
F_{ABC}	0.03	0.03	0.03	0.03
OFL (t)	**4,436**	4,436	**5,951**	**5,951**
maxABC (t)	3,327	3,327	4,463	4,463
ABC (t)	**3,327**	3,327	**4,463**	**4,463**
Status	As determined *last* year for: 2020	2021	As determined *this* year for: 2021	2022
Overfishing	No	n/a	No	n/a

ABC and OFL Calculations and Tier 6 recommendations for GOA Pacific sleeper sharks, salmon sharks and other sharks for 2023-2024. Similarity with the BSAI values are purely coincidental.

Pacific sleeper, salmon and other sharks Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
Tier	6	6	6	6
OFL (t)	570	570	**390**	390
maxABC (t)	427	427	293	293
ABC (t)	427	427	**293**	293
Status	As determined *last* year for: 2020	2021	As determined *this* year for: 2021	2022
Overfishing	No	n/a	No	n/a

For the combined GOA shark stock complex:

GOA Shark Stock Complex Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
Tier	5/6	5/6	5/6	5/6
OFL (t)	5,006	5,006	**6,341**	6,341
maxABC (t)	3,755	3,755	4,756	4,756
ABC (t)	3,755	3,755	**4,756**	4,756

GOA - Summaries for Plan Team

Species	Year	Biomass[1]	OFL[2]	ABC[2]	TAC	Catch[3]
Shark Stock Complex	2021	23,289	5,006	3,755	3,755	1,917
	2022	23,289	5,006	3,755	3,755	1,550
	2023	31,243	6,341	4,756		
	2024	31,243	6,341	4,756		

[1]Spiny dogfish random effects modelled biomass only.
[2]ABC and OFL are the sum of the individual species recommendations, Tier 6 for Pacific sleeper shark (Model PSS22.0), salmon shark (Model SS11.0), and other/unidentified sharks (Model OS22.0) and Tier 5 for spiny dogfish (Model 15.3A).
[3]Catch as of October 8, 2022.

Responses to SSC and Plan Team Comments on Assessments in General

"The SSC supports the JGPT's recommendation that stock assessment authors transition from the ADMB RE variants to the rema framework, which implements the same model variants in a single framework with several improvements."(SSC, Oct 2022)

We intend to bridge the Tier 5 spiny dogfish to the rema framework in the next full assessment.

SSC and Plan Team Comments Specific to Both Assessments

"The Teams also agree with the author's recommendation to bring forward the status quo assessment approach and the ORCS catch model as alternatives for sleeper sharks in November." (JGPT September 2022).

"*The SSC supports the JGPT and author recommendation to bring forward (1) the status quo assessment approach, (2) the ORCS catch model for sleeper sharks in GOA and BSAI, and (3) the alternative approach (90th percentile to account for extreme and rare catch events) for the other/unidentified sharks in the BSAI and GOA and for spiny dogfish in the BSAI.*" (SSC October 2022)

In response to the above two comments, we have included the status quo and all requested alternative models.

"*When bringing forward the ORCS catch model for sleeper sharks, the SSC asks for additional examination and recommendations from the author and GPTs regarding the following:*

1. *Whether the 75% ABC buffer is appropriate given the low productivity of the stock, the evaluation that sleeper sharks are considered "fully exploited" (based on an assessor evaluated score in Table 3), and the assumption that all stocks that are fully exploited are at or above BMSY.*
2. *In addition, the ORCS table of attributes (Table 1) which are evaluated for sleeper shark (Table 3) do not include any consideration of maturity of individuals caught (i.e., how best do you assess*

the exploitation status (underexploited, fully exploited, or overexploited) of a species when a majority of the individuals caught are immature?).

3. *Is it appropriate to include the "Discard rate" category for a species that is not retained?*
4. *Should uncertainty be evaluated only within the ORCS model (percentile scalar is chosen to satisfy risk tolerance and is set based on confidence that the exploitation status is correctly identified) or also outside the model in the risk table, noting that the ORCS scoring criteria also address aspects of risk."* (SSC October 2022)

For item #1, regarding the determination of "fully-exploited", we have included text supporting this determination. As part of the analyses in support of this full assessment, the authors conducted a sensitivity analysis to examine how robust the stock status score was and if it could be changed, given reasonable inferences on available information. Given current information, it was not possible to support a stock status of "overexploited". We have included some discussion of the logic behind the default buffer to the harvest recommendations section, however, the appropriateness of 75% for lower productivity stocks and whether that buffer adequately captures uncertainty is worthy of further discussions. That analysis should be collaborative because it is relevant to other long-lived, non-target, Tier 6 species and complexes, and not just sharks. Lastly, given the NPFMC Tier 6 harvest control rule (mean historical catch = OFL, i.e., the limit reference point, Amendment 56 of either FMP), the presumption is that a Tier 6 stock is at or above B_{MSY}, as per Restrepo et al. (1998). The guidance laid out by Restrepo et al. (1998) states that when a data-poor stock is at or above B_{MSY}, the limit reference point is equivalent to the historical catch and when a stock is below B_{MSY}, the limit is scaled appropriate to the status. Therefore, the current NPFMC Tier 6 harvest control rule presumes that a stock is at or above B_{MSY}.

For item #2, the ORCS framework is flexible to additions. Life history attributes were identified by Free et al. (2017) as viable attributes to add to the approach, were added a life history attribute to encompass the maturity of the animals being caught. However, being one of 13 attributes, this may not give sufficient weight to the concerns over the proportion of immature Pacific sleeper shark in the catch. The ORCS approach is robust to status misspecification, which may be a latent issue for Pacific sleeper sharks given the potential for recruitment overfishing if only immature sharks are being harvested. Free et al. (2017) demonstrated that a more conservative scalar can offset status misspecification. This could be an option for Pacific sleeper shark. At this time, data are insufficient to determine if recruitment overfishing has occurred and we recommended the 50^{th} percentile scalar.

For item #3, we chose to retain the Discard Rate attribute because the development of that attribute does not exclude species that are nearly fully discarded. The Free et al. (2017) analysis included 193 stocks, with a range of discard rates. In the ORCS approach, discard rates are a proxy for fishing mortality in that lower discards suggest higher fishing mortality when assuming some value of post-release survival (i.e., discard mortality).

Regarding item #4, while the ORCS approach and the risk tables are similar in structure, they address different aspects of uncertainty. The risk tables are intended to account for uncertainty outside of the assessment model, while the ORCS approach accounts for uncertainty within the model. The information utilized in the ORCS approach is separate from the information presented in the risk table and therefore we do not feel that these overlap.

"*The SSC requests that a column is added to Table 3 to explain sources and/or reasons for scoring because the scoring might change over time.*" (SSC October 2022)
The justification for each of the scores has been added to the model description, as well as to Table 19.9.

"*The SSC suggests exploration of whether additional IPHC data may be available (particularly in the GOA) that could provide information on trends prior to the late 1990s.*" (SSC October 2022)
We intend to explore the historical IPHC data further and will communicate with IPHC staff.

SSC and Plan Team Comments Specific to this Assessment - BSAI

"The SSC also requests the following for future assessments: Investigate the relationship between bottom temperature and catch trends…" (SSC December 2016)
This task is still outstanding. We plan to review the ESR and select a set of indicators (e.g., cold pool size, longline survey bottom temperature) as well as examine the regularly collected IPHC temperature-depth recorder data to determine which may be informative for Pacific sleeper sharks. This analysis may be informative for both the BSAI and GOA and will be tied with research efforts into the last SSC request in the previous section.

"The Teams encourage continued exploration of utilizing data limited methods for this assessment." (JGPT September 2018), *"The SSC agrees with the JGPT for continued exploration of utilizing data limited methods for this assessment. The SSC further recommends in addition to sharks, it would be helpful for the Plan Teams and other authors of Tiers 5 and 6 stocks to explore the increasing number of methods available for data limited situations."* (SSC October 2018), *"The Team accepted the author's choice of OFL and ABC (the same as 2017 and 2018) and looks forward to the author's new analysis with a greatly expanded set of data-limited methods for 2020"* (PT November 2018), *"For the next full assessment in 2020, the SSC looks forward to the authors' new analysis with a greatly expanded set of data-limited methods."* (SSC December 2018)
The 2022 assessment includes model alternatives utilizing contemporary data-limited methods (DLMs). The focus of the 2022 assessment was on Pacific sleeper shark. The authors reviewed many DLMs, at various levels of data availability and selected a suite of candidate models to present to the JGPT in September 2022 (Appendix 19E of this assessment). That exercise and the Pacific sleeper shark stock structure document (Appendix 19A of this assessment) helped identify changes in data collections that may widen the suite of candidate models in future years. After the September JGPT meeting, the FMA division and the lead author started establishing new at-sea data collection protocols that may provide expanded data streams for future assessments of Pacific sleeper sharks.

SSC and Plan Team Comments Specific to this Assessment - GOA

"In response, the Plan Team recommended: (1) Bringing forward a Pacific sleeper shark (PSS) stock structure document (across both FMPs) to the Joint Plan Team in September 2018 due to concerns that PSS in BSAI and GOA are one stock with a potentially small effective population size and that they are long-lived and slow maturing ………….(3) Continuing to work on PSS genetics" (GOA Plan Team, November 2017, paraphrased to account for points already completed).
In response to points (1) and (3): the Pacific sleeper shark stock structure analysis was presented to the September JGPT meeting and the SSC in October 2022. That analysis is included in this assessment document as Appendix 19A.

"The Team appreciates and supports the authors work on the items listed above, and in particular the Team recommended the author continue with efforts to estimate biomass in NMFS areas 649 and 659 and further suggested that steps be taken to ensure future shark catches in Federal fisheries in areas 649 and 659 be fully accounted for in reporting. In discussions, the Team recommended that the author lead a small workgroup (J. Rumble, C. Faunce, and O. Ormseth) to examine estimation approaches for 649/659 federal fisheries catches and how they should be accounted within federal assessments." (GOA Plan Team, November 2018)
We opted to delay this analysis pending results of studies to expand biomass estimates into NMFS Areas 649/659. See responses to below comments.

"The Team encouraged an examination of using VAST as it might provide a better time series of survey catches. Additionally, the author was encouraged to explore combining trawl and longline survey catches, similar to what is being done with thornyheads." (GOA Plan Team, September 2018)
See responses to below comments.

"The SSC also recommends that: (1) Authors continue exploration of spatiotemporal models, such as VAST, for spiny dogfish and various data limited assessment techniques for other sharks …….. (3) Authors continue efforts to estimate biomass in NMFS areas 649 and 659, and that steps be taken to ensure future shark catches in Federal fisheries in 649 and 659 be fully accounted for in reporting (4) A small working group examine estimation approaches for 649/659 Federal fisheries catches and how they should be accounted within federal assessments, as recommended by the PT." (SSC, December 2018)

In response to points (1), (3) and (4): the utility of VAST, or other spatiotemporal modelling approaches has not been investigated for spiny dogfish yet. The authors are collaborating with the University of Alaska Fairbanks on a Pollock Conservation Cooperative Research Center funded project investigating the incorporation of multiple survey indices into VAST and other spatiotemporal modelling approaches. The outcome of that project will be informative for the spiny dogfish assessment because the IPHC and ADFG Southeast Alaska longline surveys provide data in inside waters and may then be able to expand the biomass estimates into NMFS Areas 649 and 659.

"*The SSC recommends that the authors consider future research into variability in catchability coefficient for spiny dogfish, specifically temperature-dependent q*," (SSC December 2020)
This request will be evaluated in future model investigations for spiny dogfish.

Introduction

Alaska Fisheries Science Center (AFSC) surveys and fishery observer catch records provide biological information on shark species that occur in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan (FMP) areas (Figure 19.1). Eleven shark species have been reported in the GOA and eight shark species have been reported in the BSAI (Appendix 19B). The three shark species most likely to be encountered in both BSAI and GOA fisheries and surveys are the Pacific spiny dogfish (*Squalus suckleyi)*, the Pacific sleeper shark (*Somniosus pacificus*), and the salmon shark (*Lamna ditropis*). These three species are the main focus of this assessment. Survey and fishery catches of the remaining eight species in the GOA (common thresher shark *Alopias vulpinus*, brown cat shark *Apristurus brunneus*, white shark *Carcharodon carcharias*, basking shark *Cetorhinus maximus*, Tope or soupfin shark *Galeorhinus galeus*, bluntnose sixgill shark *Hexanchus griseus*, broadnose sevengill shark *Notorynchus cepedianus*, and blue shark *Prionace glauca*) and remaining five species in the BSAI (bluntnose sixgill shark, basking shark, brown cat shark, blue shark, and Pacific sharpnose shark *Rhizoprionodon longurio*) are rare or anecdotal. Data on these rarer species are aggregated as "other" sharks together with data on unidentified shark species in this assessment.

Of note, the current scientific name for Pacific spiny dogfish is S. suckleyi, but prior to 2010, the species name was *Squalus acanthias* (Ebert et al. 2010, Verissimo et al. 2010). Accordingly, some data sources and older citations used in this assessment refer to the previous name, *S. acanthias*.

General Distribution

Pacific Sleeper Shark

This species is distributed widely throughout the eastern and western Pacific Ocean, ranging from possibly as far north as the Chukchi Sea to at least as far south as the central South Pacific and Tasman Sea (Applegate et al. 1993, Benz et al. 2004, Ebert 2003, Grigorov and Orlov 2014, Kang et al. 2015, Orlov and Moiseev 1999, Tanaka et al. 1982, Timm et al. in review, Wang and Yang 2004).

Pacific sleeper sharks have been documented at a wide range of depths, from surface waters to depths of 2,000 m or more (Compagno 1984, Hulbert et al. 2006). This species appears to have a latitudinal relationship with depth, occurring in relatively shallow waters at higher latitudes and in deeper habitats in temperate waters (Rigby et al. 2021).

Salmon Shark

The salmon shark ranges in the North Pacific Ocean from Japan through the Bering Sea and GOA to southern California and Baja, Mexico (Mecklenburg et al. 2002). Salmon sharks are considered common in coastal littoral zones as well as inshore and offshore epipelagic waters (Mecklenburg et al. 2002). Salmon sharks have been documented at depths ranging from 0-1,864 m (Carlisle et al. 2011).

Spiny Dogfish

The Pacific spiny dogfish (hereafter, "spiny dogfish") occupies shelf and upper slope waters from the Bering Sea to the southern Baja Peninsula in the eastern North Pacific (ENP) and south through the Japanese archipelago in the western North Pacific (WNP, Ebert et al. 2010). Spiny dogfish are considered more common off the U.S. West Coast and British Columbia (BC) than in the GOA or BSAI (Hart 1973, Ketchen 1986, Mecklenburg et al. 2002). In Alaska, they are more common in the GOA than in the BSAI and tend to be most abundant in the Eastern GOA (Gasper and Kruse 2013). Spiny dogfish inhabit both benthic and pelagic environments. They are commonly found in surface waters and throughout the water column, with a maximum recorded depth of 677 m in Alaska waters (Tribuzio, unpublished data).

Evidence of Stock Structure

The stock structure of the BSAI and GOA shark stock complexes was first examined and presented to the joint Plan Teams in September 2012 (available at: https://apps-afsc.fisheries.noaa.gov/REFM/Docs/2012/BSAIshark.pdf). A new stock structure evaluation was completed for the Pacific sleeper shark in both FMP areas and presented to the joint Plan Teams in September 2022 (see Appendix 19A, this document). In summary, no genetically significant stock structure was found for the Pacific sleeper shark throughout its range (Timm et al. in review), however significant demographic structure was identified (e.g., evidence of nursery habitat). Genetic studies conducted on spiny dogfish have also indicated that there is no significant stock structure within the GOA or BSAI (Ebert et al. 2010, Verissimo et al. 2010), which are supported by tagging data (Tribuzio unpublished data, McFarlane and King 2003).

Salmon sharks are broadly distributed and make extensive migrations across the North Pacific Ocean, but it is uncertain whether there is a single stock or multiple stocks. Based on tagging data, the species is highly migratory, with the ability to make annual migrations from the central North Pacific Ocean back to Alaskan waters (Weng et al. 2005, Hulbert et al. 2005, Garcia et al. 2021). Two separate pupping and nursery grounds have been proposed, one at the transitional boundary of the subarctic and central Pacific currents (Nakano and Nagasawa 1996), and another along the western coast of North America (Goldman and Musick 2008); however, due to the relatively few captures of newborn sharks or pregnant females, these have not been confirmed. While the sex ratios differ on either side of the North Pacific Ocean (Nagasawa 1998, Goldman and Musick 2008), suggesting mixing, growth also differs on either side of the North Pacific Ocean suggesting separation (Goldman and Musick 2006). More work, particularly with genetics, is needed to determine stock structure of this species in the North Pacific Ocean.

Life History Information

Life history information is not used in the assessment for Tier 5 specifications for GOA spiny dogfish or in Tier 6 specifications for other species of sharks in either complex. The alternative models presented for the Pacific sleeper shark do use inferred qualitative life history information, such as mortality and length at maturity, as described in the model alternative and results sections. An extensive review of life history information and parameters is available in Appendix 19B of this document. Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity. Like with other slow-growing, long-lived fish, Ormseth and Spencer (2011) estimated the vulnerability of Alaska groundfish and found that the salmon shark, spiny dogfish, and Pacific sleeper shark were among the most vulnerable species in the GOA and BSAI.

Fishery

Management History and Management Units

The shark stock complexes are managed as aggregate species groups in each of the BSAI and GOA FMPs. Prior to the 2011 fishery, sharks were managed as part of the "Other Species" complexes, with sculpins, skates, and octopus. The breakout was in response to the requirements for annual catch limits contained within the reauthorization of the Magnuson Stevens Fishery Conservation and Management Act. The NPFMC passed Amendment 96 to the BSAI FMP and Amendment 87 to the GOA FMP, requiring sharks to be managed as a separate complex and Annual Catch Limits (ACLs) be established annually by the SSC starting in the 2011 fishery. The total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limits (OFL) for the shark stock complexes (and previously the Other Species complex) are set in aggregate (Table 19.1 BSAI, Table 19.2 GOA).

Directed Fishery, Effort and CPUE

There are currently no directed commercial fisheries for shark species in federal or state managed waters of the BSAI or GOA, and most incidentally caught sharks are not retained. In the GOA, there is an ADFG Commissioner's Permit fishery for spiny dogfish in lower Cook Inlet; however, only one application has been received to date and the permit was not issued. Spiny dogfish are also allowed as retained incidental catch in some ADFG managed fisheries with minimal landings reported.

Current Incidental Fishery - BSAI

Pacific sleeper shark and salmon shark are the primary species of sharks incidentally caught in the BSAI (Table 19.3, Figure 19.2). Nearly all of the shark catch within the BSAI occurs in the Bering Sea (Figure 19.3). Appendix 19C provides supplemental information about the shark stock complex catch. In the BSAI, most of the catch occurs on vessels fishing pelagic trawl gear and to a lesser extent hook-and-line gear, with only a small amount from non-pelagic trawl gear (Figure 19C.1). In the Bering Sea, nearly all of the catch results from vessels in the "full coverage" observer category, where observers monitor all of the catch, while in the Aleutian Islands catch results from a mixture of full, partial and electronic monitoring (EM). There are two EM programs in Alaskan waters: fixed-gear (i.e., pot and longline gears) and trawl EM. Each program is distinct and catch are reported differently. In fixed-gear EM cameras monitor catch and a subsample of hauls are reviewed for catch accounting. The trawl EM program requires all catch to be retained and delivered shore side for observers to sample, however, large shark species are an exception and allowed to be discarded at-sea. To account for these discards, trawl EM vessels are required to report all shark catch in their logbooks which are then reported on the fish tickets for catch accounting. The remaining category for observer coverage is the "zero selection" category, where vessels are not observed, either due to small size or specific exclusions. Very little shark catch results from vessels which are in the zero selection category (Figure 19C.2). Any catch estimates from vessels in this category is based on catch rates from vessels in other observation categories. Because most of the catch in the eastern Bering Sea is from full coverage vessels, nearly all of the catch comes from trips where an observer is onboard; whereas in the Aleutian Islands, much of the catch comes from trips with no monitoring, observers or EM (Figure 19C.3).

Pacific sleeper shark and spiny dogfish are caught primarily in the Pacific cod (*Gadus macrocephalus*) longline and the walleye pollock (*Gadus chalcogrammus*) trawl fisheries (Figure 19.4). Salmon shark are almost entirely caught in the walleye pollock fishery (Figure 19.4).

The other/unidentified shark category is difficult to assess. Most of the "other" shark species are. Since 2003, there has been one basking shark (*Cetorhinus maximus*), one brown cat shark (*Apristurus* *brunneus*) and six bluntnose sixgill sharks (*Hexanchus griseus*) observed in the BSAI. Catch estimated for the "other" sharks cannot be separated from "unidentified" sharks, and some portion of this category may actually be spiny dogfish, Pacific sleeper shark, or salmon shark. With the exception of 2006, incidental catch of "other" sharks is relatively split between the walleye pollock trawl fishery and Pacific cod longline fishery (Figure 19.4).

Sharks are not targeted and, therefore, catch is driven by other fisheries that incidentally capture the species. As such, shark catch generally occurs in two main pulses coinciding with late winter and late summer/early autumn walleye pollock fisheries (Figure 19.5). However, in the last two years, the late winter catch has been minimal and most catch has occurred later in the year. Over the last 10 years, about 12% of the catch has occurred after data are queried for use in the assessment (approximately October 1st of each year, shown as a vertical line at week 40 in Figure 19.5).

Current Incidental Fishery - GOA

Sharks are not targeted and, therefore, catch is driven by other fisheries that incidentally capture the species. Spiny dogfish are the primary species incidentally caught in the GOA. Pacific sleeper sharks, salmon sharks and other/unidentified sharks are smaller components of the complex (Table 19.3, Figure 19.2). In the GOA, most of the catch occurs on hook-and-line vessels, but in the Central GOA catch also occurs in non-pelagic trawl fisheries and with limited catch from pelagic trawl fisheries (Figure 19C.1). In the Western GOA, much of the shark catch results from pelagic trawl fisheries and the proportion has increased since 2018. In the GOA, nearly all of the catch results from vessels in the partial or EM partial observer category (Figure 19C.2). A small proportion of the GOA shark catch results from vessels which are in the zero selection category (Figure 19C.2). Because most of the catch in the GOA is from vessels in the partial or EM partial observer categories, much of the catch results from non-monitored trips because the target coverage rates for vessels in the partial coverage range from 11.1% to 17.7% and 30% for fixed-gear EM vessels (Figure 19C.3and Table 19C.1).

Shark catch in the GOA is spread across the FMP subareas (Figure 19.3). Spiny dogfish are largely caught in the Eastern GOA (NMFS areas 640 and 650), but are also often caught in the Central GOA (Figure 19.3) and predominantly in the sablefish (*Anoplopoma fimbria*) and Pacific halibut (*Hippoglossus stenolepis*) hook-and-line fisheries (Figure 19.4). Pacific sleeper sharks are generally caught in the Central GOA flatfish, pollock and Pacific cod fisheries. Salmon shark are primarily caught in the Western GOA and almost exclusively in the pollock fisheries. Catch of other/unidentified sharks is variable. There was a notably high catch of other/unidentified sharks in 2022 in the Eastern GOA in the Pacific halibut fishery (Figure 19.4), which is almost exclusively from a small number of hauls with high numbers of unidentified sharks.

Shark catch is limited in pot gears. Pot gear is becoming more commonly used in the GOA fixed-gear fisheries for Pacific cod and sablefish. As such, we anticipate seeing a decline in shark catch in those fisheries as the use of pot gear increases.

Shark catch generally occurs in two main pulses coinciding with late winter Pacific halibut and sablefish fisheries (about weeks 15-20) and late summer/early autumn walleye pollock fisheries (about weeks 35-40, Figure 19.5). Over the last 10 years, about 33% of the catch, on average, occurs after data are queried for use in the assessment (approximately week 40, or October 1st of each year).

Distribution of Catch in Fisheries

The spatial distribution of catch in fisheries both in the BSAI and GOA are presented in Appendix 19C of this document as supplemental information. Overall, catch distribution is likely more a function of the behavior of target fisheries and not indicative of areas of high biomass.

Discards

Nearly all incidental shark catch in the BSAI and GOA is discarded (rates in Table 19.4). Mortality rates of discarded sharks are unknown but are conservatively estimated in this report as 100%. This assumption is supported by a study where 10 Pacific sleeper sharks were tagged after being caught on catcher vessels in the pollock trawl fishery. All 10 appeared dead at time of release or died shortly after (Tribuzio, unpublished data). The lower discard rate (76%) for spiny dogfish in the BSAI in 2020 is due to an extrapolation of total shark catch from a single large haul, as opposed to an increase in retention. Only two observed hauls reported retention of a single spiny dogfish each in 2020. On average, 9 t and 25 t (BSAI and GOA, respectively) are retained and almost exclusively all is sold for fishmeal (A. Abelman, AFSC, pers comm.)

Data

Data for shark stock complex assessments were obtained from the following sources:

Source	Data	Years
AKRO Catch Accounting System	Fishery Catch	2003-2022
AKRO Improved pseudo-blend – GOA only	Fishery Catch	1997-2002
NMFS Bottom Trawl Survey – GOA only	Biomass Index	1990-2021
IPHC Longline Surveys – GOA only	Abundance Index	1997-2021

Fishery

Estimated catches of sharks by species are reported in four distinct time series: 1990-1998, estimated by staff at the AFSC using a “pseudo-blend” approach (GOA only, Gaichas et al. 1999); 1997-2002, estimated by staff at the AFSC using the “improved pseudo-blend” approach (Gaichas 2001, 2002), and 2003-present, estimated by the NMFS AKRO Catch Accounting System (CAS). Data prior to 1997 are not used in either assessment and thus are not included. The 1990-1998 pseudo-blend catch estimates are reported in previous stock assessments for reference (Tribuzio et al. 2018b). The improved pseudo-blend is included in the GOA assessment and the CAS time series are used in both assessments (Table 19.3). Data prior to 2002 were excluded from the BSAI stock assessment due to concerns over the accuracy of the catch estimates (Tribuzio et al. 2016). The observer program was restructured in 2013 and while the catch estimation procedure has been the same (CAS), the data inputs are different since the restructuring. This restructuring increased observer coverage on vessels between 40 and 60 ft in length as well as incorporated those participating in the Pacific halibut IFQ fishery into the program. Because a large portion of shark catch originates from the vessels now included in the observer program, the catch time series beginning in 2013 may not be comparable to prior catch time series for sharks. While vessels participating in the Pacific halibut IFQ fishery in the BSAI are now included, the majority of the change in the composition of catch after observer restructuring went into effect was due to increased coverage in small vessels targeting Pacific cod.

Estimates generated by CAS are updated retroactively, as input data are error-checked and as improvements are made to CAS. However, catch estimates prior to 2010 are no longer updated. The catch estimates used in this assessment are presented in Table 19.3.

There are two major caveats with regards to the time series of shark catch: unobserved fisheries and bias in catch estimates. The catch estimates presented here do not include catches from unobserved fisheries. Prior to 2013, the Pacific halibut IFQ fleet was not observed and discards were not reported. Based on anecdotal reports, both spiny dogfish and Pacific sleeper shark catch were common in the Pacific halibut IFQ fleet. Previously unobserved vessels are now part of the partial observer coverage category (Electronic Monitoring and human); however, gaps in coverage still exist because nearly all vessels less than 40 ft are unobserved, and as such, discard information collected by observers may not be representative of catch composition on small vessels. The other unobserved fisheries are state-managed salmon fisheries and state-managed groundfish fisheries. Discards are not reported for these fisheries. Catches may be high for the set net fisheries; unofficial reports from Yakutat Bay suggest that large numbers of spiny dogfish will sink the nets, such that the crew must abandon the gear due to the danger of retrieving the net. Thus, these fisheries have the potential to remove large numbers of spiny dogfish, which are undocumented.

Recent data also suggest a bias in the estimated catch for Pacific sleeper shark. Pacific sleeper sharks are large-bodied and difficult to bring on board most longline vessels. Any animals that are available for the observers to sample are generally small. Additionally, observers are limited to a 50 kg scale, and would need to take the time and have the space to cut anything heavier than 50 kg into smaller pieces to weigh. A special project to investigate the potential bias in the weight of animals that are measured compared to all of the Pacific sleeper sharks that were caught began in the 2018 and data collection will continue through the 2023 fishery. Preliminary results suggest that the average weight used to estimate the total catch underestimates the true size of the sharks being caught (Appendix 20A in Tribuzio et al. 2018).

Lastly, vessels operating under federal fisheries permits in Prince William Sound (NMFS area 649) and inside waters of Southeast Alaska (NMFS area 659) are now covered at a higher rate as a result of observer restructuring, and thus estimated catch from these two areas has increased. These catches do not count against the TAC, but should be monitored and are included in Table 19.2, Figure 19.3 and Table 19C.2.

Survey

AFSC Bottom Trawl Surveys-GOA

The GOA Tier 5 spiny dogfish assessment incorporates survey biomass and variance estimates from the AFSC GOA biennial bottom trawl survey (Table 19.5). Bottom trawl surveys were conducted on a triennial basis in the GOA in 1984, 1987, 1990, 1993, 1996, and a biennial survey schedule has been used since the 1999 survey. The surveys covered all areas of the GOA to a depth of 1,000 m, with the following exceptions: the 1990, 1993, 1996, and 2001 surveys did not sample deeper than 500 m; the 2003, 2011, 2013, 2017 2019, and 2021 surveys did not sample deeper than 700 m. Other important caveats are that the 2001 survey did not sample the Eastern GOA, thus removing an entire area of the estimation of biomass and the 2013, 2017 and 2019 surveys had a reduced number of stations, which likely increased uncertainty in biomass estimates. It is unlikely that these survey caveats would impact the estimation of shark biomass because most sharks are caught in strata shallower than 500 m, with the exception of the 2001 survey not sampling the Eastern GOA; however, it is important to note the potential for process error. Furthermore, the 1984 survey results should be treated with some caution, as a different survey design was used in the eastern GOA. In addition, much of the survey effort in 1984 and 1987 was by Japanese vessels that used a very different net design than the standard used by U.S. vessels in the years since, introducing an element of uncertainty regarding the standardization of these two surveys. For these reasons, we follow the NPFMC Groundfish Plan Team and SSC recommendations (September, October 2022) to exclude the bottom trawl survey data from 1984 and 1987. Henceforth, these data will no longer be reported in the SAFE report and will not be used in the estimation of spiny dogfish exploitable biomass.

The efficiency of bottom trawl gear is not known for sharks. Hulson et al. (2016) used tagging data to investigate the availability of spiny dogfish to the survey gear and found that the species spends a large portion of time in near-surface waters (i.e., out of the range of the survey gear) during the summer. It is likely that the trawl survey biomass estimate for spiny dogfish is an underestimate and should be considered a minimum biomass. Further, spiny dogfish tend to form schools and are patchily distributed, thus, survey biomass estimates can be highly variable from survey to survey (Table 19.5).

International Pacific Halibut Commission (IPHC) Longline Surveys

The IPHC conducts a longline survey each year to assess Pacific halibut. This fixed-station survey samples to depths of 500 m in the AI, EBS, and the GOA in inside and outside waters, as well as areas south of Alaska. More information about this survey can be found here. The IPHC survey is likely the most informative survey for the Pacific sleeper shark in the GOA and is included here because the data are used in the proposed model alternative for this species.

Relative population numbers (RPNs) for Pacific sleeper shark were calculated from the raw survey data using the same historical methods as for the AFSC longline survey (Table 19.6), the only difference being the depth stratum increments. An average CPUE, the number of sharks per effective hooks, was calculated by depth stratum for each FMP sub-area (e.g., EBS, AI, Central GOA, etc.). The CPUE was then multiplied by the area size of the stratum, using area sizes that are used to calculate biomass in the RACE trawl surveys. An FMP-wide RPN was calculated by summing the RPNs for all strata in the area and confidence limits estimated by bootstrap resampling of the stations within each region. Note that there are wide confidence intervals on the IPHC survey RPNs.

Additional survey information

While limited survey data are used in the assessment models, a variety of other data sources are available, including AFSC bottom trawl surveys not used for the GOA spiny dogfish model, IPHC/AFSC longline survey indices and length data for spiny dogfish and ADFG survey indices. Appendix 19D summarizes the biomass estimates, abundance indices, length/weight data and spatial distribution data when and where available. These survey data sources may be used to inform the risk tables and for future model developments.

Analytic Approach

Model Structure

BSAI Status Quo Model 16.0

The shark stock complex in the BSAI is managed as Tier 6 (harvest specifications based on the historical catch or alternatives accepted by the Science and Statistical Committee). The overfishing limit (OFL) for the BSAI is based on the maximum of the aggregate shark stock complex catch, as determined by the Plan Team (November 2010) and supported by the SSC (SSC 2010). As per Amendment 56, the harvest control rule sets the acceptable biological catch (ABC) ≤ 75% of the OFL. The assessment began using the maximum of the catch from 1997-2007 to determine OFLs for the 2011 fishery (Tribuzio et al. 2010a). The model currently in use was accepted for the 2016 stock assessment (Tribuzio et al. 2016), and following the model-naming convention, it is henceforth termed Model 16.0. Model 16.0 uses the maximum of the catch history from 2003-2015 to determine the OFL. The more recent and abbreviated time series is due to substantial concerns regarding the accuracy of catch estimates prior to 2003.

Tier 6 Model	OFL	Equation
16.0	Max complex catch 2003–2015	$OFL = max(C_{2003-2015})$

GOA Status Quo – Spiny Dogfish Model 15.3A

Spiny dogfish are managed as a Tier 5 species in the GOA FMP. Exploitable biomass is calculated using the accepted Model 15.3A, which uses the random effects model-estimated biomass (B_{RFX}) adjusted by a catchability parameter to estimate an adjusted biomass (B_a, Tribuzio et al. 2018). The random effects modelling process incorporates the process errors (step changes) from one year to the next as the random effects, which are integrated over the process error variance as a free parameter. The observations can be irregularly spaced; therefore this model can be applied to datasets with missing data (e.g., 2001, when the survey did not sample the Eastern GOA). Large observation errors increase errors predicted by the model, which can provide a way to weight predicted estimates of biomass. The random effects biomass model was fit separately by area (West, Central, and Eastern GOA) and then summed to obtain Gulf-wide biomass. We fit the random effects model to regional data because in 2001 the trawl survey did not sample the Eastern GOA, where a significant proportion of the spiny dogfish population resides within the GOA. The OFL is then calculated by multiplying the estimated exploitable biomass by the F_{OFL}.

Tier 5 Model	F_{OFL}	Adjusted Biomass	Equation
15.3A	$F_{max} = 0.04$	$B_a = B_{RFX}/q$	$OFL = F_{max} * B_a$

GOA Status Quo – Tier 6 Model 11.0

Sharks other than spiny dogfish (Pacific sleeper shark, salmon shark, and other/unidentified sharks) in the GOA are managed as Tier 6 species. Unlike the BSAI, species-specific ABC and OFL are summed for the complex level ABC/OFL and are based on the mean historical catch from 1997-2007. This approach has been used for these species since before there was a shark stock complex, thus to meet model numbering requirements, the Tier 6 models for these three species will be numbered Model 11.0, representing the first year (2011) that there was a shark stock complex total allowable catch (TAC).

Tier 6 Model	OFL	Equation
11.0	Mean catch from 1997-2007	$OFL = \overline{C}_{1997-2007}$

Description of Alternative Models

Alternative models are presented in this assessment for Pacific sleeper shark and other/unidentified sharks in both FMPs and for spiny dogfish in the BSAI. The proposed alternative model approaches for Pacific sleeper shark is the same for both FMPs and described here together. Similarly, the proposed alternative model approaches for other/unidentified and BSAI spiny dogfish are the same and are described together. Results and harvest recommendations will be presented separately for each FMP.

Pacific sleeper shark Only Reliable Catch Stock (ORCS)

The NPFMC Tier 6 control rule defines the OFL as equal to the historical average from 1978-1995 unless an alternative value is established by the SSC on the basis of the best available scientific information (NPFMC 2020a and 2020b). By definition, a historical average approach assumes that all Tier 6 stocks are at or above B_{MSY} (Restrepo et al. 1998). This assumption may be valid for many of the Tier 6 stocks because they are generally non-targeted. The exception could be for low productivity stocks where historic catch levels may or may not be an accurate proxy for MSY. A framework was developed in the Restrepo et al. (1998) guidance to allow for reductions to the OFL based on perceived stock status (above B_{MSY}, between minimum stock size threshold (MSST) and B_{MSY}, or below MSST) and recommended the use of expert judgement when quantitative stock status indicators were not available. Berkson et al. (2011) revisited the Restrepo guidance and noted that, as presented, the guidance was difficult to implement in the OFL/ABC frameworks developed in the years since because scientific uncertainty was explicitly taken into account. Berkson et al. (2011) developed the initial qualitative Only Reliable Catch Stocks (ORCS) method similar to the Restrepo et al. 1998 guidance, but fit to the modern OFL/ABC framework. The ORCS approach follows three steps:

1) Assign a stock to one of three exploitation categories using an evidence-based scoring procedure;
2) Estimate an OFL by multiplying a statistical measure of historical catch by a scalar that depends on the exploitation category;

3) Obtain an ABC as a proportion of the OFL to reflect a policy decision on acceptable risk and scientific uncertainty.

Steps 1 and 2 are part of the alternative model presented in this assessment. The third step could either be the existing Tier 6 harvest control rule where ABC ≤ 0.75*OFL, or other reductions based on risk tolerance and any other risks outlined in the risk table. The third step will be discussed as part of the harvest recommendations, risk table and reductions from maximum permissible ABC sections.

The ORCS approach is based on the concept of "pretty good yield" where a large percentage of MSY can be produced on a long-term basis over a broad range of stock sizes (Hilborn 2010). For data-limited situations, this means that successful management outcomes are possible even if the stock status is not precisely known (Berkson et al. 2011). In this case, expert judgement, where experts can encompass scientists, fishery managers, industry and others, is used to assign stocks to broad status categories. The original ORCS approach tended to bias towards moderate stock status and Free et al. (2017) refined the approach using a broader range of test species and more expansive simulation testing. The refined ORCS approach was 74% accurate (70% accuracy considered acceptable, Berkson et al. 2011) when placing a stock into one of the three status categories: underexploited, fully exploited and overexploited. Although the refined approach misclassifies some overexploited stocks, conservative catch scalars successfully buffer against classification uncertainty (Free et al. 2017). Free et al. (2017) tested six other catch-only methods and found that the ORCS approach performed the best, with the fewest stocks becoming overfished.

The refined ORCS approach uses 12 attributes to classify the stock (Table 19.7), as described in the below scoring guide (from Berkson et al. 2011, and refined by Free et al. 2017). We have included a 13th attribute to encompass life history and concerns regarding the maturity of the animals being caught, as identified in the stock structure for Pacific sleeper shark (Appendix 19A).

ORCS Attribute #1 – Status of assessed stocks in fishery
The proportion of assessed stocks in the fishery that are overfished by determining the status of all stocks within the relevant fisheries management unit. The proportion of overfished stocks is calculated using only assessed stocks in the fishery. Free et al. (2017) identified the following thresholds for scoring:
1 – <10% of assessed stocks are overfished
2 – 10-25% of assessed stocks are overfished
3 – >25% of assessed stocks are overfished
NA – Target stock is the only stock in the fishery or stock statuses are unknown

ORCS Attribute #2 – Behavior affecting capture
Review biology, FishBase species profile or other information to identify behavior that might affect the susceptibility of the taxa to capture. Only taxa exhibiting schooling, shoaling, or spawning aggregation behaviors targeted by fishermen should be scored as being highly susceptible to capture. All other taxa (those not exhibiting these behaviors or those whose spawning aggregations are not targeted by fishermen) should be scored as being moderately susceptible to capture. Free et al. (2017) note that no stocks exhibit traits that would make them unsusceptible to capture.
1 – No examples
2 – Don't exhibit schooling/shoaling/aggregation behavior
3 – Exhibit schooling/shoaling/aggregation behavior
NA – Schooling/shoaling/aggregation behavior unknown

ORCS Attribute #3 – Discard rate
Determined the proportion of the catch discarded from the relevant stock assessment or other relevant resource and used the following percentage thresholds to assign scores:
1 – <10% of catch discarded
2 – 10-25% of catch discarded

3 – >25% of catch discarded
NA – Discard rates are unknown

ORCS Attribute #4 – Targeting intensity
Review the "history of the fishery" portion of the relevant stock assessment and other relevant resources to determine the targeting intensity of the fishery. Non-targeted species are likely to be lightly exploited relative to the target stock, however, if a low-productivity species may still become overfished. Use the following classifications to assign scores:
1 – Not targeted (bycatch / incidental catch only)
2 – Occasionally targeted (often part of multi-species catch)
3 – Actively targeted (directed fishery)
NA – Targeting intensity unknown

ORCS Attribute #5 – M compared to dominant species
The natural mortality rates of the target and dominant species in the fishery should be determined from the relevant stock assessments. If the target species was dominant or if there were no other taxa in the fishery, the attribute could not be scored. The following classifications were used to assign scores when the attribute could be scored (note: natural mortality rates must differ by >10% to be considered different):
1 – M higher than M of dominant species
2 – M approximately equal to M of dominant species
3 – M lower than M of dominant species
NA (common for this attribute) – only taxa in fishery or is the dominant taxa in fishery or natural mortality rates are unknown

ORCS Attribute #6 – Occurrence in catch
Use the percentage threshold guidelines listed below to assign scores. However, this data is not often available and decisions could be fairly subjective and non-quantitative.
1 – Sporadic (0-10% of trawl tows, gillnet sets, trap pulls, etc.)
2 – Common (10-25% of trawl tows, gillnet sets, trap pulls, etc.)
3 – Frequent (>25% of trawl tows, gillnet sets, trap pulls, etc.)
NA – the relative occurrence of the taxa in the catch is unknown

ORCS Attribute #7 – Value
Determine the value (USD lb^{-1}) by deriving ex-vessel price for taxa by region from the Sea Around Us Project landings volume and value database (Sumaila et al., 2007; Pauly and Zeller, 2015). Recommend using the most recent 5 years with data for scoring. For most stocks, appropriate regional prices could be tied to the stock. For highly migratory species like tuna, marlin, swordfish and stocks managed by a RFMO (e.g., Mediterranean or West African stocks), average values from the relevant countries can be used. The following thresholds are used to assign scores:
1 – <\$1.00 lb^{-1}
2 – \$1.00-2.25 lb^{-1}
3 – >\$2.25 lb^{-1}
NA – Ex-vessel price is unknown

ORCS Attribute #8 – Recent trend in catch
Recent trend in catch for each scored stock should be determined using (1) annual catch time series in the RAM Legacy Stock Assessment Database or (2) figures and tables in the original stock assessment when catch time series were not included in the database. Identify trends in catch in the most recent 5 years where a (1) significant positive slope indicates increasing catch, (2) significant negative slope indicates decreasing catch, and (3) non-significant slope indicates stable catch over the most recent 5 years. Recommend using the Theil-Sen regression, which fits a line to a set of points by identifying the median

slope among lines through all possible point pairs and is insensitive to outliers and endpoints in short time series.
1 – Significant increase in catch in recent 5 years
2 – No significant change in catch in recent 5 years
3 – Significant decrease in catch in recent 5 years
NA – Catch data are not available

ORCS Attribute #9 – Habitat loss
Taxa that reside in threatened estuary (Lotze et al., 2006), seagrass (Orth et al., 2006; Waycott et al., 2009), mangrove (Giri et al., 2010), or coral reef (Pandolfi et al., 2003, 2011) habitats for their whole lives or a portion of their lives as being at high and moderate risk of overexploitation. Taxa that spend their entire lives outside these threatened habitats are considered at low risk of overexploitation. Taxa that spend the entirety of their lives in partially threatened inshore areas such as the intertidal zone or rocky reefs (Lotze et al., 2006; Rabalais et al., 2009) are considered at moderate risk of overexploitation.
1 – No time in threatened habitats
2 – Part time in threatened habitats (or full time in partially threatened habitats)
3 – Full time in threatened habitats
NA – Habitat preferences are unknown

ORCS Attribute #10 – Recent trend in effort
Fishing mortality rate estimates can be used as a proxy for fishing effort. Data were collected from (1) annual fishing mortality time series in the RAM Legacy Stock Assessment Database or (2) figures and tables in the original stock assessment when fishing mortality time series were not included in the database. As with trends in catch, the Theil-Sen regression is recommended to identify trends in fishing mortality in the most recent 5 years where a (1) significant positive slope indicates increasing effort, (2) significant negative slope indicates decreasing effort, and (3) non-significant slope indicates stable effort over the most recent 5 years.
1 – Significant decrease in fishing effort in recent 5 years
2 – No significant change in fishing effort in recent 5 years
3 – Significant increase in fishing effort in recent 5 years
NA – Effort data are not available

ORCS Attribute #11 – Recent trend in abundance index
Fisheries-independent CPUE for each scored stock using stock assessment model abundance estimates as a proxy for CPUE can be used to discern trends in abundance indices. Data can be collected from (1) annual abundance time series in the RAM Legacy Stock Assessment Database or (2) figures and tables in the original stock assessment when abundance time series were not included in the database. As with trends in catch, the Theil-Sen regression is recommended to identify trends in the abundance index in the most recent 5 years where a (1) significant positive slope indicates increasing abundance index, (2) significant negative slope indicates decreasing abundance index, and (3) non-significant slope indicates stable abundance index over the most recent 5 years.
1 – Significant increase in abundance index in recent 5 years
2 – No significant change in abundance index in recent 5 years
3 – Significant decrease in abundance index in recent 5 years
NA – Survey data are not available

ORCS Attribute #12 – Proportion of population protected
Determine whether the fishery was managed using (1) size limits, (2) protected areas, (3) seasonal closures, or (4) significant effort controls / gear restrictions. Fisheries employing no measures received a high risk score, one measure a moderate risk score, and size limits and one other measure a low risk score.
1 – Most of resource is protected (Size limits AND protected areas/seasonal closures)
2 – Some of resource is protected (Size limits OR protected areas OR seasonal closures)

3 – None of resource is protected (No size limits, no protected areas, no seasonal closures)
NA – Management regulations are unknown

ORCS Attribute #13 – Life history considerations
Neither the original ORCS (Berkson et al. 2011) nor the refined ORCS (Free et al. 2017) methods incorporated life history considerations. However, Free et al. (2017) noted that the performance of the refined ORCS may be further improved by identifying new predictive attributes that may include life history characteristics. For the model proposed here, we add a life history attribute. We propose the below scoring thresholds for life history characteristics which account for catch occurring on specific life stages and/or the life history (and therefore) productivity of the stock.
1 – Fishery generally catches adults and/or species is highly productive
2 – Fishery catches are distributed across life history stages
3 – Fishery generally catches immature individuals and/or the species has low productivity
NA – Life history is unknown or fishery impact on life stages are unknown

Once all of the attributes have been scored, a final score is calculated as the mean of the above attribute scores. The stock status is determined based on the mean attribute score, such that mean scores < 1.5 are considered "underexploited", mean scores between 1.5 and 2.5 are considered "fully exploited" and mean scores > 2.5 are considered "overexploited". An OFL is then calculated as a scaled "best historical catch statistic", with the statistic method determined by the stock status and the scalar is reflective of the risk of overfishing tolerance (Table 19.8). For example, the 50th percentile scalar should result in a 50% probability of overfishing if the stock is identified correctly (Free et al. 2017). The current NPFMC Tier 6 definitions, where the OFL is a historical average catch, should similarly result in a 50% probability of exceeding the OFL if the historical time series is correctly selected. Therefore, the 50th percentile scalar in the ORCS approach is recommended to be consistent with the defined NPFMC Tier 6 risk of overfishing. The scalar choice can be reevaluated as needed.

<u>BSAI spiny dogfish and GOA/BSAI other/unidentified sharks 90th percentile</u>
Catch estimates of rare species such as other/unidentified sharks (either FMP) or BSAI spiny dogfish are sensitive to the occasional "large haul" which results in large and unlikely estimated catch. For example, in 2006, there were two hauls which reported unusually high catches of unidentified sharks and resulted in an annual estimated catch well outside the range for that species category (Figure 19.2).

Using the 90th percentile of the catch time series instead of the maximum historical values will avoid undue influence from large or misreported hauls. The alternative model would be applied to other/unidentified sharks and spiny dogfish in the BSAI and other/unidentified sharks in the GOA. The years of the historical catch time series are maintained from previous assessments, i.e., the BSAI is from 2003-2015 and the GOA is from 1997-2007.

Parameter Estimates

<u>GOA Status Quo – Spiny Dogfish Model 15.3A</u>
Natural mortality of spiny dogfish (used in Model 15.3A) in the GOA is estimated to be 0.097 (Tribuzio and Kruse, 2012). This value of M is similar to an estimate for British Columbia spiny dogfish (0.094, Wood et al. 1979).

The F_{max} is estimated through a demographic analysis (Tribuzio and Kruse 2011). The demographic model is not updated for each assessment and thus not considered to be the assessment model. The parameters provided by the demographic analysis are considered estimated outside of the model.

Model 15.3A incorporates spiny dogfish catchability (q) based on spiny dogfish vertical (a_v) and horizontal (a_h) availability to the trawl survey, and gear selectivity (S). The vertical availability was estimated to be 3.1% (0-21%, 95% CI, Hulson et al. 2016). Due to the large uncertainty associated with the geolocation estimates, Hulson et al. (2016) recommended that using the point estimate of a_v may not be appropriate. Thus, we recommend the more conservative approach using the upper confidence limit of a_v (0.21). Horizontal availability is set equal to 1 because there are tagging data showing movement both into and out of the FMP area, but there are not sufficient data to quantify the net rate of movement. The susceptibility (in this case net efficiency) was also set equal to 1 based on trawl survey net efficiency estimates of a closely related species, *S. acanthias* (Rago and Sosebee, 2009). Thus, $q = S*a_h*a_v = 1*1*0.21=0.21$.

Results

Model Evaluation

GOA Status Quo – Spiny Dogfish Model 15.3A

The GOA spiny dogfish Model 15.3A updated random effects (RFX) biomass estimate (31,243 t) increased 25% from the 2020 assessment value (23,289 t, Tribuzio et al. 2020 and Table 19.10 and Figure 19.6). The increase was due to a substantial increase of the Eastern GOA biomass estimate, from 9,917 t to 18,494 t (Table 19.10 and Figure 19.6). There are no alternative models presented for GOA spiny dogfish

FMP	Approach	Model	F_{OFL}	F_{ABC}	B_{RFX} (95% CI)	Ba (95% CI)	OFL (95% CI)	ABC (95% CI)
GOA	RFX	SD15.3A	0.04	0.03	31,243 (22,613-43,166)	148,775 (107,681-205,551)	5,951 (4,307-8,222)	4,463 (3,230-6,167)

Tier 6 Status Quo

Standard quantitative metrics (e.g., retrospective analysis, AIC, etc.) are not applicable for the Tier 6 models presented here. However, qualitative discussions are useful.

In the status quo BSAI Tier 6 model (16.0), the OFL equals the maximum historical catch of the full complex, whereas the status quo GOA Tier 6 model (11.0) is the summed species-specific OFLs, which are equal to the mean catches for the individual Tier 6 species. Results of the status quo Tier 6 models are below.

FMP	Tier 6 Model	OFL	ABC
BSAI (full complex)	16.0	689	517
GOA (Tier 6 species only)	11.0	570	427

For the GOA, the above tables summarize for the complex as:

Species	Tier	Model	OFL	ABC
Pacific Sleeper	6	11.0	312	234
Salmon	6	11.0	70	53
Other/Unid	6	11.0	188	141
Spiny Dogfish	5	SD15.3A	5,951	4,463
Shark Stock Complex			6,521	4,891

Maximum and average historical catch methods are generally not recommended for data-limited species due the high likelihood of a species becoming overfished (e.g., Carruthers et al. 2014). This is particularly problematic for long-lived, slow-growing, low-productivity species. The time series used for determining ABC/OFL should encompass a time when the stock shows no evidence of decline (Restrepo et al. 1998, Berkson et al. 2011), which is potentially violated for the GOA and BSAI Pacific sleeper shark (Appendix 19D, see IPHC survey data). To mitigate this risk, the ORCS approach uses qualitative information to classify stocks and apply scalars that result in reduced risk of overfishing. This approach is robust to misspecification, an improvement over traditional catch-scalars because the approach incorporates recent and relevant information and is a more appropriate tool for data-limited stocks (Berkson et al. 2011, Free et al. 2017).

Pacific sleeper shark Only Reliable Catch Stock (ORCS)

The attribute scores and justifications for the BSAI and GOA Pacific sleeper shark stock are summarized in Table 19.9 and described in detail below. Because of the continuity of the stock between FMPs and the potential for significant life history connections between the stocks (see Appendix 19A for Pacific sleeper shark stock structure analysis), we present the attribute justifications together.

ORCS Attribute #1 – Status of assessed stocks in fishery
The catch of BSAI Pacific sleeper shark is distributed across multiple fisheries, with 77%, on average, of the catch from the last five years being in walleye pollock and Pacific cod fisheries. Similarly, in the GOA, catch occurs in multiple fisheries, but 75%, on average, occurs in the Pacific halibut and other flatfish fisheries. We reviewed the most recent stock assessments for each of those fisheries and none of them are either overfished or recently experienced overfishing (Figure 2 in each SAFE intro, NPFMC 2021a, NPFMC 2021b). Because 0% of the fishery stocks in either FMP are overfished, they are below the <10% threshold and this attribute was given a score of 1 for each FMP.

ORCS Attribute #2 – Behavior affecting capture
Limited data are available to identify behavior. The Pacific sleeper shark stock structure document (Appendix 19A of this document) identified potential for nursery aggregations in the BSAI. While the species is caught in both trawl and longline gears, there is generally not a large number of animals caught together. A few exceptions to this have been documented where some hauls may have caught many small Pacific sleeper sharks, but that appears to be a rare occurrence. The life history potential for nursery aggregations or other life history considerations are accounted for in Attribute #13. This attribute was given a score of 2 in both FMPs because sufficient data are available to infer that the species does not exhibit significant schooling/shoaling/aggregations in either FMP.

ORCS Attribute #3 – Discard rate
All sharks are almost exclusively discarded. Over the last 5 years (2017-2021) the average discard rate for Pacific sleeper shark in the BSAI was 88% and 99% in the GOA (Table 19.4). This attribute was scored as 3 for both FMPs because nearly all Pacific sleeper shark catch is discarded.

ORCS Attribute #4 – Targeting intensity
All sharks are non-targeted and strictly incidental bycatch and this attribute was scored 1 for both FMPs.

ORCS Attribute #5 – M compared to dominant species
On average, 77% of the Pacific sleeper shark catch in the BSAI occurs in the Pacific cod and pollock fisheries. For the BSAI evaluation, Pacific cod and pollock are considered the dominant species of the catch. The most recent stock assessments for each of these species were reviewed. The most recent M value for BSAI Pacific cod was 0.34 (Thompson et al. 2021) and 0.30 for BSAI pollock (Ianelli et al. 2021). In the GOA, 75% of the catch occurs in the Pacific halibut and other flatfish fisheries and these species are considered the dominant species. The most recent flatfish M values in the GOA range from 0.113 (Deep Water Flatfish complex, McGilliard and Palsson 2021) to 0.35 (arrowtooth flounder, Shotwell et al. 2021) and the Pacific halibut M value ranges from 0.15 to 0.22 (IPHC 2022) There is not an estimate of M available for Pacific sleeper shark, however using the potential maximum age from Greenland shark (352 years, Greenland shark, Nielsen et al. 2016) and pilot ageing results from Alaskan Pacific sleeper shark (35 years for an immature Pacific sleeper shark, Tribuzio unpublished data)

produces a plausible range of 0.015 < M < 0.15, assuming the proxy maximum ages (35 and 352) and the Hamel maximum age method for estimating M (Hamel 2015). Given that the Alaskan pilot study data were from an immature specimen, it is likely that the upper limit of M is an overestimate. The range of M from these proxy data are at least 20% lower than the dominant species M in the BSAI and are likely 20% lower than the dominant species M in the GOA. The score for this attribute is 3 for both FMPs because Pacific sleeper shark M is likely at least 20% lower that the M values of the dominant species fisheries which catch Pacific sleeper shark.

ORCS Attribute #6 – Occurrence in catch
Pacific sleeper shark occur in about 1% of observed hauls in the BSAI fisheries and about 1.5% of observed hauls in the GOA (Data queried from the AKRO via AKFIN 10/1/2022). This attribute is scored 1 for both FMPs.

ORCS Attribute #7 – Value
Sharks have no market value in Alaska, and sales, if any, are generally for fish meal at a low value (A. Abelman, AFSC, pers comm.). This attribute is scored 1 for both FMPs. Ex-vessel value data queried from the AKRO via AKFIN October 1, 2022.

ORCS Attribute #8 – Recent trend in catch
The Theil-Sen regression of the last five years of catch of Pacific sleeper shark in either FMP showed no trend in catch (Table 19.3 and Figure 19.2). This attribute is scored 2 for both FMPs.

ORCS Attribute #9 – Habitat loss
The species does not occupy any of the threatened habitats identified. Because of the broad geographic range of the species over its life history (i.e., nearshore environments to benthos), it is unlikely to spend significant portions of its life in threatened habitats. This attribute is scored 1 in both FMPs.

ORCS Attribute #10 – Recent trend in effort
The Pacific sleeper shark is a bycatch-only species that is not retained. It is not desirable, however, it is generally not actively avoided either. Standardized effort metrics are not available at this time. Using the proportion of observed hauls which reported Pacific sleeper sharks as a metric for effort, the Thiel-Sen regression found no significant trends in either FMP (Data queried from the AKRO via AKFIN 10/1/2022). This attribute was scored 2 for both FMPs.

ORCS Attribute #11 – Recent trend in abundance index
The IPHC survey provides the best fishery-independent index for the species (Table 19.6 and Figure 19D.3). The relative population numbers are an area-weighted CPUE index. The IPHC began an alternative spatially adaptive sampling grid in the BSAI in 2021 and it is unclear how to interpret the new sampling regime with respect to Pacific sleeper shark in the BSAI. Further, there was no survey in 2020. Therefore, the most recent available survey data in the BSAI are from 2019 and the index is not informative in the BSAI without further analyses. Data are available to inform abundance index trends in the GOA. The Thiel-Sen regression of the most recent 5 years of GOA data found no significant trend in the abundance index (Data queried from AKFIN 10/1/2022). Due to the lack of informative recent survey data in the BSAI, the attribute was scored NA for the BSAI. For the GOA, the attribute was scored 2.

ORCS Attribute #12 – Proportion of population protected
The Pacific sleeper shark does not have specific protection measures in place in either FMP. Catch limits are for the complex as a whole. There are no size limits, protected areas or seasonal closures in place for this species. It is possible that some of the management actions for the directed fisheries may impact the Pacific sleeper shark stock, but data are insufficient to make inferences regarding any secondary protections from which Pacific sleeper sharks may benefit. There are restrictions against sharks becoming a targeted species. This attribute is scored 3 for both FMPs.

ORCS Attribute #13 – Life history considerations

The species has a high productivity-susceptibility analysis (PSA) score in both FMPs (Ormseth and Spencer 2011) and life history characteristics that are consistent with low productivity. Based on pilot studies of the Pacific sleeper shark and proxy data from a closely related species, Greenland shark, the Pacific sleeper shark has extreme longevity, matures late, and likely has long generation times (Tribuzio unpublished data, Nielsen et al. 2016 and Nielsen dissertation). Due to the maximum size of the species and the length data available, it appears that most of the catch occurring in the BSAI is on very young Pacific sleeper sharks and likely immature sharks in the GOA (Appendix 19A). Given these characteristics, and studies on other shark species, it is a reasonable assumption that fishing on immature stages results in the greatest risk of overfishing (Tribuzio and Kruse 2011 and others). This attribute is scored 3 in both FMPs.

The mean attribute score for each FMP was 1.92, classifying the Pacific sleeper shark in each FMP as "fully exploited", i.e., the biomass is not below B_{MSY}. This classification is warranted given the data available. While there are substantial concerns regarding recruitment overfishing and the high proportion of immature Pacific sleeper sharks in the catch and the likely low productivity of the species, data are insufficient to classify the species as "overexploited". During the scoring process the authors conducted sensitivity trials to determine what scoring would force the stock status to change. In order for the stock to be classified as overexploited, many of the attribute scores would have to have been scored in such a way that they would be unsupported by the information available.

The OFL is based on the 25th percentile of the previous 10 years of catch and scaled by a factor of 2.16 to be consistent with the NPFMC Tier 6 structure where the OFL has an approximately 50% risk of overfishing. For comparison to the below table, if the Pacific sleeper shark were to be classified as overexploited, the ABC/OFL would be 52 t/73 t and 70 t/97 t in the BSAI and GOA, respectively.

As per Amendment 56, the Tier 6 ABC can be set less than, or equal to 75% of the OFL. The buffer between OFL and ABC is intended to capture management and model uncertainty, and 75% was a default value initially recommended for species that are at or above B_{MSY} (Restrepo et al. 1998). Given the ORCS determined stock status of both Pacific sleeper shark stocks, we continue to recommend that ABC = 0.75*OFL. The appropriateness of 75% for lower productivity stocks, or the question if that buffer adequately captures the uncertainty is worthy of further discussions. That analysis is beyond the scope of the shark stock complex assessments as it would impact multiple assessments over a range of stocks.

FMP	Approach	Model	Mean Attribute Score	Status	Catch Statistic	50th scalar	OFL	ABC
BSAI	ORCS	PSS22.0	1.92	Fully exploited	54	2.16	117	88
GOA	ORCS	PSS22.0	1.92	Fully exploited	91	2.16	197	148

<u>BSAI spiny dogfish and GOA/BSAI other/unidentified sharks 90th percentile</u>

The 90th percentile model was applied to rare shark species, which are the Other/Unidentified sharks in both FMPs and spiny dogfish in the BSAI. The ABC is 75% of the OFL and model results are presented below.

FMP	Species	Approach	Model	OFL	ABC
BSAI	Other/Unid	90th Percentile	OS22.0	55	41
BSAI	Spiny Dogfish	90th Percentile	SD22.0	20	15
GOA	Other/Unid	90th Percentile	OS22.0	123	92

BSAI - Harvest Recommendations

We recommend harvest specifications for the BSAI shark stock complex based on the alternative models described above. We have not evaluated any alternative models for the salmon shark; however, if the alternative models presented here are accepted, the result will require that species-specific ABC/OFLs be estimated and summed for the complex level ABC/OFL, which is a change from status quo. The status quo BSAI model considers the complex as a whole, not as the sum of the individual species. The proposed models will result in an OFL that is the sum of the individual species, thus, the species-specific salmon shark maximum historical catch would be included.

The harvest recommendations for the BSAI shark stock complex are below. Note that the model numbers have changed from the document presented to the September Plan Team to be more logical within each FMP.

Species	Model	Catch Statistic	OFL (t)	ABC (t)
Pacific Sleeper Shark	PSS22.0	54*2.16	117	88
Salmon Shark	SS22.0	199	199	149
Other/Unidentified Sharks	OU22.0	55	55	41
Spiny Dogfish	SD22.0	20	20	15
Shark Stock Complex			391	293

Historical catch has not exceeded the recommended shark stock complex ABC in the last 15 years.

Amendment 56 Reference Points
The BSAI sharks is a Tier 6 complex, thus the only reference points are those which are used to set the Tier 6 OFL.

Specification of OFL and Maximum Permissible ABC

Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
Tier	6	6	6	6
OFL (t)	689	689	**391**	391
maxABC (t)	517	517	293	293
ABC (t)	517	517	**293**	293

Harvest Recommendations (GOA)

We recommend the status quo model for GOA spiny dogfish, updated with the 2021 GOA bottom trawl survey data:

Model	F_{OFL}	F_{ABC}	B_{RFX} (95% CI)	Ba (95% CI)	OFL (95% CI)	ABC (95% CI)
15.3A	0.04	0.03	31,243 (22,613-43,166)	148,776 (107,681-205,551)	5,951 (4,307-8,222)	4,463 (3,230-6,167)

For the Tier 6 component of the GOA shark stock complex, we recommend the alternative models for the Pacific sleeper shark and the other/unidentified sharks. We did not evaluate any alternative models for salmon shark and therefore recommend status quo for that species. The GOA Tier 6 harvest recommendations are below. Note that the model numbers have changed from the document presented at the September Plan Team to be more logical within each FMP.

Species	Model	Catch Statistic	OFL (t)	ABC (t)
Pacific Sleeper Shark	PSS22.0	91*2.16	197	148
Salmon Shark	SS11.0	70	70	53
Other/Unidentified Sharks	OU22.0	123	123	92

The harvest recommendations for the GOA shark stock complex are below. Historical catch is well below the recommended ABC.

	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other/Unid Sharks	Shark Stock Complex
OFL	5,951	197	70	123	6,341
ABC	4,463	148	53	92	4,756

Amendment 56 Reference Points

The GOA shark stock complex is a Tier 5/6 complex, however there is only one OFL and ABC set for the full complex. The Amendment 56 reference points are for the full complex, but we provide the individual species values to show how the complex reference points are generated.

Specification of OFL and Maximum Permissible ABC

GOA Shark Stock Complex Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
Tier	5/6	5/6	5/6	5/6
OFL (t)	5,006	5,006	**6,341**	6,341
maxABC (t)	3,755	3,755	4,756	4,756
ABC (t)	3,755	3,755	**4,756**	4,756

Risk Table and ABC Recommendation

Overview

The following template is used to complete the risk table:

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very	Stock trends are highly unusual; very rapid	Multiple indicators showing consistent adverse signals a) across the same	Multiple indicators showing consistent adverse signals a) across

	poor fits to data; high level of uncertainty; strong retrospective bias.	changes in stock abundance, or highly atypical recruitment patterns.	trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment Considerations

The GOA spiny dogfish are managed under a Tier 5 assessment model. The assessment model accounts for the productivity of the stock and incorporates life history information. However, at this time the model is based on the AFSC bottom trawl survey, which does not sample the species well. Research is ongoing to incorporate data from more informative surveys. Another concern regarding the spiny dogfish assessment relates to catch in unobserved/unreported ADFG managed fisheries that can be substantial and is not accounted for. This species is highly mobile and moves between management areas often; thus catch in ADFG managed fisheries impacts the GOA stock. While these are major considerations for the spiny dogfish assessment, they are not emergent and efforts are ongoing to address these issues. For that reason, we consider the spiny dogfish assessment risk to be Level 1.

The Tier 6 species, both in the BSAI and GOA, are severely data-limited and the assessment does not incorporate life history or any other biological information in the OFL/ABC calculations. For non-targeted, low value (i.e., discarded) species, a catch-scalar approach may suffice if the species is sufficiently productive to be sustainably harvested at that rate. For Pacific sleeper sharks, in particular, it is unclear how productive the species is, and indications are that it is highly vulnerable to overfishing.

Further, the vast majority of the catch occurs on immature animals, which carries a high risk of overfishing for lower productivity species. There are concerns over the accuracy of the catch estimates due to the difficulty in sampling such large species. Lastly, as demonstrated in the stock structure analysis in Appendix 19A, the catch occurring in the BSAI is composed of a large number of small Pacific sleeper sharks and genetic analyses have identified sibling pairs in the BSAI, which, taken together suggest significant life history residence areas, possibly nursery habitat in the BSAI. The proposed model alternative for Pacific sleeper shark would incorporate life history and biological information. The remaining species are of lesser concern due to their rarity or likely productivity. If the proposed model for Pacific sleeper shark is adopted, the Assessment Considerations level would be ranked as 1. If status quo is retained, we rank assessment considerations as 3 because of the concerns over the productivity of the Pacific sleeper shark which are not included in the assessment method.

Population Dynamics Considerations

The spiny dogfish survey trends appear to be stable. With the exception of the ADFG Southeast Alaska longline survey (Figure 19D.2), all surveys show highly variable indices with no apparent trends. The ADFG longline survey CPUE has been consistently declining for over 10 years. However, that survey samples a relatively small portion of the stock's range and may be reflecting local abundances as opposed to stock trends. The ADFG longline survey is not incorporated in the assessment model, but is informative for the species. Tagging data have shown that spiny dogfish are highly mobile and move easily between management jurisdictions (Tribuzio unpublished data). Spiny dogfish population dynamics risk is considered Level 1.

The IPHC longline survey index is incorporated in the proposed alternative model for Pacific sleeper shark in the GOA. If the model alternative is accepted, then the index in the GOA is no longer a risk table consideration. The Pacific sleeper shark RPNs declined from their peak at the beginning of the time series and have remained low since 2004. This trend is mirrored in other regions (e.g., GOA, Canada and U.S. West Coast) of the IPHC survey and in other surveys, such as the ADFG Southeast Alaska longline survey. It is unclear if the peak at the beginning of the time series was unusual, or if the current low state reflects low population sizes. The proposed alternative model only considers recent trends in abundance. Because of the likely low productivity of the stock and the continued decline in the ADFG longline survey, the sharp declines in the early part of the time series are concerning, however, as noted, it is unclear how to interpret those trends. We continue to rank Pacific sleeper shark in both FMPs as level 2 for Population Dynamics Considerations.

Environmental/Ecosystem Considerations (contributions from Ebett Siddon, Bridget Ferris and Ivonne Ortiz)

Data are insufficient on linkages between shark productivity and ecological or other extrinsic factors. However, we summarize recent trends in environmental processes and potential trophic connections that may be relevant for sharks in the BSAI and GOA FMP areas.

Environmental processes:
Thermal conditions in the BSAI and GOA were moderate in 2022, not considered a limiting factor for highly mobile sharks that are able to shift distributions with temperatures. The extended warm phase experienced by the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022). Thermal conditions in the GOA were moderate in 2022. The 2022 conditions in the BSAI and GOA are not considered a limiting factor for highly mobile sharks that are likely able to shift distributions with temperatures (Tribuzio unpublished data, Hulbert et al. 2006, Sigler et al. 2006, Weng et al. 2004, Garcia et al. 2021).

Prey:
Sharks are opportunistic feeders and species may have the ability to prey switch depending on what is available. Preferred prey items vary by species and size. Sleeper sharks feed on squid, fish (e.g., salmon, pollock), and mammals (e.g., Steller sea lions [SSLs]). Salmon sharks are almost exclusively fish eaters (salmon, fish, forage fish), but do consume some squid. Spiny dogfish are highly generalized feeders from small invertebrates to larger fish (Tribuzio et al. 2017). No information is available on the abundance trends of squid or SSLs in the EBS. Within the Aleutian Islands, sea lion counts remained stable from 2002 to 2018 with increases in non-pup and pup counts in the eastern AI offsetting the stability in non-pups and decline in pups in the central and declines in the western Aleutians (Sweeney and Gelatt, 2018). North of the eastern Aleutians and the slope/souther outer shelf of the EBS (NMFS areas 517 and 519) squid bycatch has increased since 2019 offsetting the decrease in bycatch in NMFS area 518 (Orsmeth and Yasumiishi 2021). Abundance trends of fish as prey for sharks are mixed, though largely average to above average for 2022. Foraging guild information is derived from NOAA AFSC's standard bottom trawl survey. The pelagic foragers guild increased sharply from 2021 to 2022, up more than 70%, to just below their long-term mean. The trend in the pelagic forager guild is largely driven by walleye pollock and Pacific herring. The biomass of apex predators increased from 2021 to 2022 and is nearly equal to their long term mean. The trend in the apex predator guild is largely driven by Pacific cod and arrowtooth flounder (Whitehouse 2022). In the AI however, apex predators decreased 18% in 2022, compared to 2018 driven by lower biomass of all predators except for large sculpins (Ortiz 2022). The abundance trends of salmon stocks vary, from record run sizes of Bristol Bay sockeye salmon (Cunningham et al. 2022) to adult run failures in the Arctic-Yukon-Kuskokwim river drainage system (Whitehouse 2022b).

Foraging conditions for sharks in the GOA were above average in 2022, but there were concerns of prey availability along the shelf edge and slope habitat. The GOA is potentially above average in productivity and prey availability in 2022, beneficial to opportunistic shark predators. Forage fish biomass (key prey for dogfish) was above average in 2022, with continued high herring biomass in southeast GOA (Hebert 2022) and above average piscivorous seabird reproductive success across the GOA (Drummond and Renner 2022 and Hatch et al. 2022). Salmon (one of key prey for salmon sharks) had below average returns in 2022, including reduced chum and coho salmon, and low, even year returns of pink salmon. Groundfish biomass trends vary by species but overall biomass caught by trawl surveys remains relatively constant (AFSC bottom trawl survey 2021, Whitehouse 2021) or increasing (ADF&G trawl survey 2022, Worton 2022). Trends in squid biomass are unknown. Sleeper sharks have been reported to feed on Steller sea lions in the GOA (Horning and Mellish, 2014). Steller sea lion pups have been generally increasing in the western GOA since 2002, but remain well below previous peaks, and pups remain elevated in the eastern GOA but have been slightly decreasing since 2010 (Sweeney 2022).

Competitors and Predators
Little information on predators of the shark complex exist. Sharks are likely preyed upon by larger sharks, predatory fish species (e.g., lingcod preying on small spiny dogfish) and predatory mammals. There are no indicators of predation upon sharks except indirect evidence of killer whale presence in the Bering Sea based on depredation noted during the NOAA AFSC longline survey. While rates of depredation increased from 1997 - 2009, depredation interactions remained relatively consistent from 2009-2021 (Siwicke, pers. comm.), suggesting no increased predation on sharks by killer whales.

There is no cause to suspect increased predation or competition on the shark complex in the GOA, although information is limited. Trends in offshore orca populations, known shark predators, are unknown.

Due to the fact that there are little to no empirical linkages between sharks in Alaskan waters and ecosystem processes, we assign this as a level 1.

Fishery Performance

Defining fishery performance indicators is difficult for non-targeted, low retention species, especially when confounded with concerns over accuracy of catch estimates. We examined the mean catch weight of sharks per trip (or more accurately by landings event) by species as a possible index of fishery performance through time, with one caveat being that average weight may fluctuate through time.

Within the BSAI, Pacific sleeper sharks mean catch per trip has been flat or variable with no apparent trend since 2010, however, current levels (~0.05 t per trip) are substantially lower than those in the earlier part of the time series (~0.17 t per trip). When examining mean catch per trip of Pacific sleeper sharks by gear and target fishery, there are some trends. Initially, the greatest mean catches were from longline fisheries (primarily Pacific cod), but over the last ten years the greatest mean catch has been in the non-pelagic trawl fisheries (primarily Atka mackerel *Pleurogrammus monopterygius* and flatfish). The non-pelagic trawl walleye pollock fishery mean catch per trip has declined steeply since 2016. The mean catch per trip of salmon shark has been increasing within the walleye pollock fisheries (pelagic trawl gear in particular) since 2010. Spiny dogfish are sparse in the BSAI and were not evaluated. In summary, if the mean catch of sharks per trip is considered an indicator of fishery performance, then Pacific sleeper shark is currently stable and salmon shark is increasing.

Within the GOA, only spiny dogfish mean catch per trip, although variable, showed any trend: increasing on average since 2003. This trend somewhat mirrors total catch, however, when total catch is broken into pre- and post-observer restructuring, the catch trends in each time period are flat. When examining mean catch per trip of spiny dogfish by gear and target fishery, it is evident that the increasing trend is primarily in the longline fisheries for Pacific halibut and Pacific cod. This trend could be due in part to the increased observer coverage resulting from the 2013 observer restructuring. There has also been a substantial increase in the mean catch per trip of Pacific sleeper shark in the GOA Pacific halibut longline fishery since 2017, although there is no overall trend for all fisheries combined.

The fishery performance indicators are a risk level 1 for both FMPs.

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: No increased concerns	Level 2: Substantially increased concerns	Level 1: No increased concerns	Level 1: No increased concerns

With the author recommended models, the above levels of concern do not warrant an ABC reduction below the maximum permissible ABC at this time for either the BSAI or the GOA shark stock complexes. However, if status quo methods are retained, a reduction from maximum ABC may be warranted due to the concerns the assessment related considerations for Pacific sleeper shark.

Status Determination

Overfishing is not occurring in either the BSAI or GOA because catch has not exceeded the OFL for this for either complex. Data are insufficient to determine stock status.

Status	As determined *last* year for: 2020	2021	As determined *this* year for: 2021	2022
Overfishing	No	n/a	No	n/a

Ecosystem Considerations

The ecosystem considerations for the BSAI and GOA shark stock complex are summarized in Table 19.11

Ecosystem Effects on Stock

Pacific sleeper shark

There are few formal diet studies on Pacific sleeper sharks, but most evidence collected to date suggests they are opportunistic feeders with a varied diet, fulfilling ecological roles as both active predators and facultative scavengers. Pacific sleeper sharks were once thought to be relatively sedentary and benthic because their stomachs commonly contain offal, cephalopods, and bottom-dwelling fish such as flounder (*Pleuronectidae*) (e.g., Yang and Page 1999). However, prey from different depths, such as giant grenadier (*Albatrossia pectoralis*) and pink salmon (*Oncorhynchus gorbuscha*), have been documented in the stomachs of a single shark, indicating that they make depth oscillations in search of food (Orlov and Moiseev 1999). Other diet studies have found that Pacific sleeper sharks prey on fast-moving fish such as salmon (*O.* spp.*)* and tuna (*Thunnus* spp.), and marine mammals such as harbor seals (*Phoca vitulina*), that live near the surface (e.g., Bright 1959; Ebert et al. 1987; Crovetto et al. 1992; Sigler et al. 2006), suggesting that these sharks may not be as benthic-oriented as once thought. These studies are corroborated by tagging efforts demonstrating that sleeper sharks make diel vertical movements, remaining at depth during the day and rising towards the surface at night (Hulbert et al. 2006). Recent research using stable isotope concentrations in both liver and muscle tissue determined that Pacific sleeper sharks likely obtain a significant portion of their energy from lower trophic prey (teleost fish), but that they also feed on prey from a wide variety of trophic levels (Schaufler et al. 2005, Courtney and Foy 2012). Pacific sleeper sharks go through an ontogenetic shift in their diet, indicated by an increase in their trophic level with increasing body size (Sigler et al. 2006, Courtney and Foy 2012). Pacific sleeper sharks use suction-feeding and may be effective ambush predators of faster-moving prey (Ebert et al. 1987, Bizzarro et al. 2017). One tagging study has provided evidence of predation by Pacific sleeper sharks upon Steller sea lions *Eumetopias jubatus* (Horning and Mellish 2014), though other studies suggest these predation events may be rare (Loughlin and York 2000, Sigler et al. 2006). Pacific sleeper sharks have also been observed feeding on or near whale falls (Smith et al. 2002). Overall, cetaceans and fish are likely important components of the diet (Schaufler et al. 2005, Sigler et al. 2006). Similar to spiny dogfish, fluctuations in environmental conditions and prey availability may not significantly affect this species because of its wide dietary niche.

The only known predator of Pacific sleeper sharks is the killer whale (*Orcinus orca*). One study observed two predation events of the 'offshore' orca ecotype on Pacific sleeper sharks in British Columbia and Prince William Sound (Ford et al. 2011). In each event, multiple individual sharks were identified from prey remains using DNA. This is likely a specialized behavior in specific areas where the sharks must swim shallow to pass over sills between water bodies, which puts them within the diving range of the orca. Ford et al. (2011) suggested these orcas may selectively feed on the liver of the sleeper sharks, as its large size (20% of shark body mass) and rich lipid content make it a valuable food source for orcas. Mulitple similar incidents have been reported to occur in or near Resurrection Bay, Alaska (M. Horning, Alaska Sea Life Center, pers comm). Incidents of Steller sea lions feeding on what appeared to be Pacific sleeper shark liver have been reported in Southeast Alaska, near Juneau, but identity of the prey was not confirmed, nor was it able to be confirmed if the sea lions predated or were opportunistically scavenging (J. Moran, NMFS, AFSC pers. comm.).

Data suggest that most of the Pacific sleeper sharks caught in the BSAI and GOA are immature and there is no information on pupping, mating, or gestation, so it remains unknown how the fishery affects their recruitment.

Salmon Shark

Salmon sharks are broadly dispersed, highly mobile, and have the ability to migrate long distances among ecoregions within the North Pacific Ocean (Weng et al. 2008). Salmon sharks are opportunistic feeders, sharing the highest trophic level of the subarctic Pacific food web with marine mammals and seabirds (Brodeur 1988, Nagasawa 1998, Goldman and Human 2004). They feed on a wide variety of prey, from squid and shrimp to salmon (*Oncorhynchus* spp.) and rockfishes (family Sebastidae) and even other sharks (Sano 1962, Hart 1973, Compagno 1984, Nagasawa 1998), but primarily (>70% of diet) consume fish (Bizzarro et al. 2017). The species is a significant seasonal predator of returning salmon in some areas such as Prince William Sound (Hulbert et al. 2005), and there is evidence that salmon shark predation may also represent a significant source of mortality in immature or maturing Chinook salmon and other salmon species in oceanic waters of the GOA and BSAI (Nagasawa 1998, Seitz et al. 2019). To the best of our knowledge, there are no known predators of salmon sharks, though orcas have been known to kill and consume other related mobile large sharks such as the white shark (Pyle et al. 1999).

Like many other shark species, salmon sharks undergo an ontogenetic shift in diet and habitat use (Carlisle et al. 2015a). Salmon shark are endothermic, which enables them to have a broad thermal tolerance range and inhabit highly varying environments. Because of this ability, it has been presumed that they can adapt to changing climate conditions and prey availability. However, there is some evidence that juveniles may have a narrower thermal tolerance than adults and may be more likely to become stranded following upwelling events (Carlisle et al. 2015b). Furthermore, salmon sharks in the California Current are predicted to experience habitat loss due to anticipated changes in temperature and chlorophyll (Hazen et al. 2012).

Salmon sharks generally mate in the fall and give birth the following spring (Conrath et al. 2014). Much of the salmon shark catch in the BSAI occurs in the summer months after pupping.

Spiny dogfish

Previous studies have shown spiny dogfish to be generalist opportunistic feeders that are not wholly dependent on one food source (Alverson and Stansby 1963). Spiny dogfish make seasonal migrations for feeding (McFarlane and King 2003), and consequently, impacts of predation upon community structure by this top predator may not be felt uniformly across time and space (Andrews and Harvey 2013). Spiny dogfish are known to group-feed on schools of forage fish (Bizzarro et al. 2017). Small dogfish are limited to consuming smaller fish and invertebrates, while larger animals eat a wide variety of foods (Bonham 1954). In the GOA, preliminary diet studies further suggest that spiny dogfish are highly generalized, opportunistic feeders (Tribuzio, unpublished data). Thus, fluctuations in environmental conditions and prey availability likely have little effect on the species because of its ability to switch prey, although this also depends on the overall abundance of the prey species. In an analysis of climate forcing and fishing effects on North Pacific fish species, spiny dogfish was among the species believed to be least affected by environmental change, though due to inherently low productivity associated with its life history strategy, would likely not withstand heavy fishing pressure (Yatsu et al. 2008).

The primary predators of spiny dogfish are other sharks, but data suggest other potential predators could be orcas, lingcod (*Ophiodon elongatus*), and halibut (Tribuzio, unpublished data). Pinnipeds including harbor seals, California sea lions (*Zalophus californianus*), and Steller sea lions have also been known to consume spiny dogfish, with representation in the diet varying seasonally (Trites et al. 2007, Weise and Harvey 2008, Bromaghin et al. 2013).

It is not well known if fishing activity occurs when and where sharks mate or pup. Spiny dogfish have an 18- to 24-month gestation period; therefore, fishing activity overlaps with reproduction regardless of when it occurs.

Fishery Effects on Ecosystem

Because there has been virtually no directed fishing for sharks in Alaska, the reader is referred to the discussion on Fishery Effects in the SAFE reports for the target species that generally have the greatest shark bycatches, Pacific cod and walleye pollock. It is assumed that all sharks presently caught in commercial fishing operations that are discarded do not survive. This could constitute a source of dead organic material to the ecosystem that would not otherwise be there but may have greater impacts due to the removal of a top predator. Removing sharks can have the effect of releasing competitive pressure or predatory pressures on prey species. Studies have shown that removal of top predators may alter community structure in complex and non-intuitive ways and that indirect demographic effects on lower trophic levels may occur (Ruttenberg et al. 2011).

Data Gaps and Research Priorities

Data limitations are severe for shark species in the BSAI and GOA, making effective management of sharks extremely difficult. Gaps include inadequate catch estimation (e.g., large-bodied, difficult to measure species), unreliable biomass estimates, lack of fishery size frequency collections, and a lack of life history information (e.g., length-at-age and maturity-at-length and -age), especially for Pacific sleeper sharks. It is essential to continue to improve the collection of biological data on sharks by fisheries observers and surveys. Future shark research priorities are:

1. Catch estimation for large, hard to measure species.
    a. Actions: Investigating catch in numbers for Pacific sleeper sharks and exploring management options.
    b. Actions: Funded study to examine using EM to improve catch estimates in numbers of large sharks.
    c. Actions: Ongoing project to examine how frequently “other” sharks are caught, and if species identifications can be improved.
2. Define the stock structure and migration patterns (i.e., tagging and genetic studies)
    a. Actions: Analyses of a tagging and migration study of spiny dogfish.
    b. Actions: Genetic stock structure study of Pacific sleeper shark using genomics and next generation DNA sequencing.
    c. Actions: Collaborating with ADFG on salmon shark tagging and migration studies.
3. Explore ageing methods for difficult to age species
    a. Actions: Pilot study is underway to examine using ^{14}C (bomb-radiocarbon) in the eye lens core of Pacific sleeper shark as an indicator of age. Proposals have been submitted to fully fund the study.
4. Investigate improved data-limited assessment methods.
    a. Actions: Working with DLM experts to develop an appropriate assessment for the Tier 6 sharks. While Pacific sleeper shark model changes were proposed in this assessment, the remaining Tier 6 species need to be evaluated.

Acknowledgments

We gratefully acknowledge the following for their timely and efficient work in providing data and information for shark species: the Groundfish Assessment Program for AFSC bottom trawl survey estimates; the International Pacific Halibut Commission for longline survey data; the Alaska Regional Office (NMFS) for estimates of commercial catch; Sarah Gaichas for catch estimates for 1997-2003; Bob Ryzner, Rob Ames, Jean Lee, Matt Callahan and Neils Leuthold (AKFIN, Pacific States Marine Fisheries

Commission) for a user-friendly portal to access Catch Accounting System data and multiple AFSC survey data sources; Bridget Ferris, Ivonne Ortiz, and Ebett Siddon (AFSC) for their contributions to the Ecosystem Considerations sections; Sarah Webster (ADFG) for the shark state-wide harvest survey/sport catch estimates.

Literature Cited

Alverson, D. L. and M. E. Stansby. 1963. The spiny dogfish (*Squalus acanthias*) in the northeastern Pacific. USFWS Spec Sci Rep-Fisheries. 447:25p.

Andrews, K. S., and C. J. Harvey. 2013. Ecosystem-level consequences of movement: seasonal variation in the trophic impact of a top predator. Marine Ecology Progress Series 473:247-260.

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.

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.

Bizzarro, J. J., A. B. Carlisle, W. D. Smith, and E. Cortes. 2017. Diet composition and trophic ecology of Northeast Pacific Ocean sharks. Pages 111-148 in S. E. Larson and D. Lowry, editors. Northeast Pacific Shark Biology, Research and Conservation, Part A.Bonham, K. 1954. Food of the dogfish *Squalus acanthias*. Fish Res Paper. 1:25-36.

Bonham, K. 1954. Food of the dogfish *Squalus acanthias*. Fish Res Paper. 1:25-36.

Bright, D.B. 1959. The occurrence and food of the sleeper shark, *Somniosus pacificus*, in a central Alaskan Bay. Copeia 1959. 76-77.

Brodeur, R.D. 1988. Zoogeography and trophic ecology of the dominant epipelagic fishes in the northern Pacific. *In* The biology of the subarctic Pacific. Proceedings of the Japan-United States of America seminar on the biology of micronekton of the subarctic Pacific (eds., T. Nemoto and W.G. Percy). Bulletin of Ocean Research Institute, University of Tokyo, No. 26 (Part II), 1-27.

Bromaghin, J. F., M. M. Lance, E. W. Elliott, S. J. Jeffries, A. Acevedo-Gutiérrez, and J. M. Kennish. 2013. New insights into the diets of harbor seals (*Phoca vitulina*) in the Salish Sea revealed by analysis of fatty acid signatures. Fishery Bulletin 111:13-26.

Campbell, R. and McKinstry, K. 2020. Temperature trends in the near surface waters of Prince William Sound. In Ferriss, B., and Zador, S., 2020. Ecosystem Status Report 2020: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501

Carlisle, A. B., C. R. Perle, K. J. Goldman, B. A. Block, and J. M. Jech. 2011. Seasonal changes in depth distribution of salmon sharks (*Lamna ditropis*) in Alaskan waters: implications for foraging ecology. Canadian Journal of Fisheries and Aquatic Sciences 68:1905-1921.

Carlisle, A. B., K. J. Goldman, S. Y. Litvin, D. J. Madigan, J. S. Bigman, A. M. Swithenbank, T. C. Kline, Jr., and B. A. Block. 2015a. Stable isotope analysis of vertebrae reveals ontogenetic changes in habitat in an endothermic pelagic shark. Proc Biol Sci 282:20141446.

Carlisle, A. B., S. Y. Litvin, E. L. Hazen, D. J. Madigan, K. J. Goldman, R. N. Lea, and B. A. Block. 2015b. Reconstructing habitat use by juvenile salmon sharks links upwelling to strandings in the California Current. Marine Ecology Progress Series 525:217-228.

Carruthers, T. R., A.E. Punt, C. J. Walters, A. MacCall, M. K. McAllister, E. J. Dick, and J. Cope. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fish. Res. 153:48-68.

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.

Conrath, C.L., C.A. Tribuzio, and K.J. Goldman. 2014. Notes on the reproductive biology of female salmon sharks in the eastern North Pacific Ocean. Transactions of the American Fisheries Society. 143:363-368.
Courtney, D. L. and R. Foy. 2012. Pacific sleeper shark *Somniosus pacificus* trophic ecology in the eastern North Pacific Ocean inferred from nitrogen and carbon stable-isotope ratios and diet. Journal of Fish Biology. 80:1508-1545.
Crovetto, A., J. Lamilla, and G. Pequeno. 1992. *Lissodelphis peronii,* Lacepede 1804 (Delphinidae, cetacean) within the stomach contents of a sleeping shark, *Somniosus cf. pacificus*, Bigelow and Schroeder, 1944, in Chilean waters. Mar. Mammal Sci. 8: 312-314.
Ebert, D. A. 2003. Sharks, rays, and chimaeras of California. University of California Press, Berkeley, CA.
Ebert, D.A., T.W. White, K.J. Goldman, L.J.V. Compagno, T.S. Daly-Engel and R.D. Ward. 2010. Resurrection and redescriptions of *Squalus suckleyi* (Girard, 1854) from the North Pacific, with comments on the *Squalus acanthias* subgroup (Squaliformes: Squalidae). Zootaxa. 2612:22-40.
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.
Fergusson, E., and M. Rogers. 2020. Zooplankton nutritional quality trends in Icy Strait, Southeast Alaska. In Ferriss, B., and Zador, S., 2020. Ecosystem Status Report 2020: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.
Ford, J.K.B., G.M. Ellis, C.O. Matkin, M.H. Wetklo, L.G. Barrett-Lennard and R.E. Withler. 2011. Shark predation and tooth wear in a population of northeastern Pacific killer whales. Aquatic Biology. 11:213-224.
Gasper, J.R. and G.H. Kruse. 2013. Modelling the spatial distribution of Pacific spiny dogfish (*Squalus suckleyi*) in the Gulf of Alaska using generalized additive and generalized linear models. Can. J. Fish. Aquat. Sci. 70:1372-1385.
Goldman, K.J. and Human B. 2004. Salmon shark, *Lamna ditropis*. *In* Sharks, rays and chimaeras: the status of the chondrichthyan fishes. (eds. Fowler, S.L., M. Camhi, G. Burgess, S. Fordham and J. Musick). IUCN/SSG Shark Specialist Group. IUCN, Gland, Switzerland, and Cambridge, UK.
Goldman, K.J. and J.A. Musick. 2006. Growth and maturity of salmon sharks in the eastern and western North Pacific, with comments on back-calculation methods. Fish. Bull 104:278-292.
Goldman, K. J., and J. A. Musick. 2008. The biology and ecology of the salmon shark, *Lamna ditropis*. Pages 95-104 in M. D. Camhi, E. K. Pikitch, and E. A. Babcock, editors. Sharks of the open ocean: Biology, fisheries and conservation. Blackwell Publishing, Oxford, UK.
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.
Hart, JL. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada (Bull. 180), Ottawa, Canada. 749 pp.
Hazen, E. L., S. Jorgensen, R. R. Rykaczewski, S. J. Bograd, D. G. Foley, I. D. Jonsen, S. A. Shaffer, J. P. Dunne, D. P. Costa, L. B. Crowder, and B. A. Block. 2012. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change 3:234-238.
Horning, M., and J. A. E. Mellish. 2014. In cold blood: evidence of Pacific sleeper shark (*Somniosus pacificus*) predation on Steller sea lions (*Eumetopias jubatus*) in the Gulf of Alaska. Fishery Bulletin 112:297-310.
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.
Hulson, P.J.F., C.A. Tribuzio, and K. Coutre. 2016. The use of satellite tags to inform the stock assessment of a data-poor species: estimating vertical availability of spiny dogfish in the Gulf of Alaska. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks.

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.

Ketchen, K. S. 1986. The spiny dogfish (*Squalus acanthias*) in the northeast Pacific and a history of its utilization. Can Spec Publ Fish Aquat Sci. 88:78p.

Kimmel, D., C. Harpold, J. Lamb, M. Paquin, and L. Rogers. 2019. Rapid zooplankton assessment in the western Gulf of Alaska. In Zador, S., and Yasumiishi, E., 2019. Ecosystem Status Report 2019: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Loughlin, T. R., and A. E. York. 2000. An accounting of the sources of Steller sea lion, *Eumetopias jubatus*, mortality. Marine Fisheries Review 62:40-45.

McFarlane. G.A., and J.R. King. 2003. Migration patterns of spiny dogfish (*Squalus acanthias*) in the North Pacific Ocean. Fishery Bulletin. 101:358-367.

Mecklenburg, C.W., T.A. Anthony, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda Maryland 1037 pp.

Murphy, J.M., R. Brenner, and B. Ferriss. 2020. Low Abundance of Gulf of Alaska Salmon in 2020. In Ferris, B., and Zador, S., 2020. Ecosystem Status Report 2020: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Nagasawa, K. 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus spp.*) in the North Pacific Ocean. Bulletin of the North Pacific Anadromous Fish Commission, No. 1:419-433.

Nakano, H., and K. Nagasawa. 1996. Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. Fisheries Science 62:860-865.

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.

Ormseth, O.A., P.D. Spencer. 2011. An assessment of vulnerability in Alaska groundfish. Fisheries Research. 112:127-133.

Pyle, P., M. J. Schramm, C. Keiper, and S. D. Anderson. 1999. Predation on a white shark (*Carcharodon carcharias*) by a killer whale (*Orcinus orca*) and a possible case of competitive displacement. Marine Mammal Science 15:563-568.

Rago, P. J. and K. A. Sosebee. 2009. The agony of recovery: Scientific challenges of spiny dogfish recovery programs. In: V. G. Gallucci, G. A. McFarlane, G. G. Bargmann (eds) Biology and Management of Dogfish Sharks. p. 343-372.

Rigby, C. L., D. Derrick, Y. V. Dyldin, D. A. Ebert, K. Herman, et al. 2021. *Somniosus pacificus*. The IUCN Red List of Threatened Species. Available at https://www.iucnredlist.org/species/161403/887942.

Ruttenberg B. I., S. L. Hamilton, S. M. Walsh, M. K. Donovan, A. Friedlander, et al. 2011. Predator-induced demographic shifts in coral reef fish assemblages. PLoS ONE 6(6): e21062. doi:10.1371/journal.pone.0021062

Sano, O. 1962. The investigation of salmon sharks as a predator on salmon in the North Pacific, 1960. Bulletin of the Hokkaido Regional Fisheries Research Laboratory, Fisheries Agency 24:148–162 (in Japanese).

Schaufler, L. R. Heintz, M. Sigler and L. Hulbert. 2005. Fatty acid composition of sleeper shark (*Somniosus pacificus*) liver and muscle reveals nutritional dependence on planktivores. ICES CM 2005/N:05.

Seitz, A. C., M. B. Courtney, M. D. Evans, and K. Manishin. 2019. Pop-up satellite archival tags reveal evidence of intense predation on large immature Chinook salmon (*Oncorhynchus tshawytscha*) in the North Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences 76:1-8.

Sigler M.F., L. Hulbert, C. R. Lunsford, N. Thompson, K. Burek, G. Corry-Crowe, and A. Hirons. 2006. Diet of Pacific sleeper shark, a potential Steller sea lion predator, in the north-east Pacific Ocean. J. Fish Biol. 69:392-405.

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.

Thoman, R. and J.E. Walsh. 2019. Alaska's changing environment: documenting Alaska's physical and biological changes through observations. H. R. McFarland, Ed. International Arctic Research Center, University of Alaska Fairbanks.

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 the 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. and G. H. Kruse. 2012. Life history characteristics of a lightly exploited stock of *Squalus suckleyi*. Journal of Fish Biology. 80:1159-1180.

Tribuzio, C.A., K. Echave, C. Rodgveller, J. Heifetz, K.J. Goldman. 2010a. Assessment of the sharks 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 2012. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. Pgs. 1451-1500.

Tribuzio, C.A., K. Echave, C. Rodgveller, P.J. Hulson. 2016. 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 2012. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. Pgs. 1915-1962.

Tribuzio, C. A., K. Echave, C. Rodgveller, and P. J. Hulson. 2018a. Assessment of the shark stock complex in the Bering Sea and Aleutian Islands. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK.

Tribuzio, C. A., C. Rodgveller, K. Echave, and P. J. Hulson. 2018b. Assessment of the shark stock complex in the Gulf of Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, AK.

Trites, A. W., D. G. Calkins, and A. J. Winship. 2007. Diets of Steller sea lions (*Eumetopias jubatus*) in Southeast Alaska, 1993−1999. Fishery Bulletin 105:234-248.

Verissimo, A., J.R. McDowell, and J.E. Graves. 2010. Global population structure of the spiny dogfish, *Squalus acanthias*, a temperate shark with an antitropical distribution. Molecular Ecology. 19:1651-1662.

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.

Watson, J. 2020. Satellite-derived sea surface temperature and marine heat waves in the Gulf of Alaska. In Ferriss, B., and Zador, S., 2020. Ecosystem Status Report 2020: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Weise, M. J., and J. T. Harvey. 2008. Temporal variability in ocean climate and California sea lion diet and biomass consumption: implications for fisheries management. Marine Ecology Progress Series 373:157-172.

Weng, K.C., A. Landiera, P.C. Castilho, D.B. Holts, R.J. Schallert, J.M. Morrissette, K.J. Goldman, and B.A. Block. 2005. Warm sharks in polar seas: satellite tracking from the dorsal fins of salmon sharks. Science 310:104-106.

Weng, K. C., D. G. Foley, J. E. Ganong, C. Perle, G. L. Shillinger, and B. A. Block. 2008. Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. Marine Ecology Progress Series 372:253-264.

Wood, C. C., Ketchen, K. S., and Beamish, R. J. 1979. Population dynamics of spiny dogfish (*Squalus acanthias*) in British Columbia waters. Journal of the Fisheries Research Board of Canada 36, 647-656.

Yang, M., and B.N. Page. 1999. Diet of Pacific sleeper shark, *Somniosus pacificus*, in the Gulf of Alaska. Fish. Bull. 97: 406-4-9.

Yatsu, A., K. Y. Aydin, J. R. King, G. A. McFarlane, S. Chiba, K. Tadokoro, M. Kaeriyama, and Y. Watanabe. 2008. Elucidating dynamic responses of North Pacific fish populations to climatic forcing: Influence of life-history strategy. Progress in Oceanography 77:252-268.

Tables

Table 19.1. Time series of Bering Sea/Aleutian Islands (BSAI) Other Species Total Allowable Catch (TAC), Other Species and shark catch, and Acceptable Biological Catch (ABC) for sharks and the shark stock complex (management method) for 1997-2022, BSAI. All data queried through AKFIN Oct 8, 2022.

Year	TAC	Est. other spp. catch	Est. shark catch	ABC	Management Method
1997	25,800	25,176	368	N/A	Other Species TAC
1998	28,800	25,531	497	N/A	Other Species TAC
1999	32,860	20,562	530	N/A	Other Species TAC
2000	31,360	26,108	590	N/A	Other Species TAC
2001	26,500	27,178	764	N/A	Other Species TAC
2002	30,825	26,296	1,362	N/A	Other Species TAC
2003	32,309	25,498	589	N/A	Other Species TAC
2004	27,205	29,455	515	N/A	Other Species TAC
2005	29,000	29,483	417	N/A	Other Species TAC
2006	29,000	27,018	689	N/A	Other Species TAC
2007	37,355	26,800	332	463	Other Species TAC
2008	50,000	29,474	194	463	Other Species TAC
2009	50,000	27,883	151	447	Other Species TAC
2010	50,000	23,374	61	449	Other Species TAC
2011	50		107	1,020	Shark Stock Complex TAC
2012	50		96	1,020	Shark Stock Complex TAC
2013	100		119	1,020	Shark Stock Complex TAC
2014	125		138	1,022*	Shark Stock Complex TAC
2015	125		109	1,022	Shark Stock Complex TAC
2016	125		135	1,022	Shark Stock Complex TAC
2017	125		143	517	Shark Stock Complex TAC
2018	180		103	517	Shark Stock Complex TAC
2019	180		151	517	Shark Stock Complex TAC
2020	150		180	517	Shark Stock Complex TAC
2021	200		221	517	Shark Stock Complex TAC
2022	500		123	517	Shark Stock Complex TAC

*The change from 1,020 t to 1,022 t was due to the Plan Team recommending and the SSC accepting the use of a rounded value in the assessments prior to the 2013 assessment. The rounded value was converted to the actual value for the 2014 fishery, as per the 2013 assessment.

Table 19.2. Time series of catch, total allowable catch (TAC), and acceptable biological catch (ABC) for sharks and Other Species in the Gulf of Alaska (GOA). Note that the decrease in TAC in 2008 was a regulatory change and not based on biological trends. The Other Species complex was dissolved and the shark stock complex was created for the 2011 fishery. Catches in state waters (Prince William Sound Inside, PWSI - NMFS area 649, and Southeast Inside, SEI - NMFS area 659) are also included, but are not used in calculations of ABC, nor do those catches count against the TAC. The column “Shark Catch GOA” only includes catch which counts against the TAC while the “Total Shark Catch” includes the state waters catch. Sources: TAC and Other Species catch from AKRO. Estimated shark catches from 1992-1996 from Gaichas et al. 1999, catches from 1997-2002 from Gaichas et al. 2003 and catches from 2003-2022 from AKRO Catch Accounting System (CAS, queried through AKFIN on October 8, 2022).

Year	TAC	Other Sp. Catch	Shark Catch GOA	Shark Catch INSD	Total Shark Catch	ABC	Management Method
1992	13,432	12,313	517			N/A	Other Species TAC (included Atka)
1993	14,602	6,867	1,027			N/A	Other Species TAC (included Atka)
1994	14,505	2,721	360			N/A	Other Species TAC
1995	13,308	3,421	308			N/A	Other Species TAC
1996	12,390	4,480	484			N/A	Other Species TAC
1997	13,470	5,439	1,041			N/A	Other Species TAC
1998	15,570	3,748	2,389			N/A	Other Species TAC
1999	14,600	3,858	1,037			N/A	Other Species TAC
2000	14,215	5,649	1,117			N/A	Other Species TAC
2001	13,619	4,801	853			N/A	Other Species TAC
2002	11,330	4,040	427			N/A	Other Species TAC
2003	11,260	6,266	715	35	750	N/A	Other Species TAC
2004	12,592	1,705	544	27	571	N/A	Other Species TAC*
2005	13,871	2,513	1,054	48	1102	N/A	Other Species TAC
2006	13,856	3,881	1,557	95	1652	N/A	Other Species TAC
2007	12,229	3,035	1,337	30	1367	1,792	Other Species TAC
2008	4,500	2,967	617	6	623	1,792	Other Species TAC
2009	4,500	3,188	1,741	101	1842	777	Other Species TAC
2010	4,500	1,724	716	18	734	957	Other Species TAC
2011	6,197	NA	523	8	531	6,197	Shark Complex TAC#
2012	6,028	NA	701	19	720	6,028	Shark Complex TAC
2013	6,028	NA	2,156	281	2,437	6,028	Shark Complex TAC
2014	5,989	NA	1,582	161	1,743	5,989	Shark Complex TAC
2015	5,989	NA	1,389	135	1,524	5,989	Shark Complex TAC
2016	4,514	NA	1,951	158	2,109	4,514	Shark Complex TAC
2017	4,514	NA	1,772	324	2,096	4,514	Shark Complex TAC
2018	4,514	NA	3,410	181	3,591	4,514	Shark Complex TAC
2019	8,184	NA	1,989	191	2,180	8,184	Shark Complex TAC
2020	8,184	NA	1,358	251	1,609	8,184	Shark Complex TAC
2021	3,755	NA	1,917	197	2,114	3,755	Shark Complex TAC
2022	3,755	NA	1,550	115	1,665	3,755	Shark Complex TAC

*Skates were removed from the GOA Other Species category in 2003.

#Other Species were broken up, shark stock complex is formed

IOTC-2023-WPEB19-32

Table 19.3. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) by species and for the total shark stock complex. Data are provided by NMFS AKRO Catch Accounting System, queried through AKFIN on Oct 8, 2022.

FMP	Year	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other Sharks	Total
BSAI	2003	13	342	199	34	589
	2004	9	421	26	60	515
	2005	11	333	47	26	417
	2006	7	313	63	305	689
	2007	3	257	44	28	332
	2008	17	127	41	8	194
	2009	20	51	71	10	151
	2010	15	28	12	6	61
	2011	8	47	47	5	107
	2012	20	48	26	3	96
	2013	24	68	25	2	119
	2014	19	63	54	2	138
	2015	8	61	36	3	109
	2016	6	81	48	1	135
	2017	10	56	75	2	143
	2018	10	40	51	2	103
	2019	4	53	92	1	151
	2020	4	68	106	2	180
	2021	2	78	141	1	221
	2022	1	73	48	2	123
GOA	1997	658	136	124	123	1041
	1998	864	74	71	1,380	2389
	1999	314	558	132	33	1037
	2000	398	608	38	73	1117
	2001	494	249	33	77	853
	2002	117	226	58	26	427
	2003	357	270	35	53	715
	2004	183	282	41	39	544
	2005	443	482	60	69	1054
	2006	1188	252	34	83	1557
	2007	794	295	141	107	1337
	2008	531	66	7	12	617
	2009	1653	56	9	24	1741
	2010	429	170	108	9	716
	2011	486	26	7	5	523
	2012	459	180	50	12	701
	2013	2050	94	3	9	2156
	2014	1335	93	147	6	1582
	2015	947	60	362	21	1389
	2016	1782	71	90	9	1951
	2017	1609	140	13	11	1772
	2018	3129	250	6	24	3410
	2019	1868	92	15	14	1989
	2020	1217	98	37	6	1358
	2021	1763	91	45	19	1917
	2022	1381	65	33	71	1550

Table 19.4. Estimated discard rates of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) by species and for the total shark stock complex. Data are provided by NMFS AKRO Catch Accounting System, queried through AKFIN on Oct 8, 2022.

FMP	Year	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other Sharks	All Sharks
BSAI	2003	84%	80%	98%	87%	87%
	2004	98%	98%	94%	97%	97%
	2005	99%	96%	98%	74%	95%
	2006	98%	95%	98%	97%	96%
	2007	98%	93%	99%	47%	90%
	2008	100%	94%	97%	47%	93%
	2009	99%	96%	100%	64%	96%
	2010	100%	93%	96%	31%	89%
	2011	99%	86%	93%	60%	89%
	2012	99%	82%	92%	63%	87%
	2013	100%	93%	96%	79%	95%
	2014	100%	91%	95%	76%	94%
	2015	97%	93%	97%	78%	94%
	2016	90%	92%	97%	42%	94%
	2017	100%	86%	98%	71%	93%
	2018	100%	81%	92%	32%	88%
	2019	100%	91%	97%	44%	95%
	2020	76%	88%	95%	70%	92%
	2021	95%	94%	98%	89%	97%
	2022	90%	95%	94%	62%	94%
GOA	2003	98%	100%	100%	93%	98%
	2004	96%	100%	100%	91%	98%
	2005	98%	99%	98%	69%	97%
	2006	96%	99%	97%	78%	96%
	2007	96%	100%	100%	90%	97%
	2008	93%	98%	94%	59%	93%
	2009	98%	98%	99%	7%	97%
	2010	95%	95%	98%	24%	95%
	2011	98%	94%	98%	14%	97%
	2012	97%	100%	99%	53%	97%
	2013	99%	100%	100%	72%	99%
	2014	99%	100%	100%	54%	99%
	2015	99%	100%	100%	70%	99%
	2016	99%	100%	99%	75%	99%
	2017	98%	99%	73%	35%	98%
	2018	99%	100%	93%	77%	99%
	2019	98%	100%	91%	87%	98%
	2020	98%	95%	82%	89%	97%
	2021	99%	98%	90%	98%	99%
	2022	100%	99%	96%	99%	99%

Table 19.5. Gulf of Alaska (GOA), Alaska Fisheries Science Center bottom trawl survey estimates of spiny dogfish total biomass (t) with coefficient of variation (CV) and number of hauls with catches of sharks. Data updated October 8, 2022 (RACEBASE, queried through AKFIN). The dashed line between 1987 and 1990 identifies when a shift in the survey standardization occurred. Data from 1990 on are used in the spiny dogfish model.

	Western GOA				Central GOA				Eastern GOA				GOA-wide			
Year	**Hauls in area**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls in area**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls in area**	**Hauls w/Catch**	**Biomass**	**CV**	**Total # of Survey Hauls**	**Hauls w/Catch**	**Biomass**	**CV**
1984	242	5	43	0.44	485	57	2,141	0.27	202	63	7,959	0.25	929	125	10,143	0.21
1987	177	32	655	0.30	446	41	1,592	0.42	160	49	7,859	0.33	783	122	10,107	0.27
1990	135	7	305	0.52	371	59	15,391	0.46	202	48	3,251	0.22	708	114	18,947	0.38
1993	170	7	158	0.43	412	74	7,574	0.26	192	85	25,913	0.25	774	166	33,645	0.20
1996	200	7	228	0.42	393	31	3,209	0.28	214	61	25,041	0.84	807	99	28,478	0.74
1999	147	3	182	0.67	414	84	16,216	0.13	203	81	15,345	0.25	764	168	31,743	0.14
2001*,#	139	4	247	0.53	350	71	31,527	0.45	0	0	0	0.00	489	75	31,774	0.45
2003	230	2	79	0.71	420	133	59,855	0.34	159	69	38,810	0.20	809	204	98,744	0.22
2005	180	1	29	1.00	470	77	15,936	0.32	187	78	31,974	0.20	837	156	47,939	0.17
2007	205	4	88	0.55	470	93	27,409	0.17	141	64	135,263	0.42	816	161	162,759	0.35
2009	196	9	187	0.37	470	91	11,157	0.17	157	76	16,536	0.16	823	176	27,880	0.12
2011$	163	0	0	0.00	383	60	15,678	0.32	124	37	25,415	0.29	670	97	41,093	0.22
2013$	136	5	203	0.47	313	25	19,307	0.42	99	28	140,874	0.46	548	58	160,384	0.40
2015	189	6	220	0.45	434	40	18,744	0.41	148	35	32,953	0.33	771	81	51,916	0.25
2017$	125	0	0	0.00	296	63	27,385	0.25	115	49	26,593	0.28	536	112	53,978	0.19
2019$	123	2	153	0.74	297	70	13,313	0.19	121	38	8,548	0.23	541	110	22,014	0.15
2021$	114	1	161	1.00	292	46	12,461	0.25	123	33	19,697	0.24	529	80	32,319	0.18

#Survey maximum depth was 500m
$Survey maximum depth was 700m
*Survey did not sample the Eastern Gulf of Alaska

Table 19.6. IPHC RPN table for Pacific sleeper shark in the GOA.

Year	Hauls	Hauls w/Catch	RPN	lower 95%	Upper 95%
1998	387	116	1091	733	1733
1999	389	113	1385	946	2110
2000	376	131	1345	965	1987
2001	375	115	1589	1084	2362
2002	373	121	1682	1164	2424
2003	387	114	1530	1082	2086
2004	368	80	1072	669	1662
2005	387	82	1077	661	1826
2006	383	91	1044	656	1781
2007	389	74	1134	718	1847
2008	387	61	749	447	1242
2009	378	84	715	442	1298
2010	383	40	372	198	704
2011	383	38	337	159	761
2012	387	36	310	163	594
2013	381	55	524	299	992
2014	383	38	234	121	507
2015	385	34	230	96	543
2016	384	41	270	138	536
2017	389	55	287	160	552
2018	380	23	106	44	225
2019	431	42	191	104	383
2020	360	12	56	15	166
2021	382	25	171	64	506

Table 19.7. ORCS Table of attributes used in this analysis. Adapted from Table 1, Free et al. (2017).

		Stock status		
#	Attribute	Underexploited (1)	Fully exploited (2)	Overexploited (3)
1	Status of assessed stocks in fishery	<10% overfished	10–25% overfished	>25% overfished
2	Behavior affecting capture	----------	No aggregation behavior	Exhibits aggregation behavior
3	Discard rate	Discards <10% of catch	Discards 10–25% of catch	Discards >25% of catch
4	Targeting intensity	Not targeted	Occasionally targeted	Actively targeted
5	M compared to dominant species	Higher mortality rate	Equivalent mortality rates	Lower mortality rate
6	Occurrence in catch	Sporadic *(in <10% of efforts)*	Common *(in 10–25% of efforts)*	Frequent *(in >25% of efforts)*
7	Value (US$/lb, 5-year mean)	<$1/lb	$1-$2.25/lb	>$2.25/lb
8	Recent trend in catch	Increasing last 5 years	Stable last 5 years	Decreasing last 5 years
9	Habitat loss	No time in threatened habitats	Part time in threatened habitats *(full time in partially threatened habitats)*	Full time in threatened habitats
10	Recent trend in effort	Decreasing last 5 years	Stable last 5 years	Increasing last 5 years
11	Recent trend in abundance index	Increasing last 5 years	Stable last 5 years	Decreasing last 5 years
12	Proportion of population protected	Most of resource is protected *(size limits AND time/space closures)*	Some of resource is protected *(size limits OR time/space closures)*	None of resource is protected *(no size limits or time/space closures)*
13	Life history considerations	Fishery generally catches adults and/or species is highly productive	Fishery catches are distributed across life history stages	Fishery generally catches immature individuals and/or the species has low productivity

Table 19.8. Status-specific historical catch statistics and potential status-specific catch scalars for relating the best catch statistic to the overfishing limit (OFL). The 50th percentile scalars should promote a 50% probability of overfishing if stock status is correctly identified. From Table 3 in Free et al. (2017).

		OFL Scalars								
Stock status	Catch statistic	50th	45th	40th	35th	30th	25th	20th	15th	10th
Underexploited	90th percentile, whole time series	1.90	1.78	1.62	1.53	1.41	1.34	1.29	1.11	0.88
Fully exploited	25th percentile, previous 10 years	2.16	1.84	1.77	1.57	1.41	1.22	1.15	1.02	0.85
Overexploited	10th percentile, whole time series	1.56	1.53	1.49	1.00	0.52	0.51	0.50	0.45	0.41

Table 19.9. ORCS results for the Pacific sleeper shark in the BSAI and GOA

	Attribute Description	BSAI	GOA	Justification
1	Status of assessed stocks in fishery	1	1	0% of fishery stocks in either FMP are overfished
2	Behavior affecting capture	2	2	Species does not exhibit significant aggregating behaviors
3	Discard rate	3	3	Discard rates are 88% and 99%, BSAI and GOA, respectively
4	Targeting intensity	1	1	All sharks are non-targeted in either FMP
5	M compared to dominant species	3	3	M is >20% than dominant species in BSAI, likely 20% lower that the dominant species in the GOA
6	Occurrence in catch	1	1	Occurs in <2% of observed hauls in either FMP
7	Value	1	1	Little to no market value in either FMP
8	Recent trend in catch	2	2	No significant trends
9	Habitat loss	1	1	Species does not occupy identified threatened habitats
10	Recent trend in effort	2	2	No significant trends
11	Recent trend in abundance index	NA	2	No recent BSAI data, no trend in GOA data
12	Proportion of population protected	3	3	No specific protection measures
13	Life history considerations	3	3	Low productivity and large proportion of catch is immature
Mean Score		1.92	1.92	
Stock Status		Fully Exploited		
Catch Statistic		54 t	91 t	
Scalar		2.16		
OFL		117	197	
ABC		88	148	

Table 19.10 Biomass (mt) of spiny dogfish estimated using random effects model with 95% confidence intervals (CI). Note that the model ends in 2021, the last year of survey data availability. Forward projections of the random effects model will result in a constant biomass until new data are included.

Year	Western	Central	Eastern	Total GOA	Lower 95% CI	Upper 95% CI
1990	304	9,982	3,728	14,014	5,589	24,378
1991	256	9,024	6,792	16,073	16,635	32,265
1992	216	8,158	12,375	20,749	30,608	40,569
1993	182	7,376	22,546	30,103	35,933	43,547
1994	192	5,952	22,218	28,362	58,299	62,901
1995	203	4,803	21,895	26,902	64,488	67,451
1996	215	3,876	21,576	25,668	56,483	59,175
1997	207	6,224	19,681	26,112	57,871	62,341
1998	198	9,994	17,953	28,145	46,951	57,106
1999	190	16,046	16,376	32,612	25,864	42,481
2000	189	21,841	20,141	42,171	52,516	79,974
2001	187	29,729	24,772	54,688	72,126	103,452
2002	135	37,111	30,468	67,714	77,845	130,001
2003	98	46,327	37,473	83,898	53,886	120,133
2004	82	30,113	35,667	65,862	77,235	117,421
2005	69	19,574	33,948	53,591	48,835	72,752
2006	82	22,550	49,511	72,143	113,081	135,566
2007	97	25,979	72,210	98,285	140,831	163,497
2008	127	17,516	36,103	53,746	81,707	99,345
2009	168	11,811	18,050	30,029	24,593	37,639
2010	175	13,506	22,357	36,038	49,082	64,516
2011	183	15,444	27,691	43,318	45,498	62,952
2012	191	16,947	45,965	63,104	108,435	124,356
2013	200	18,597	76,301	95,098	154,372	170,857
2014	204	19,142	52,029	71,375	124,140	142,135
2015	209	19,702	35,479	55,390	61,153	84,206
2016	197	22,159	29,576	51,933	67,303	94,697
2017	186	24,923	24,656	49,765	40,040	69,313
2018	175	18,510	15,637	34,323	34,780	60,600
2019	166	13,748	9,917	23,830	15,134	31,147
2020	165	13,154	13,543	26,861	29,908	47,279
2021	164	12,585	18,494	31,243	28,798	43,166

Table 19.11 Analysis of ecosystem considerations for the shark stock complex.

Ecosystem effects on *BSAI and GOA Sharks*			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Unknown
Non-pandalid shrimp and other benthic organism	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Composes the main portion of spiny dogfish diet	Unknown
Sandlance, capelin, other forage fish	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Salmon	Populations are stable or slightly decreasing in some areas	Small portion of spiny dogfish diet, maybe a large portion of salmon shark diet	No concern
Flatfish	Increasing to steady populations currently at high biomass levels	Adequate forage available	No concern
Walleye pollock	High population levels in early 1980s, declined to stable low level at present	Primarily a component of salmon shark diets	No concern
Other Groundfish	Stable to low populations	Varied in diets of sharks	No concern
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Not likely a predator on sharks	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	No concern
Fish (walleye pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to juvenile spiny dogfish mortality	
Sharks	Stable to increasing	Larger species may prey on spiny dogfish	Currently, no concern
Changes in habitat quality			
Temperature regime	Warm and cold regimes	May shift distribution, species tolerate wide range of temps	No concern
Benthic ranging from inshore waters to shelf break and down slope	Sharks can be highly mobile, and benthic habitats have not been monitored historically, species may be able to move to preferred habitat, no critical habitat defined for BSAI	Habitat changes may shift distribution	No concern

***BSAI and GOA Sharks* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Not Targeted	None	No concern	No concern
Fishery concentration in space and time	None	No concern	No concern
Fishery effects on amount of large size target fish	If targeted, could reduce avg size of females, reduce recruitment, reduce fecundity, skewed sex ratio (observed in areas targeting species)	No concern at this time	No concern at this time
Fishery contribution to discards and offal production	None	No concern	No concern
Fishery effects on age-at-maturity and fecundity	Age at maturity and fecundity decrease in areas that have targeted species	No concern at this time	No concern at this time

Figures

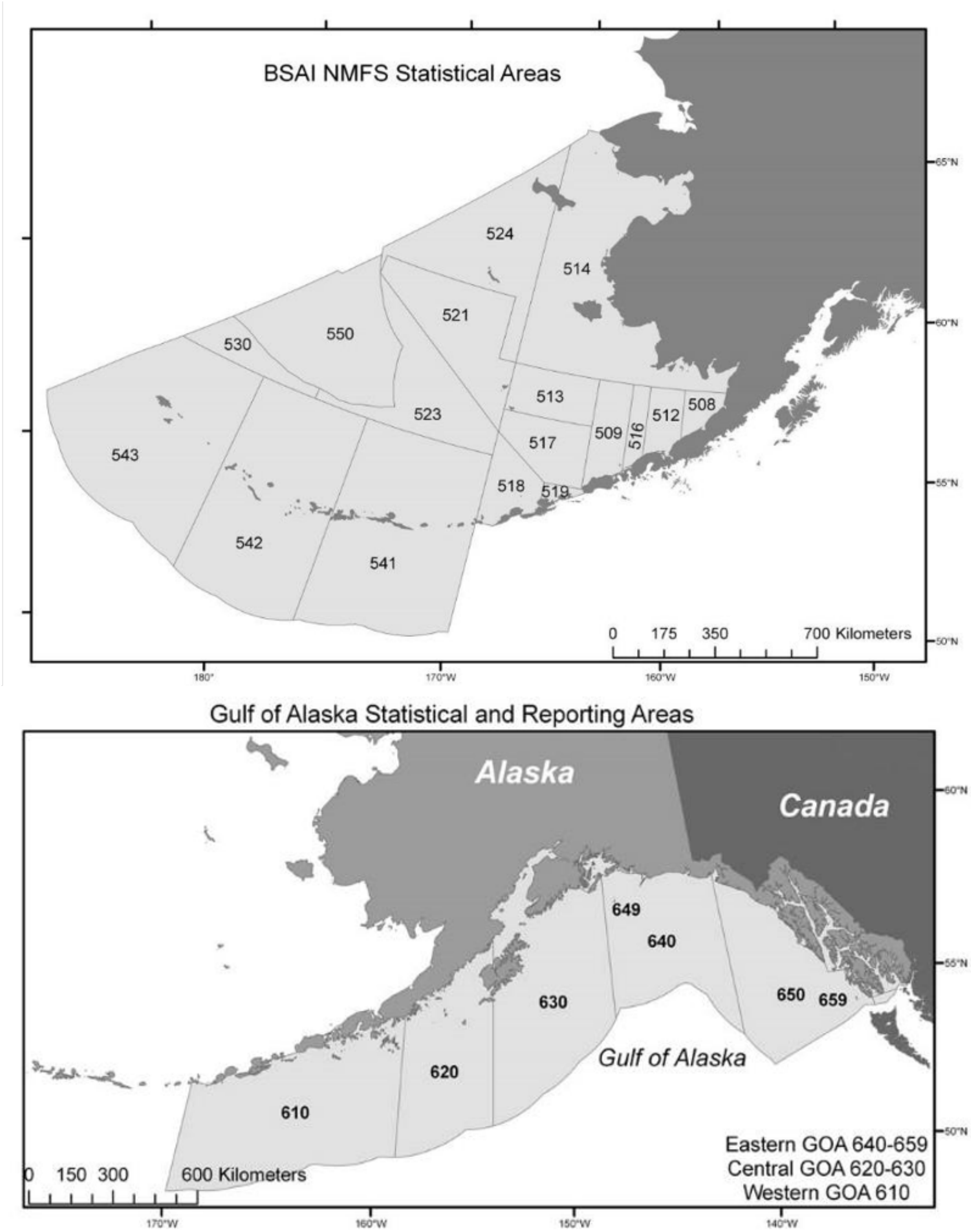


Figure 19.1 NMFS statistical and regulatory areas in the Bering Sea (NMFS Areas 508-530 and 550) and Aleutian Islands (NMFS Areas 541-543), top panel, and the Gulf of Alaska, bottom panel, NMFS Area 649 is Prince William Sound and 659 is Southeast Alaska.

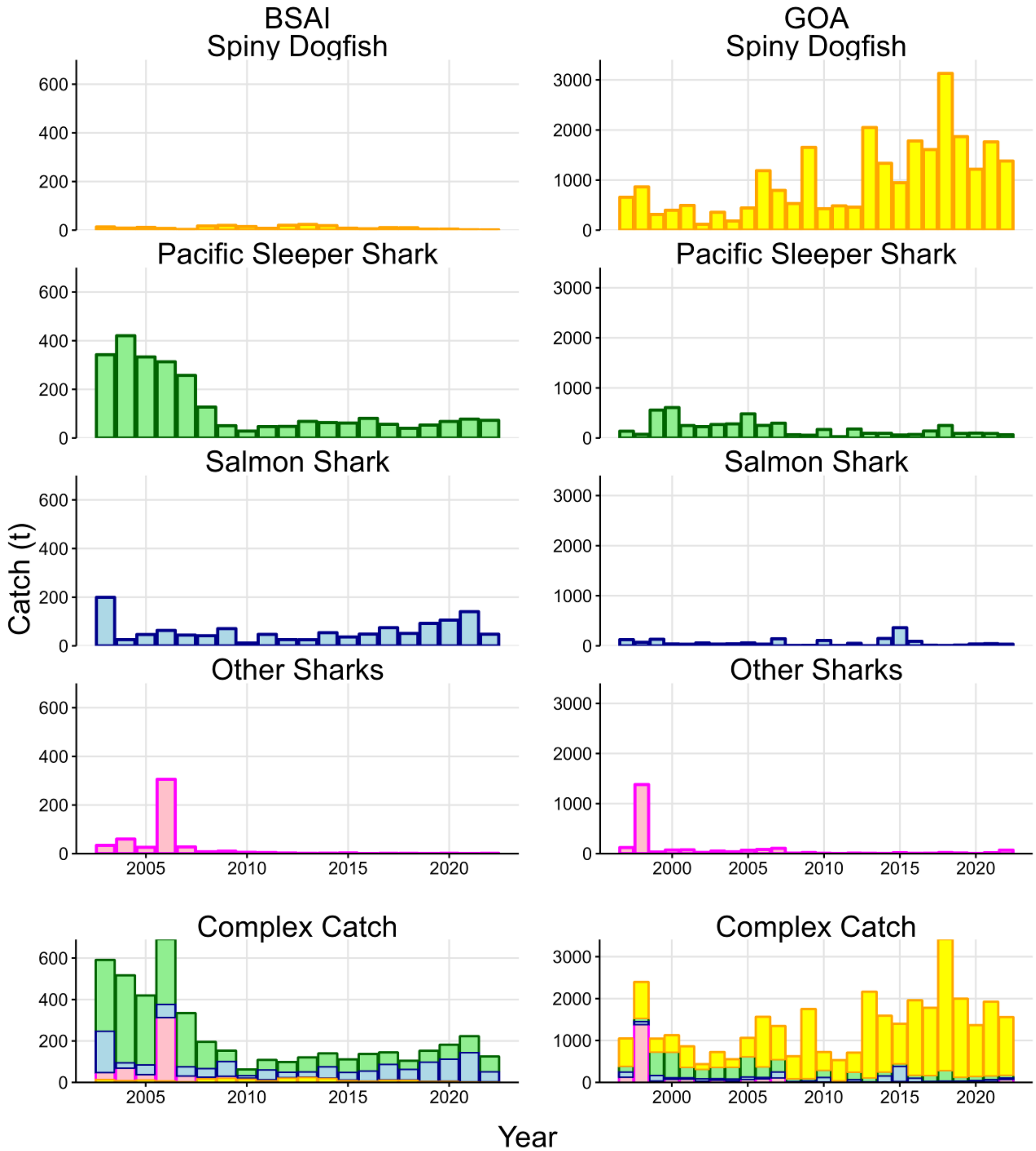


Figure 19.2 Estimated incidental catch (t) of sharks in Bering Sea/Aleutian Islands (BSAI), left column, and the Gulf of Alaska (GOA), right column, by species and the complex total. Data provided by the Alaska Regional Office Catch Accounting System (queried through AKFIN on October 8, 2022).

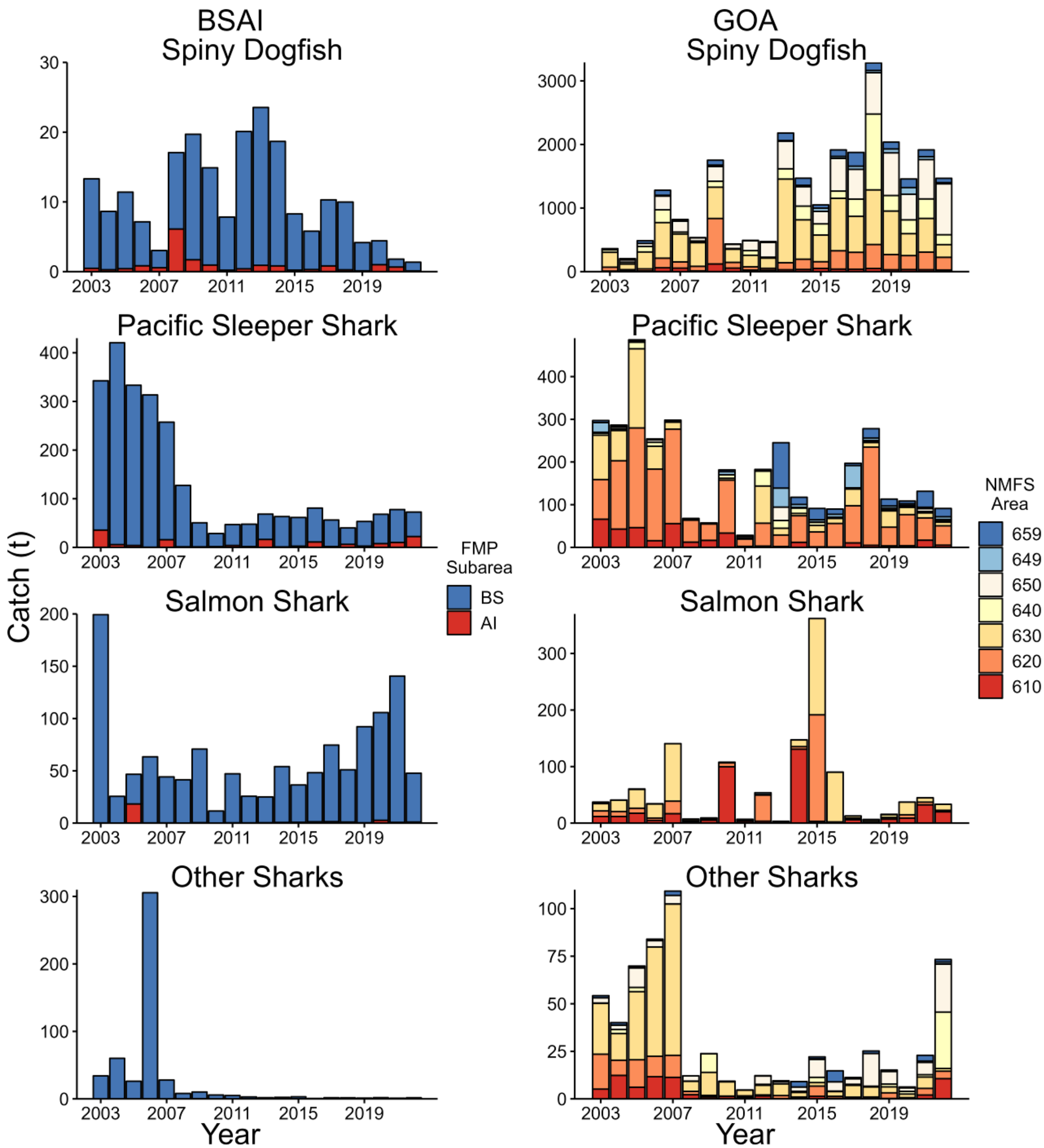


Figure 19.3 Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI), left column, and Gulf of Alaska (GOA), right column by species and FMP Subarea (BSAI) or NMFS reporting area (GOA) Note that y-axis scales differ. Catches for the GOA are shown by NMFS reporting area, as opposed to FMP subarea, because of substantial differences within FMP subareas. Catch occurring in NMFS areas 649 (Prince William Sound) and 659 (Southeast Alaska inside waters), those areas in shades of blue on the GOA panels, are presented here to show presence of catch, but do not count against the total allowable catch (TAC). Data provided by the Alaska Regional Office Catch Accounting System (queried through AKFIN on October 8, 2022).

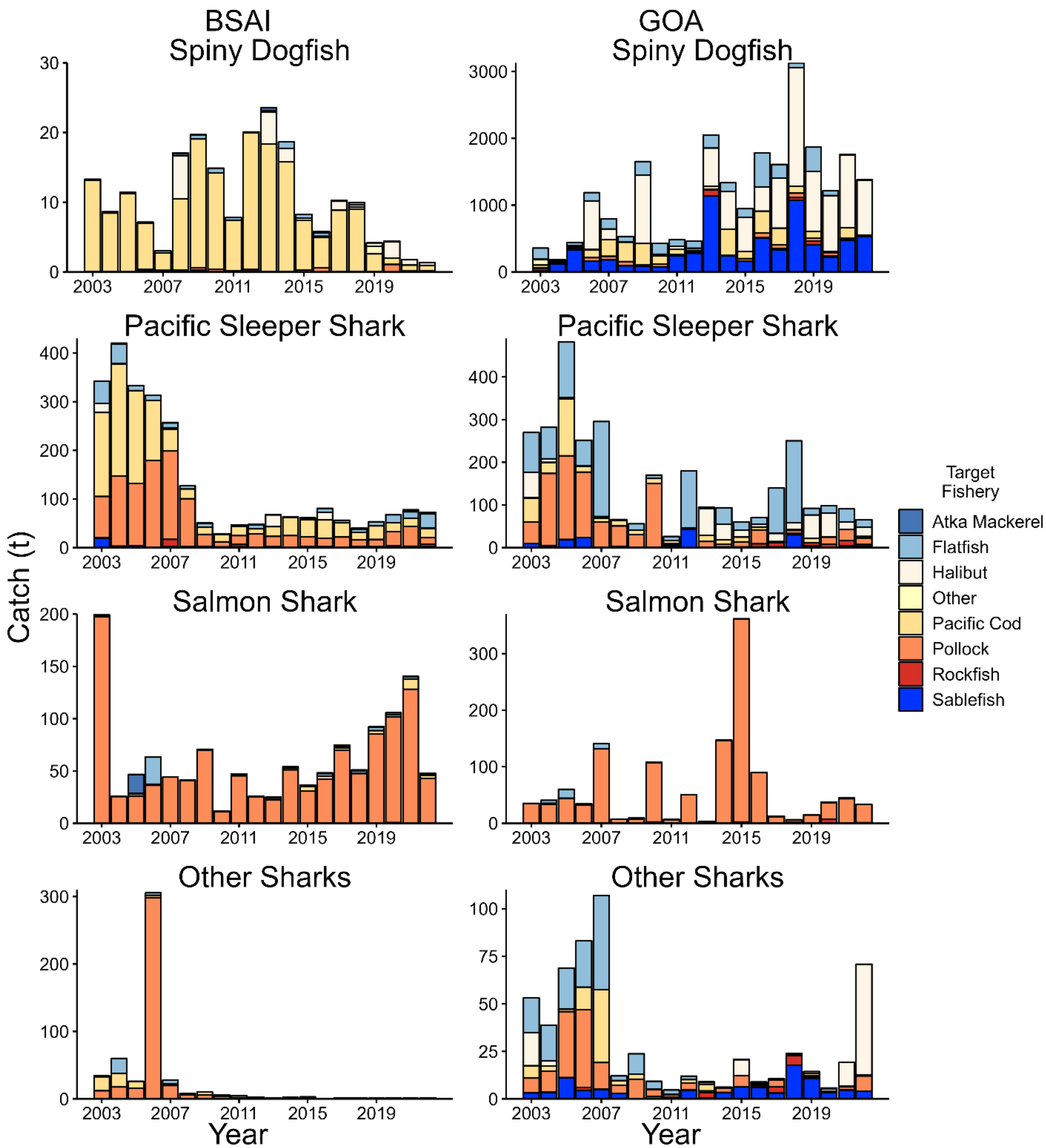


Figure 19.4 Estimated catch of sharks by target fishery in the Bering Sea and Aleutian Islands (BSAI, left column) and the Gulf of Alaska (GOA, right column), from 2003-2022, These data are form the Alaska Regional Office Catch Accounting System queried through AKFIN on October 13, 2020.

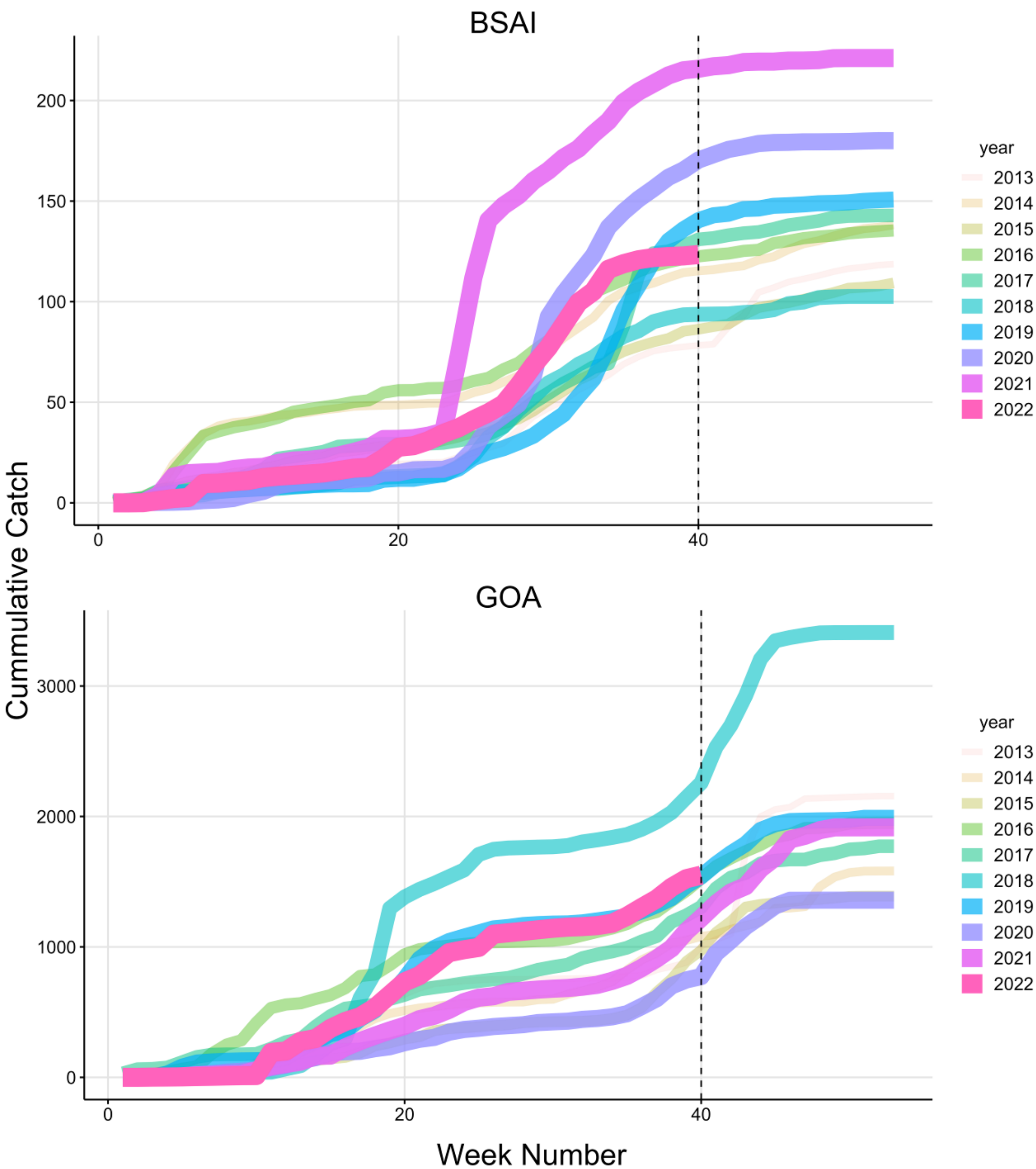


Figure 19.5. Cumulative catch in tons of all sharks in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA), from 2013-2022. Vertical line at week 40 represents the approximate date that data are queried for the stock assessments. Data are provided by the AKRO, queried through AKFIN October 8, 2022.

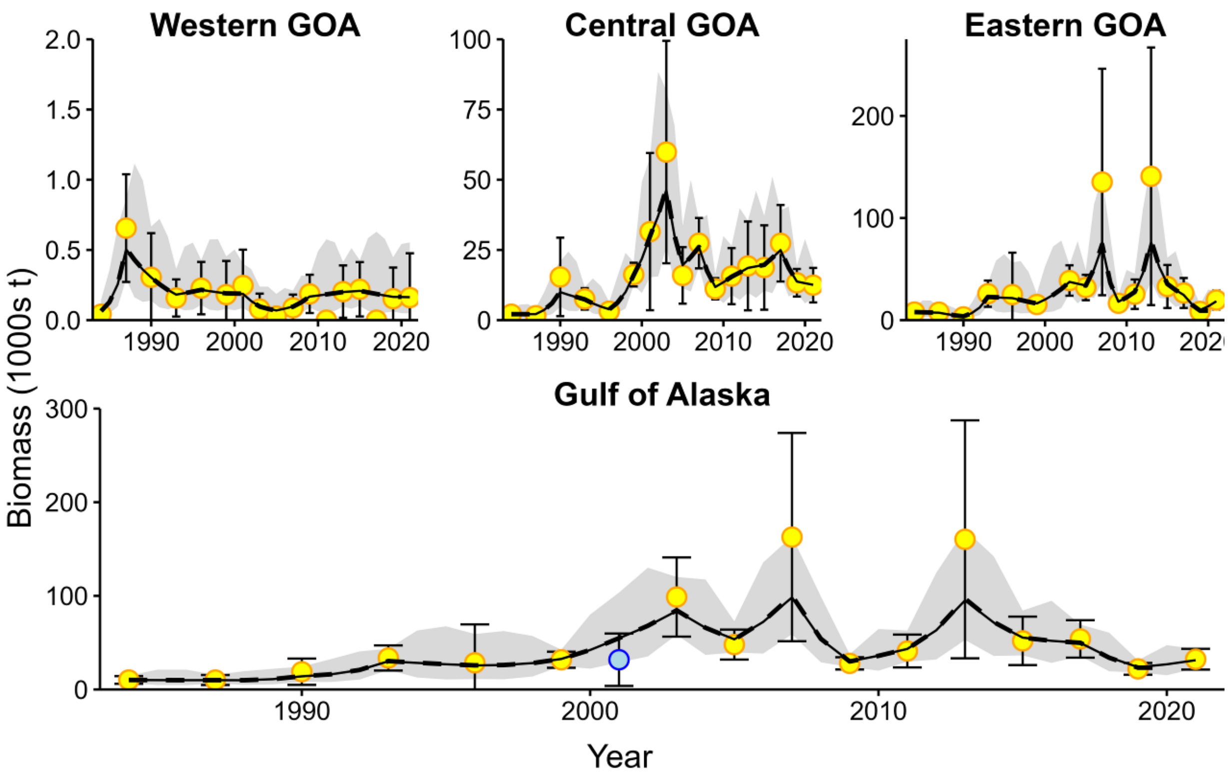


Figure 19.6 Fit of the random effects survey averaging model to the Alaska Fisheries Science Center Gulf of Alaska (GOA) trawl survey biomass estimates by regulatory area (Western GOA, Central GOA, and Eastern GOA) for spiny dogfish. The yellow points are the survey biomass with 95% confidence intervals, the black line is the random effects estimated biomass, and the shaded areas are the confidence intervals of the random effects biomass. The blue point is the year in which the survey did not sample the Eastern GOA. The black dashed line shows the random effects model output from the previous assessment, which did not include the 2021 survey data.

IOTC-2023-WPEB19-32

Appendix 19A. 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 (Appendix 20B of the 2012 BSAI stock assessment, Tribuzio et al. 2020). 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 (Appendix 20B of the 2012 BSAI stock assessment, Tribuzio et al. 2020). 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 19A.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 19A.1). In the eastern Bering Sea, small individuals are more prominent and there is a noted lack of large, mature sharks (Figure 19A.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 19A.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 19A.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 19A.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 19A.3; Tribuzio et al. 2020b). Catch estimates in numbers of individual sharks are available from 2011 to 2021 (Figure 19A.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 19A.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 19A.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 19A.6).

Catch of Pacific sleeper sharks occurs in "inside" waters of Alaska as well (Figure 19A.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 19A.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 19A.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 19A.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 19A.5). Similarly to the GOA, the spatial extent of the catch has become reduced since the beginning of the time series (Figure 19A.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 19A.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 19A.8, Figure 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.6, Figure 19A.8, Figure 19A.9, Figure 19A.11). The proportion of fixed stations with Pacific sleeper shark catch in the IPHC survey has decreased over time, especially in the GOA (Figure 19A.9). Trends in the fishery time series data are more variable, but generally indicate a reduction in the spatial extent of the catch (Figure 19A.6, Figure 19A.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 19A.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 19A.12-Figure 19A.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 19A.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 19A.13). Fishery catches also occur in relatively small amounts along the Aleutian chain (Figure 19A.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 19A.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 19A.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 19A.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 19A.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 19A.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 19A.1; Matta et al. in prep.). The vast majority of the catch is likely immature (Figure 19A.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 19A.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 19A.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 19A.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 19A.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 19A.3).

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

<u>Isolation by distance</u>

Not applicable due to lack of genetic structure

<u>Dispersal distance</u>

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.

<u>Pairwise genetic differences</u>

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 19A.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 19A.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 19A.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 19A.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

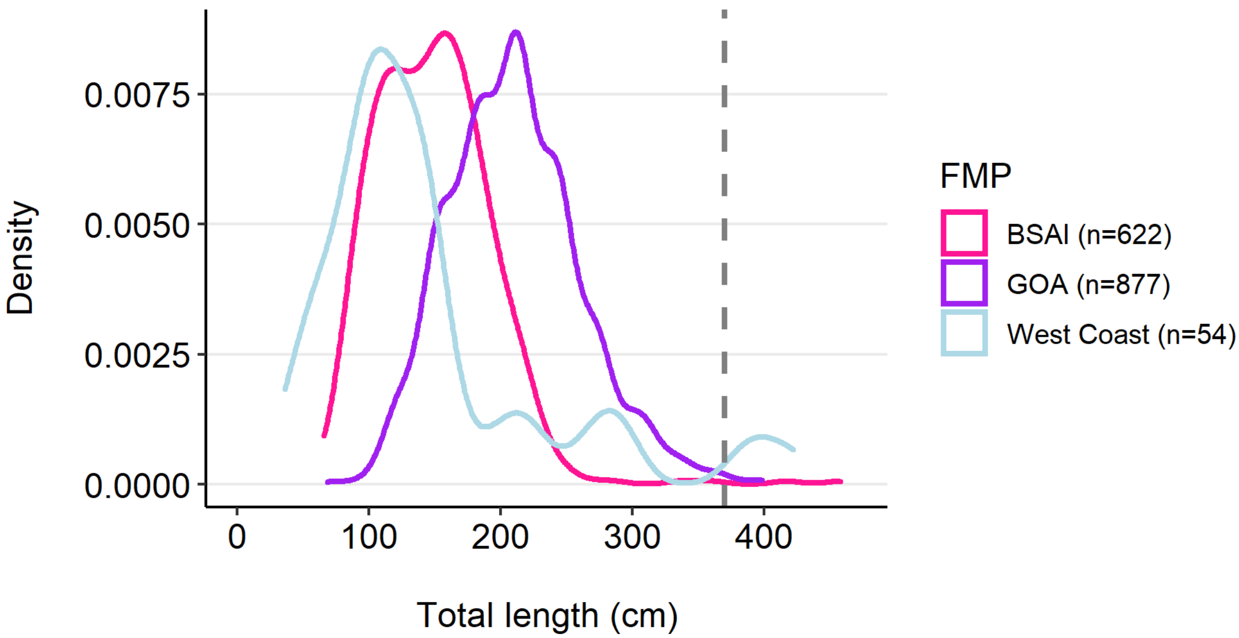


Figure 19A.1. Length distributions of Pacific sleeper sharks (*Somniosus pacificus*) caught from various sources (opportunistic fishery-dependent and survey sampling) in Alaska Fishery Management Plan (FMP) areas (BSAI=Bering Sea/Aleutian Islands, GOA=Gulf of Alaska) and the U.S. West Coast. Note that 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).

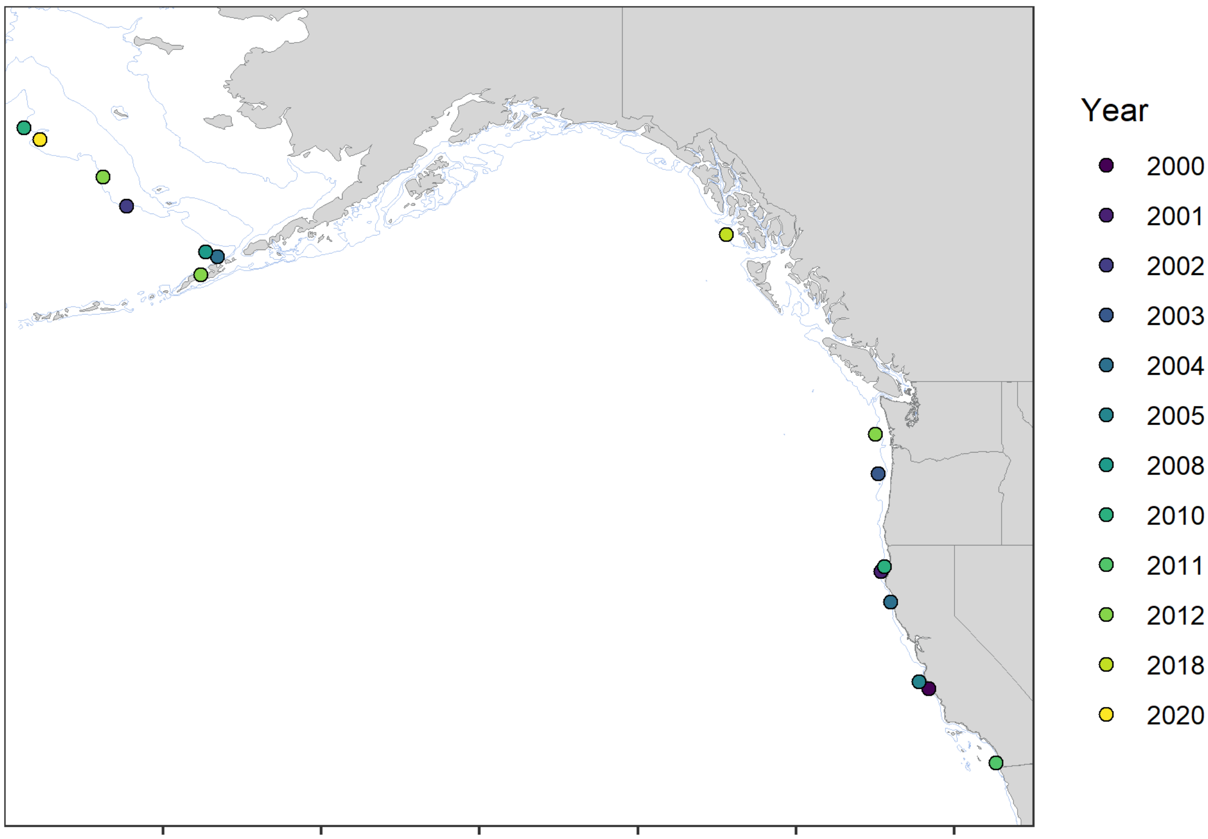


Figure 19A.2. Capture locations of juvenile Pacific sleeper sharks (*Somniosus pacificus*) under 75 cm total length in the eastern North Pacific Ocean. Data sources include NMFS bottom trawl surveys and non-confidential fishery-dependent collections.

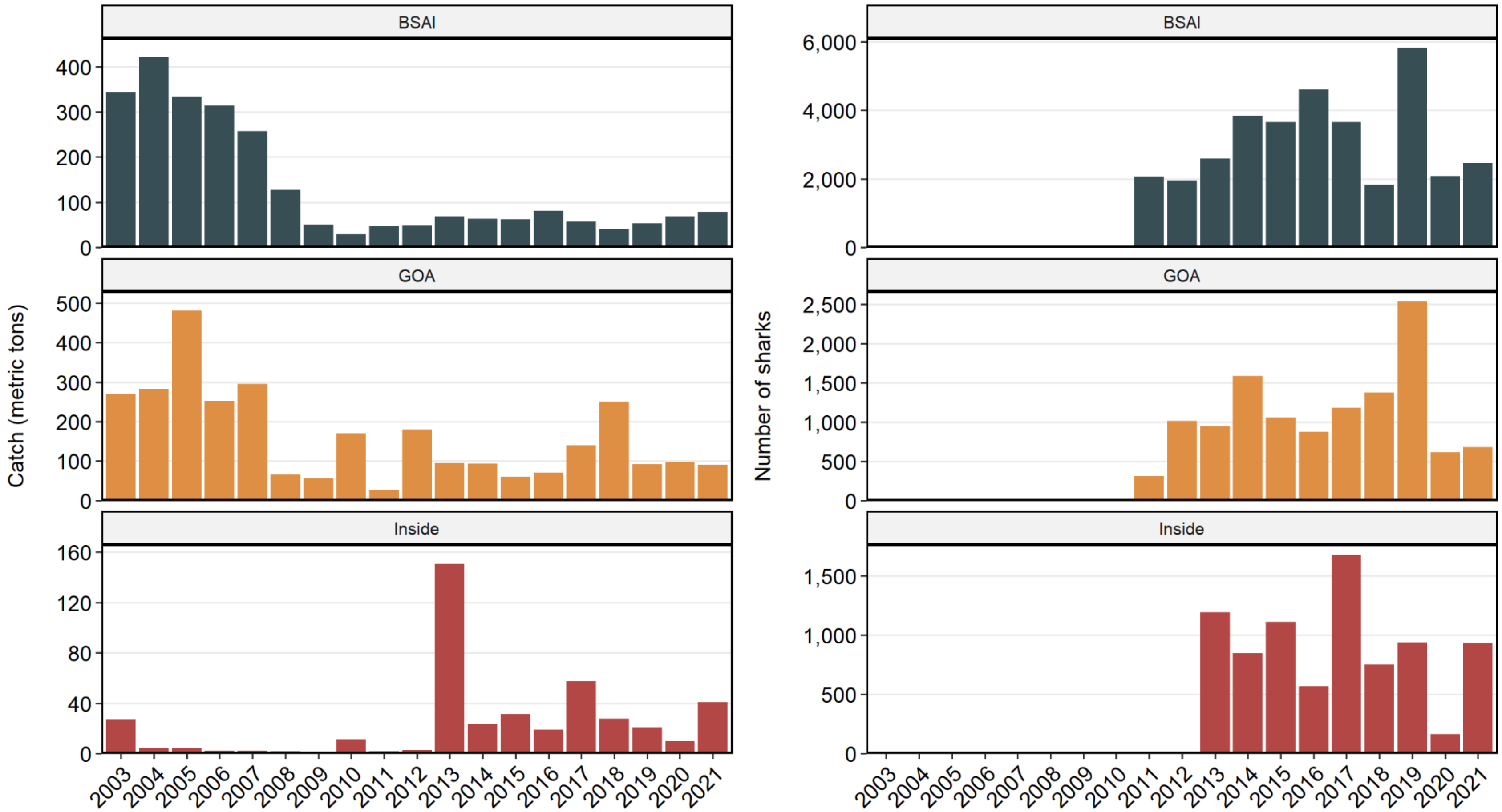


Figure 19A.3. Total fisheries catch in weight (left) and numbers (right) of Pacific sleeper sharks (*Somniosus pacificus*) in the Bering Sea/Aleutian Islands (BSAI), Gulf of Alaska (GOA), and Inside Waters of the GOA (NMFS areas 649 and 659 within 3 nm of shore). Catch data were obtained from the Alaska Regional Office's Catch Accounting System.

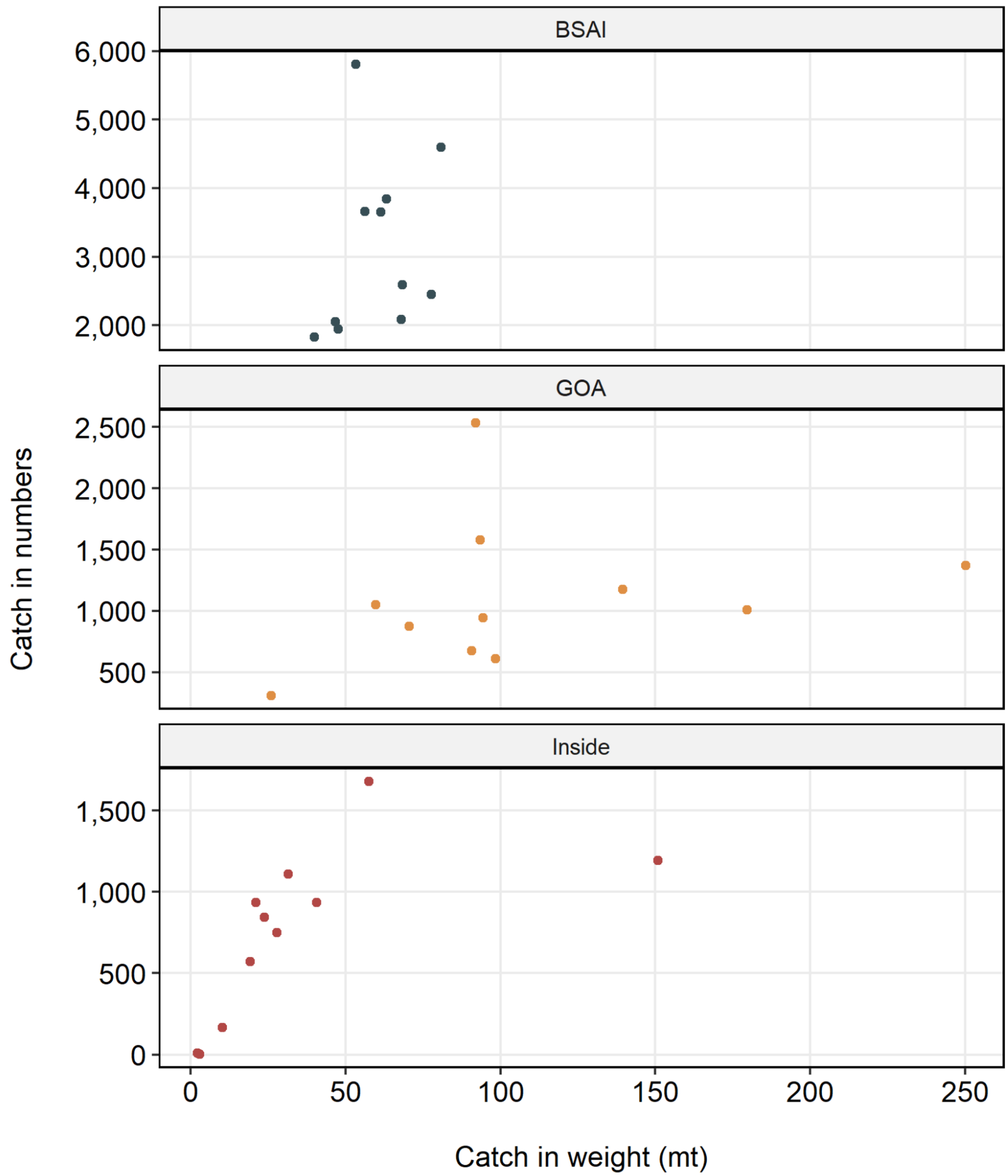


Figure 19A.4. Relationship of estimated catch numbers to catch weight (metric tons) of Pacific sleeper sharks (*Somniosus pacificus*) in the Bering Sea/Aleutian Islands (BSAI), Gulf of Alaska (GOA), and Inside Waters of the GOA (NMFS areas 649 and 659 within 3 nm of shore) from 2011-2021. Catch data were obtained from the Alaska Regional Office's Catch Accounting System.

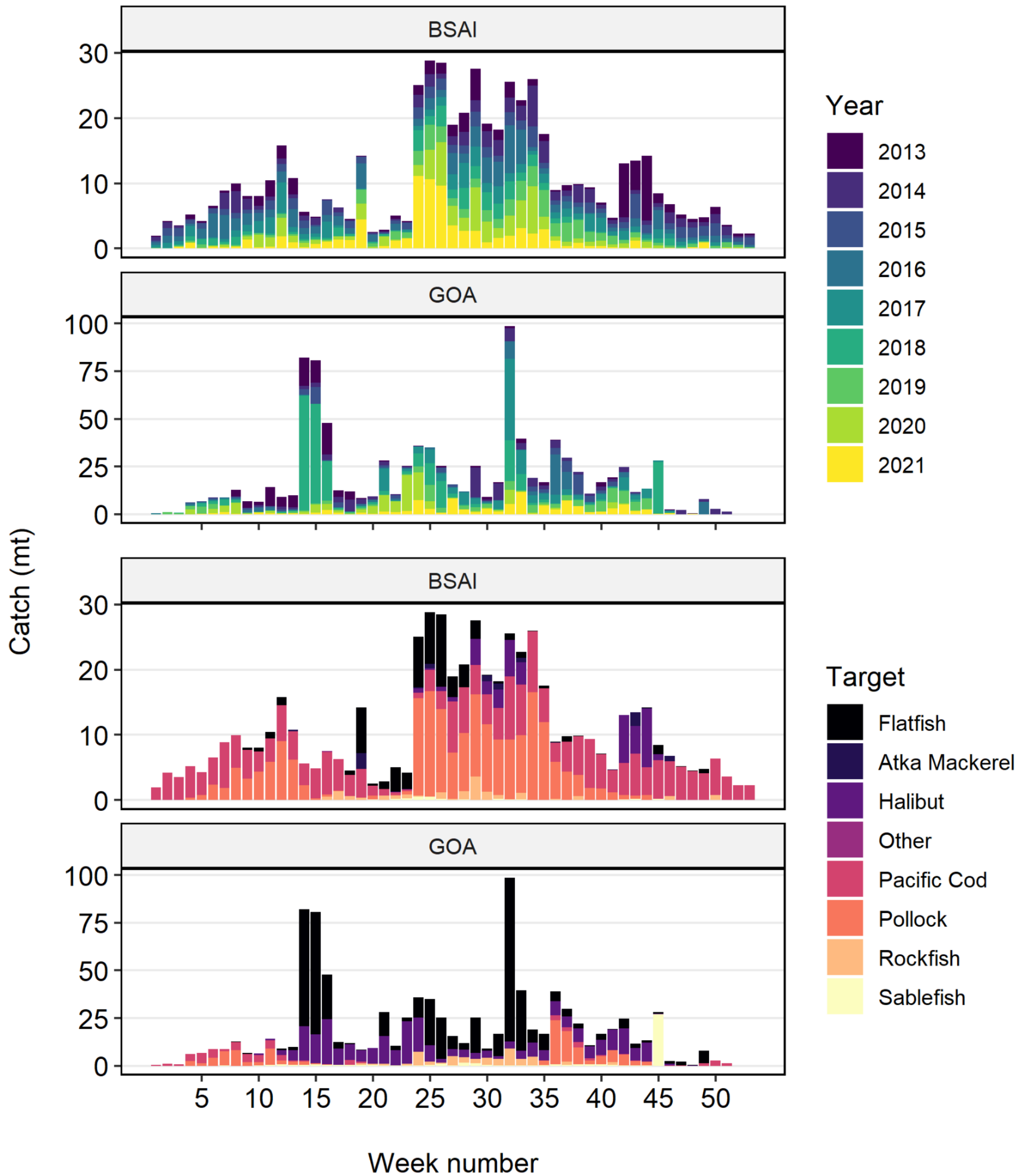


Figure 19A.5. Weekly cumulative catches (metric tons) of Pacific sleeper sharks (*Somniosus pacificus*) in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas from 2013-2021, shaded by year (top) and target species group (bottom). Does not include Inside Waters of the GOA (NMFS Areas 649 and 659). Catch data were obtained from the Alaska Regional Office's Catch Accounting System.

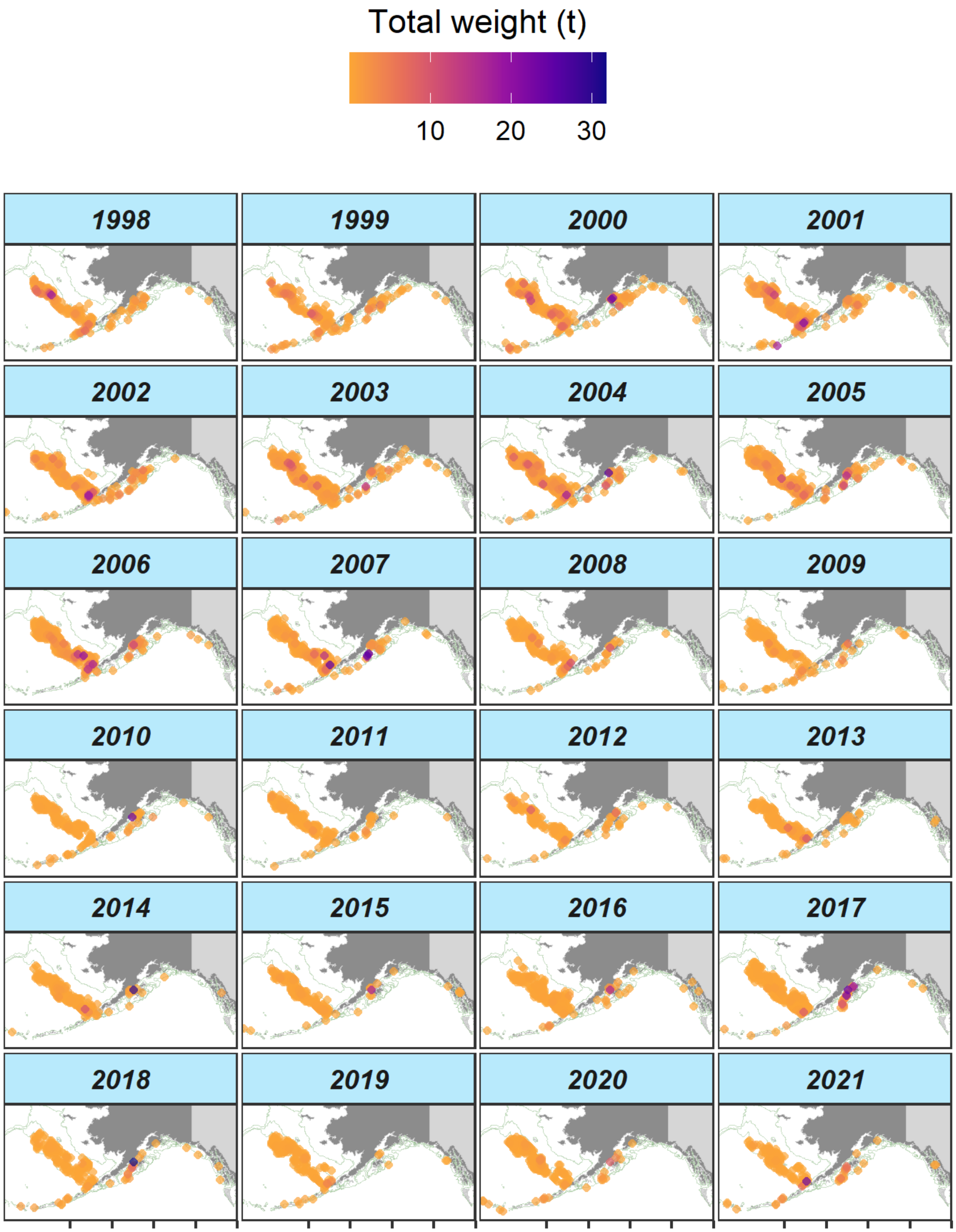


Figure 19A.6. Observed fishery bycatch (metric tons) of Pacific sleeper sharks (*Somniosus pacificus*) in Alaska waters from 1998-2021 (all fisheries combined). Data are nonconfidential and aggregated to 400 km^2 grid cells, and were obtained from [https://www.fisheries.noaa.gov/resource/map/spatial-data-collected-groundfish-observers-alaska.](https://www.fisheries.noaa.gov/resource/map/spatial-data-collected-groundfish-observers-alaska)

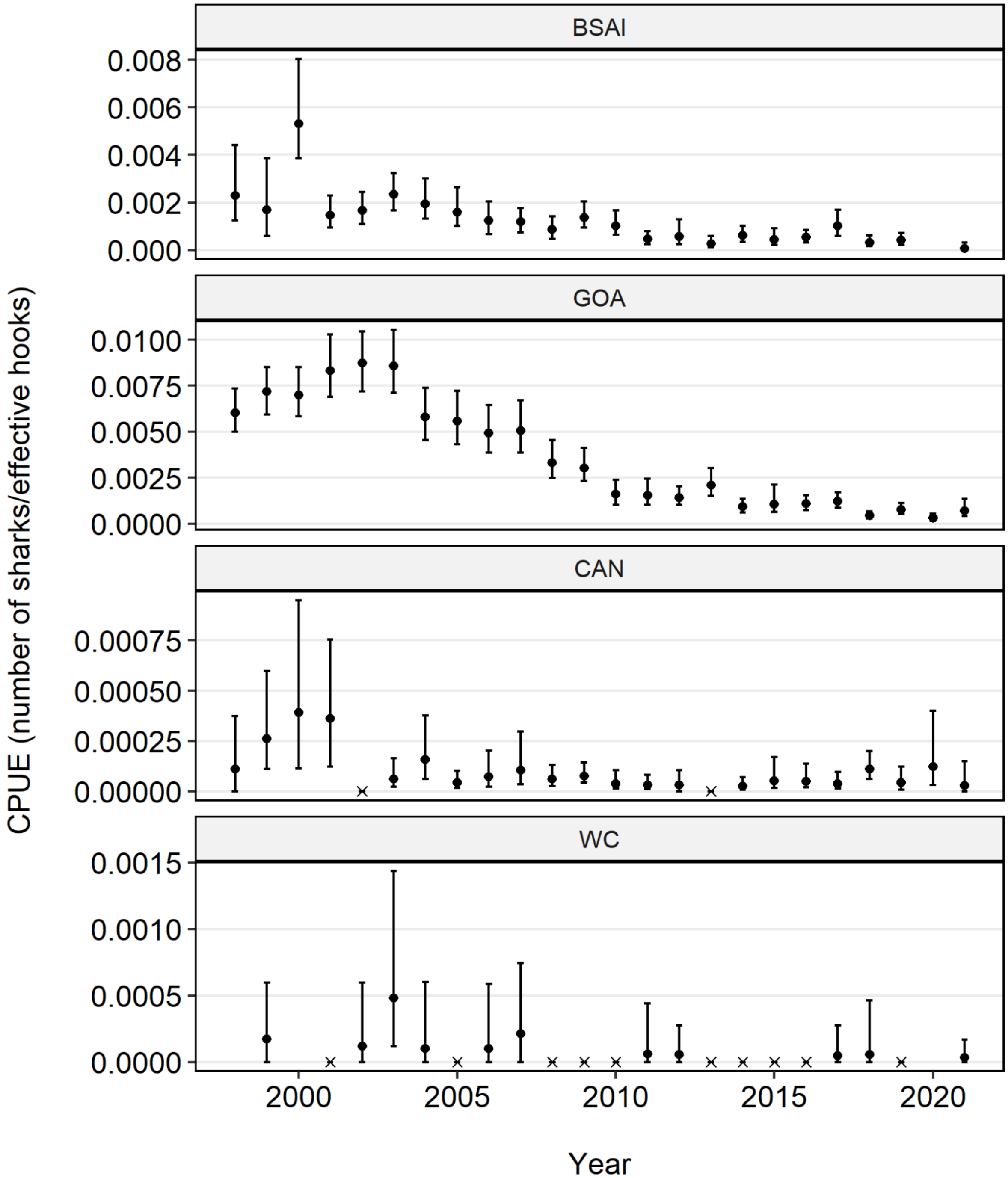


Figure 19A.7. Trends in International Pacific Halibut Commission (IPHC) longline survey estimates of Pacific sleeper shark (*Somniosus pacificus*) catch per unit effort (CPUE) reported here as an index of relative abundance for Alaska Fishery Management Plan areas (BSAI = Bering Sea/Aleutian Islands, 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.

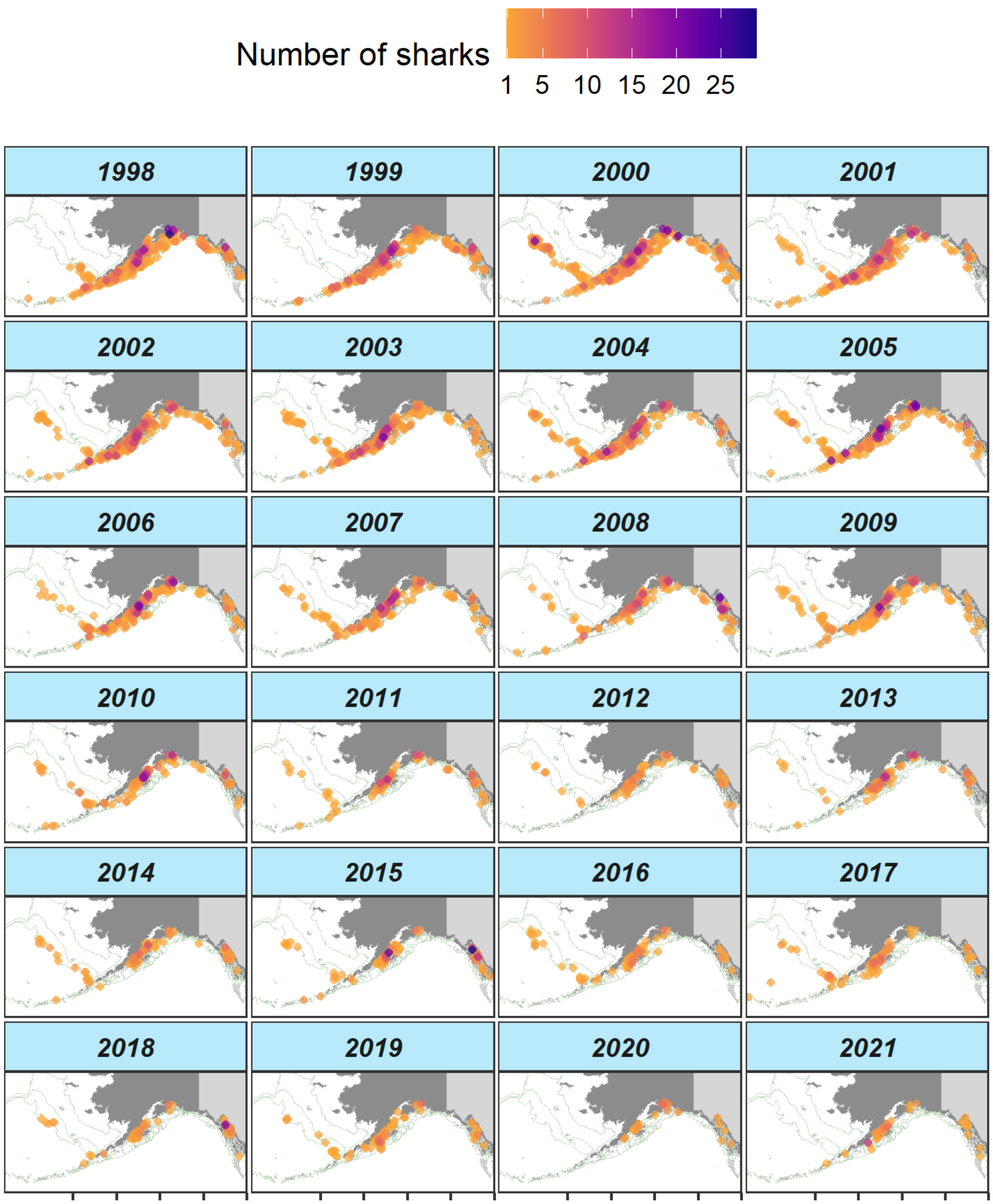


Figure 19A.8. Spatial distribution of the Pacific sleeper shark (*Somniosus pacificus*) catch during annual International Pacific Halibut Commission (IPHC) longline surveys. Colors represent the number of sharks observed and each point represents one survey haul. Hauls with zero catch were removed for clarity.

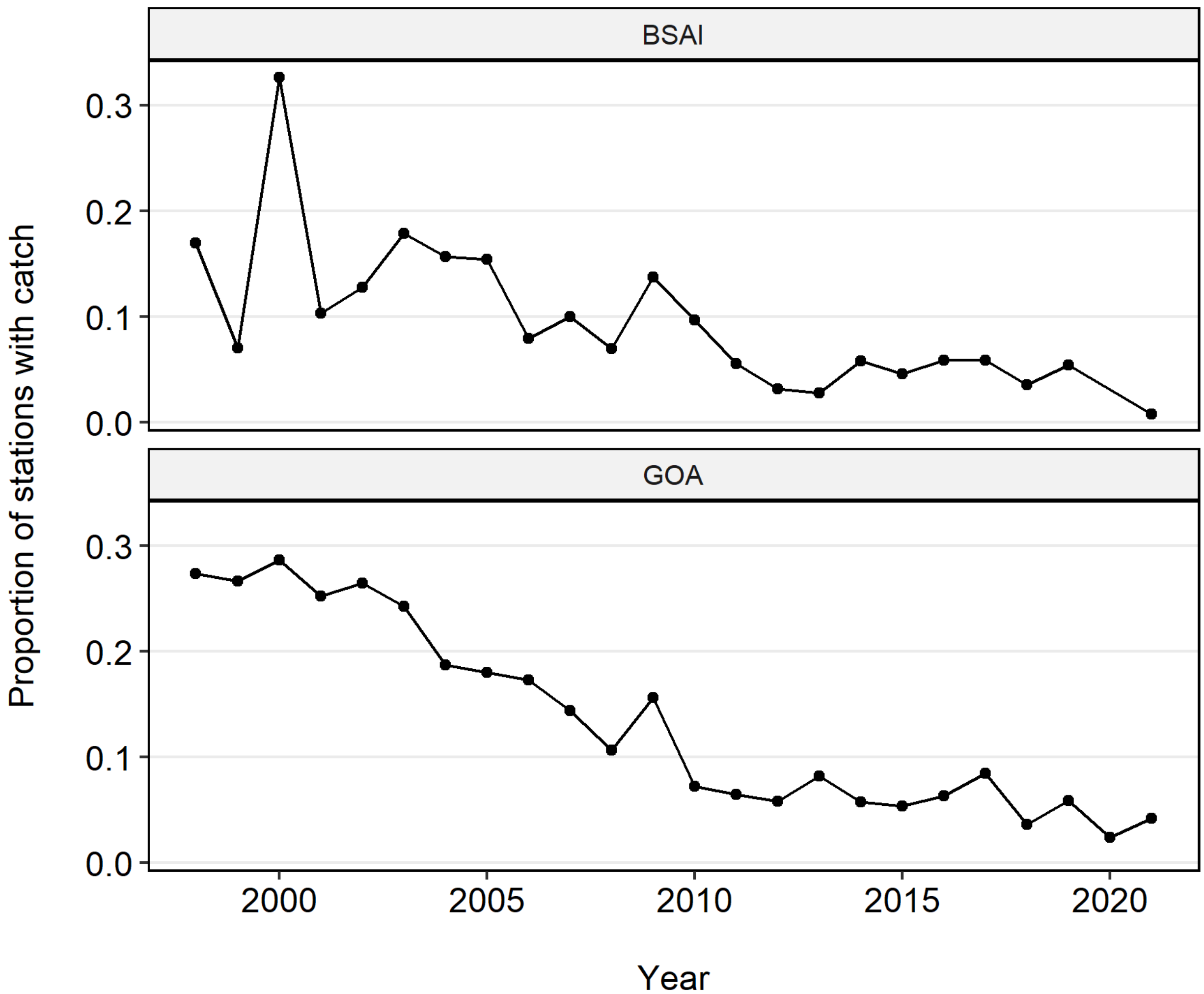


Figure 19A.9. Proportion of fixed International Pacific Halibut Commission (IPHC) longline survey stations with Pacific sleeper shark (*Somniosus pacificus*) catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas.

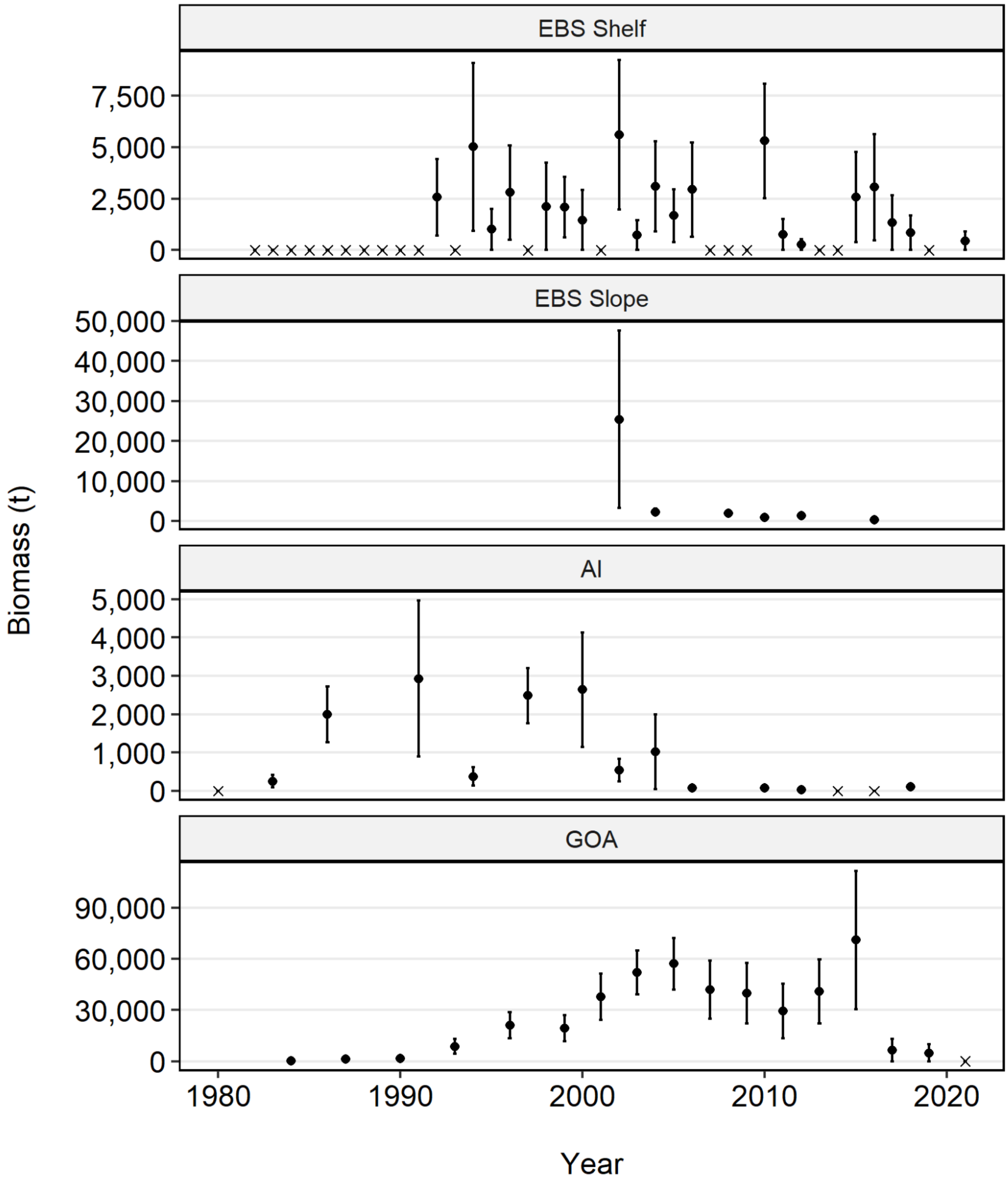


Figure 19A.10. Trends in Alaska Fisheries Science Center (AFSC) bottom trawl survey estimates of Pacific sleeper shark (*Somniosus pacificus*) total biomass (metric tons), reported here as an index of relative abundance. Error bars represent 1 standard error. Note that y-axis scales differ among survey areas (EBS = eastern Bering Sea, AI = Aleutian Islands, GOA = Gulf of Alaska). Years with zero catch are denoted by "✕". Updated through 2021.

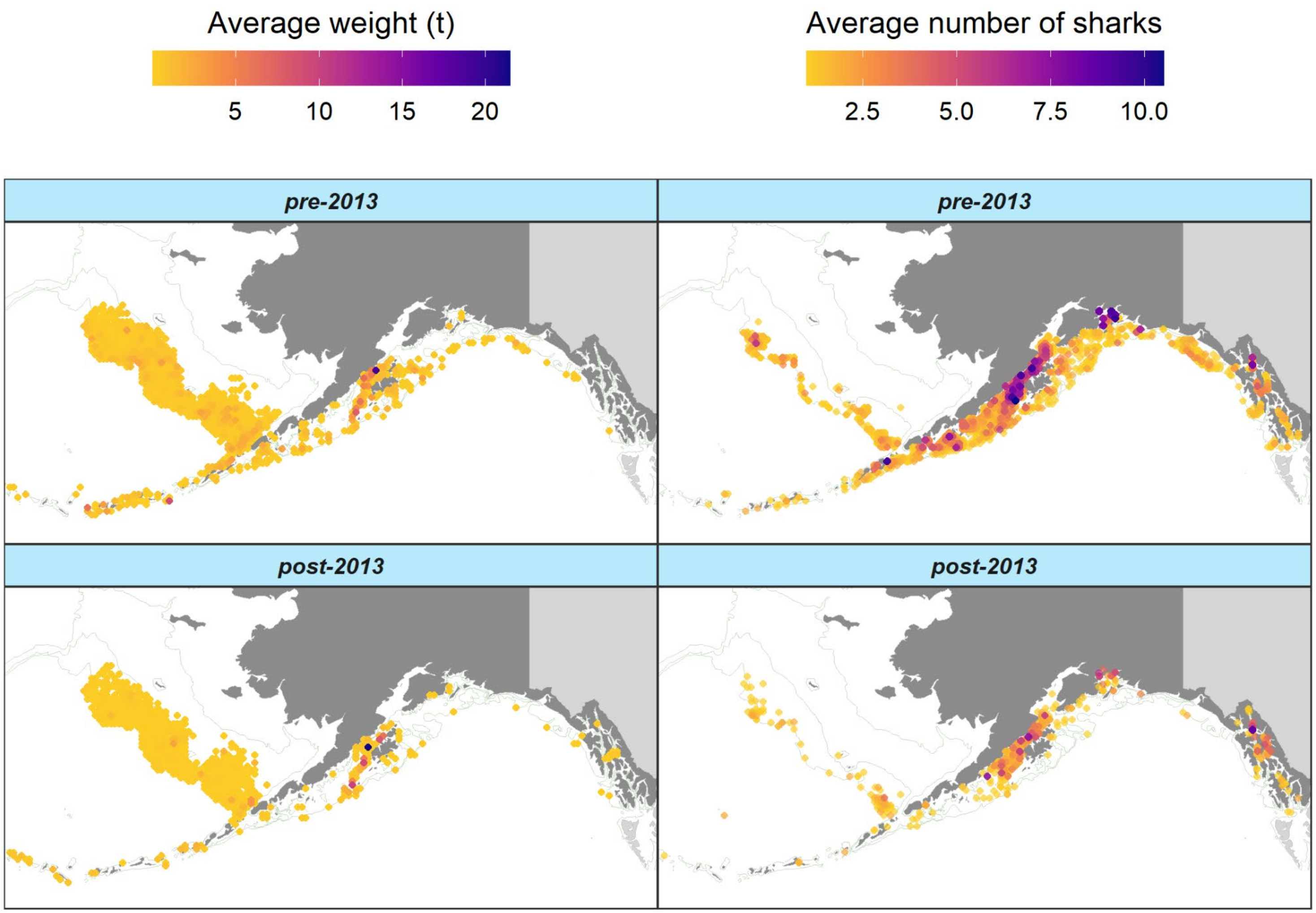


Figure 19A.11. Spatial trends in nonconfidential observed fishery and survey catches of Pacific sleeper sharks (*Somniosus pacificus*) over recent (2013-2021) and historic (1998-2012) time periods. Left panels show the fishery average weight (metric tons) per nonconfidential grid cell before and after 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).

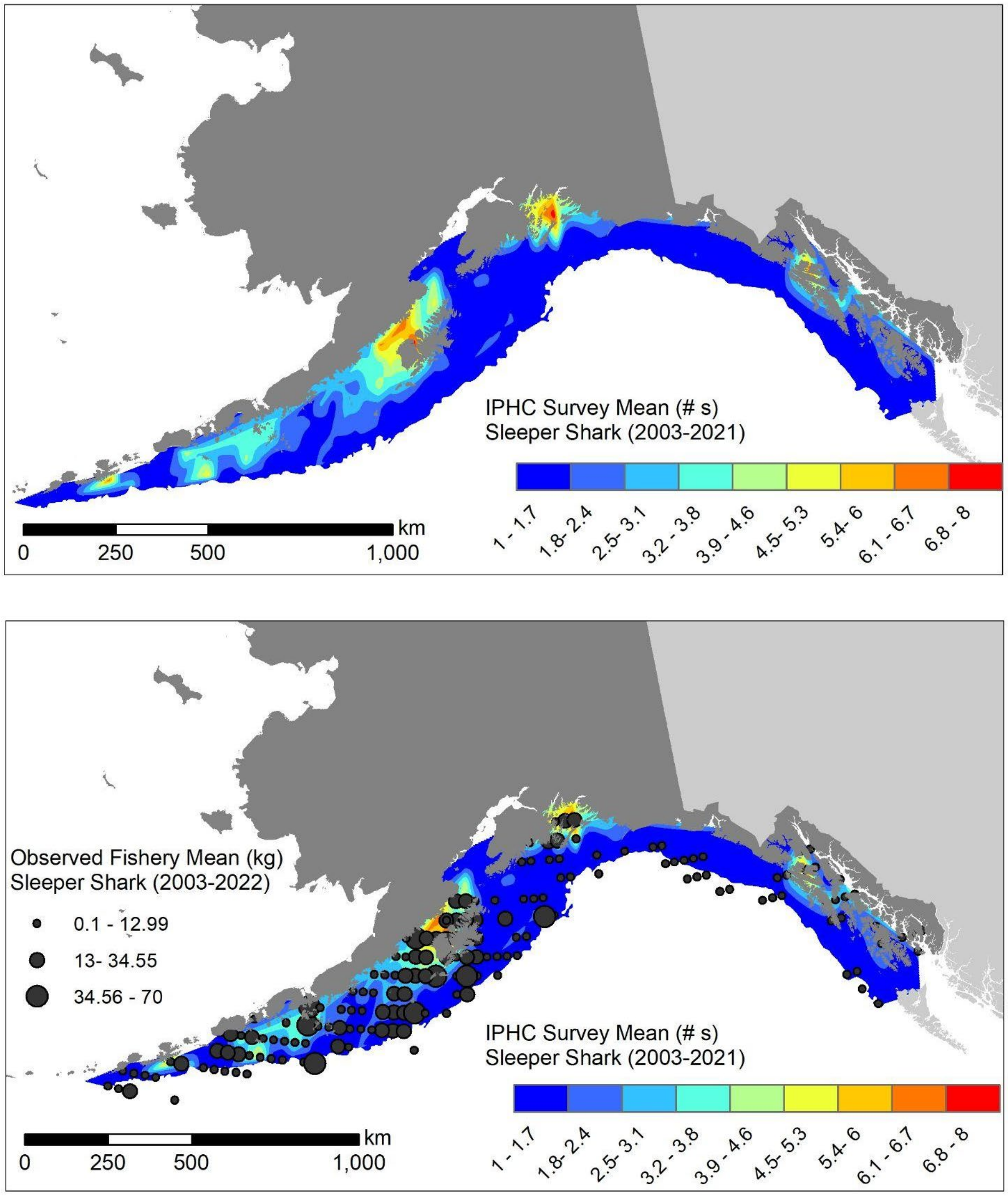
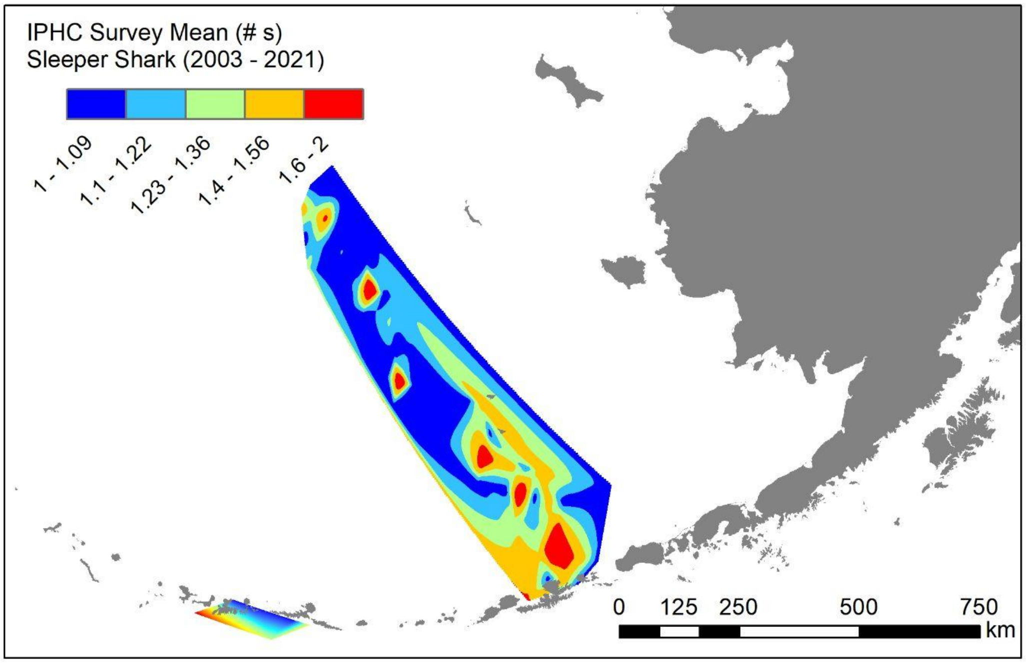


Figure 19A.12. Comparison of the spatial distribution of Pacific sleeper sharks (*Somniosus pacificus*) based on mean (2003-2021) International Pacific Halibut Commission (IPHC) survey conditions with the spatial distribution of the mean (2003-2022) fishery catch in the Gulf of Alaska. Top panel shows the IPHC mean conditions and bottom panel shows the overlay of the fishery mean on the IPHC mean.



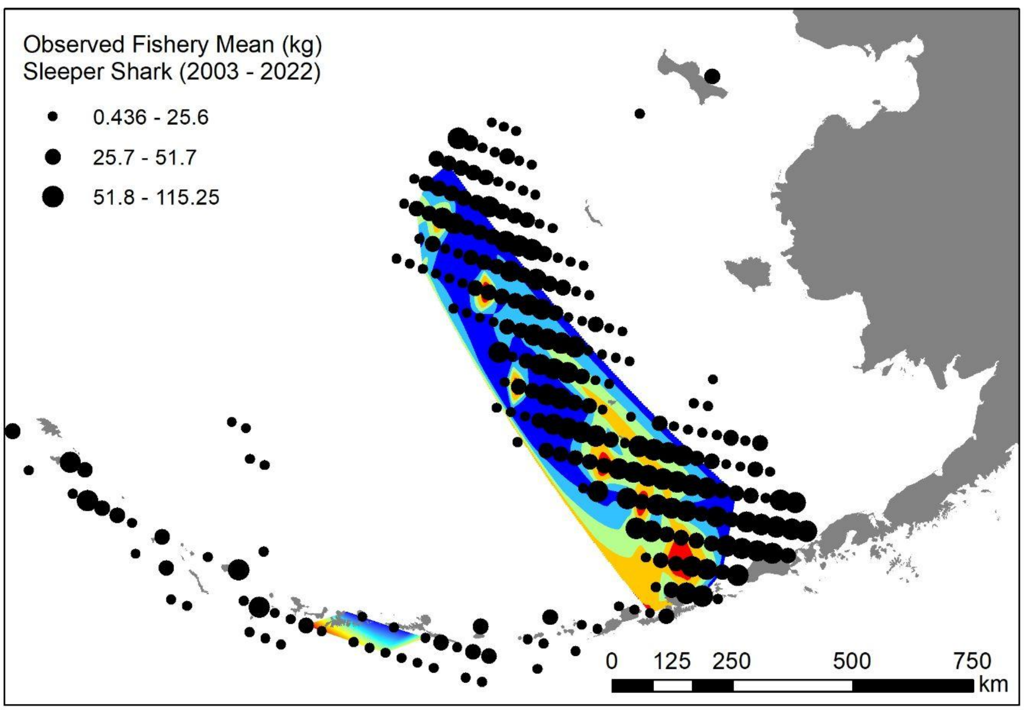


Figure 19A.13. Comparison of the spatial distribution of Pacific sleeper sharks (*Somniosus pacificus*) based on mean (2003-2021) International Pacific Halibut Commission (IPHC) survey conditions with the spatial distribution of the mean (2003-2022) fishery catch in the Bering Sea/Aleutian Islands. Top 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.

Appendix 19B. Life History of the Shark Stock Complex in the Bering Sea/Aleutian Islands and the Gulf of Alaska

Introduction

The shark stock complex is managed differently in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan (FMP) areas. The shark stocks in both FMP areas are relatively data-limited. In the BSAI, all shark species are managed in aggregate as Tier 6 stocks, meaning only catch history is used to create harvest specifications. In the GOA, there is sufficient information on Pacific spiny dogfish (*Squalus suckleyi*) to manage it as a Tier 5 stock, for which the harvest specifications are based on estimates of biomass and natural mortality (*M*). All other shark species in the GOA are managed as Tier 6 stocks. Though life history information is only used to inform the spiny dogfish specifications in the GOA, we present a thorough review of specific-specific life history for the three main shark species (Pacific spiny dogfish, Pacific sleeper shark *Somniosus pacificus*, and salmon shark *Lamna ditropis*) in both FMPs and provide any life history parameters available as auxiliary information. In general, there is little data specific to the BSAI region for any of the three primary shark species, thus GOA information is presented.

Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity (Musick et al. 2000; Table 19B.1 and Table 19B.2). The productivity of shark populations is very low relative to most commercially exploited teleosts (Holden 1974, Compagno 1990, Hoenig and Gruber 1990). Shark reproductive strategies in general are characterized by long gestational periods (6 months to 2 years), with small broods of large, well-developed offspring (Pratt and Casey 1990). Because of these life-history characteristics, many large-scale directed fisheries for sharks have collapsed, even where management was attempted (Castro et al. 1999). Ormseth and Spencer (2011) estimated the vulnerability of Alaska groundfish and found that the salmon shark, spiny dogfish, and Pacific sleeper shark were among the most vulnerable species in the GOA and BSAI FMPs.

Pacific Spiny Dogfish

Of the species in the shark stock complex, Pacific spiny dogfish (hereafter, "spiny dogfish") has been relatively well studied and life-history parameters are available. There is evidence that spiny dogfish make diel vertical migrations, residing on the bottom during the day and rising towards the surface at night (Orlov et al. 2011). Additionally, spiny dogfish make seasonal feeding migrations within the North Pacific Ocean, following thermal clines (Bizzarro et al. 2017). The rate of migration is variable among individual spiny dogfish and within regions, but some individuals make extensive migrations, including across the Pacific basin (McFarlane and King 2003).

Spiny dogfish grow to a maximum size of 160 cm in the ENP (Compagno 1984). The estimated age-at-50% maturity of spiny dogfish in the GOA is 36 years for females and 21 years for males (Tribuzio and Kruse 2012), similar to estimates from British Columbia (BC), Canada, of 35 years and 19 years, respectively (Saunders and McFarlane 1993). Longevity in the ENP is between 80 and 100 years (Campana et al. 2006). Growth coefficients (κ) for this species are among the slowest of all shark species, $\kappa = 0.03$ for females and 0.06 for males (Tribuzio et al. 2010b). Spiny dogfish is the only species within the shark stock complex that has been age-validated (Campana et al. 2006).

The mode of reproduction for spiny dogfish is lecithotrophic viviparity, previously termed "aplacental viviparity" or "ovoviviparity" (Blackburn et al. 2015, Musick and Ellis 2005). Embryos are nourished by their yolk sac while being retained in utero for 18-24 months. In the GOA, pupping may occur during winter months, based on the size of embryos observed during summer and fall sampling (Tribuzio and Kruse 2012). Ketchen (1972) reported timing of parturition in BC to be October through December, and in the Sea of Japan, parturition occurs between February and April (Kaganovskaia 1937, Yamamoto and

Kibezaki 1950). Off of Washington State, spiny dogfish have a long pupping season, which peaks from October to November (Tribuzio et al. 2009). Pupping is believed to occur in estuaries and bays or in mid-water over depths of approximately 165-370 m (Ketchen 1986). Small juveniles and young-of-the-year tend to inhabit the water column near the surface or areas not fished commercially, and are therefore not available to commercial fisheries until they grow or migrate to fished areas (Beamish et al. 1982, Tribuzio and Kruse 2012). The average litter size is 8.5 pups for spiny dogfish in the GOA (Tribuzio and Kruse 2012), 6.9 in Puget Sound, WA (Tribuzio et al. 2009), and 6.2 in BC (Ketchen 1972). The number of pups per female also increases with the size of the adult female, with estimates ranging from 0.20-0.25 more pups for every additional centimeter in length (Ketchen 1972, Tribuzio et al. 2009, Tribuzio and Kruse 2012).

Pacific Sleeper Shark

The Pacific sleeper shark is perhaps the most poorly understood of the three major shark species in the shark stock complex. As a consequence, some of the following life history information is borrowed from the better-studied Greenland shark (*S. microcephalus*), the North Atlantic congener of the Pacific sleeper shark. Sleeper sharks (*Somniosus* spp.) attain large sizes and are likely slow-growing and long-lived (Hansen 1963, Fisk et al. 2002). Ages are not readily available because the cartilage comprising the hard structures in sleeper sharks does not calcify to the degree of many other shark species, precluding age determination methods typically used for sharks (Wischniowski 2009, Matta et al. 2017). However, there are several lines of evidence suggesting that sleeper sharks grow slowly to old ages. A Greenland shark tagged in Northwest Atlantic Fisheries Organization Subarea 1 had only a small increase in growth, from 262 to 270 cm total length (TL) over the course of 16 years at liberty, an extremely slow rate of growth for an immature fish. A Greenland shark sampled in 1999 was determined to have been alive during the 1950s - 1970s because it had high levels of DDT, a persistent organic pollutant known to bioaccumulate in fatty tissues (Fisk et al. 2002). A more recent study employing radiocarbon analysis of eye lenses suggested extreme longevity of the Greenland shark (Nielsen et al. 2016), though the ages of sharks born prior to the bomb radiocarbon pulse (pre-1950) should be viewed with caution due to assumptions made during age estimation (Natanson et al. 2019). The most compelling argument for high longevity and late maturity from the Nielsen et al. (2016) study was an immature 220-cm TL Greenland shark estimated to be 49 years old based on a bomb pulse signal detected in its eye lens (Nielson et al. 2016). The assessment authors have initiated a pilot study employing eye lens radiocarbon analysis to investigate age and growth of Pacific sleeper sharks. Preliminary results suggest that, while still extremely slow, Pacific sleeper sharks grow about two times faster than Greenland sharks (Tribuzio, unpublished data), though more work is needed to confirm estimates of longevity and growth rate. The authors have submitted proposals to further fund this project.

Sleeper shark length data are not prevalent because their large size makes handling difficult. Large *Somniosus* sharks (including those presumed to be *S. pacificus*) observed in photographs taken in deep water have estimated lengths of up to 700 cm (Compagno 1984). The maximum lengths of captured Pacific sleeper sharks are 440 cm TL for females and 400 cm TL for males (Mecklenburg et al. 2002), in contrast to the largest (640 cm TL) confirmed Greenland shark (Davis et al. 2013). Pacific sleeper sharks as large as 430 cm TL have been caught in the western North Pacific Ocean (Orlov 1999). This species exhibits sexual dimorphism, with females growing to larger sizes than males (Orlov and Baitalyuk 2014).

The reproductive mode of sleeper sharks is likely aplacental viviparity, with embryos thought to be nourished by yolk in utero (Carter and Soma 2020), and, as in all elasmobranchs, fertilization is internal. Size at maturity is estimated based on limited reports of mature animals. Published observations suggest that mature female Pacific sleeper sharks are in excess of 365 cm TL and mature male Pacific sleeper sharks are in excess of 397 cm TL (Gotshall and Jow 1965, Yano et al. 2007). Three mature females 370 - 430 cm TL were opportunistically sampled off the coast of California. One of these sharks had 372 large vascularized eggs (24 - 50 mm) present in the ovaries (Ebert et al. 1987). Another mature Pacific sleeper shark 370 cm TL long was caught off Trinidad, California (Gotshall and Jow 1965) with ovaries containing 300 large ova. Despite these ovarian reserves of large ova, litter sizes of *Somniosus* species are thought to be small due to oxygenation limitations in the uterus (Carter and Soma 2020). To date, no pregnant females of *S. pacificus* have ever been landed; however, there is one record of a pregnant 5-meter female *S. microcephalus* caught south of the Faroe Islands in 1954, containing 10 embryos of about the same size, 37 cm (Koefoed 1957). These embryos appeared to be near-term, and size at birth of *Somniosus* species is thought to be approximately 40 cm TL (Yano et al. 2007). Very small Pacific sleeper sharks are not frequently encountered. Of two 74-cm TL *S. pacificus* that were caught off the coast of California (at depths of 1300 and 390 m), one still had an umbilical scar (Ebert et al. 1987); unfortunately, the date of capture was not reported. A newly-born shark of 41.8 cm was also caught at a depth of 35 m off Hiraiso, Ibaraki, Japan (Yano et al. 2007). Additionally, three small sharks, 65–75 cm TL, have been sampled in the Northwest Pacific, but the date of sampling was not reported (Orlov and Moiseev 1999). Sharks under 80 cm TL have only been captured in AFSC surveys a handful of times, mostly in the summer bottom trawl survey in the Bering Sea. Because of a lack of observations of mature and newly-born sharks, and the absence of capture dates in literature, the mating and pupping seasons are unknown for sleeper sharks. One study has examined the lengths of Pacific sleeper shark caught in the GOA, eastern Bering Sea (AFSC trawl survey data for both regions), western Bering Sea, along the Kamchatka Peninsula and in the Sea of Okhotsk (Russian survey and fishery data), and found that there were very few fish greater than 200 cm (Orlov and Baitalyuk 2014). These data indicate that the animals caught in the BSAI are small, some possibly even being neonates, and are all likely immature. In all of the other regions, the animals being caught are also primarily small, but occasionally larger, possibly mature animals are captured.

Because few large, mature Pacific sleeper sharks are found in surveys or fisheries, it is possible that adults inhabit abyssal depths and are generally not available nor susceptible to fishing or survey gear. Another possibility is that adults inhabit the nearshore environments but are not susceptible to the gear. At this time, the only evidence of the presence of large presumably adult Pacific sleeper sharks in any area comes from camera footage from deepwater drop cameras (e.g., Monterey Bay Research Institute) or the occasional adult that has been reported in the literature (Ebert et al. 1987, Yano et al. 2007). It is possible that the larger animals (>350 cm TL) captured in the GOA or BSAI are mature; however, maturity is generally not collected during surveys because the animals are released alive and biological information is not routinely collected from animals caught in commercial fishing activities.

Salmon Shark

Like other lamnid sharks, salmon sharks are active and highly mobile, capable of maintaining a body temperature up to 21.2 °C above ambient water temperature, and appear to maintain a constant body core temperature regardless of ambient temperatures (Goldman et al. 2004). Salmon sharks tend to be more pelagic and surface-oriented than the other major shark species in the GOA spending 72% of their time at depths less than 50 m (Weng et al. 2005), although time spent at deeper depths increases in offshore habitats (Coffey et al. 2017) and varies throughout the year, most likely related to seasonal changes in foraging behavior (Carlisle et al. 2011). Habitat use also varies with ontogeny, shifting from oceanic to neritic with approaching maturity (Carlisle et al. 2015a). Salmon sharks have been documented making extensive seasonal migrations from Alaska waters to other areas of the North Pacific (Weng et al. 2008). However, migration appears to be variable among individuals. While some salmon sharks migrate south during the winter months, others remain in Alaska waters throughout the year (Hulbert et al. 2005, Weng et al. 2005).

Salmon sharks show a high degree of size and sex segregation within the North Pacific Ocean. Larger sharks are found further north, and males dominate the western North Pacific (WNP) and females dominate the eastern North Pacific (ENP), particularly at high latitudes (Nagasawa 1998, Goldman and Musick 2008). Adult salmon sharks typically range in size from 180–210 cm pre-caudal length (PCL*)*

(Goldman and Musick 2006) in the ENP and can weigh upwards of 220 kg. Length-at-maturity in the WNP is approximately 140 cm PCL for males and 170–180 cm PCL for females (Tanaka 1980), and these lengths correspond to approximate ages of 5 years and 8–10 years, respectively. Length-at-maturity in the ENP is 125-145 cm PCL (3-5 years) for males and from 160–180 cm PCL (6-9 years) for females (Goldman and Musick 2006). Salmon sharks in the ENP and WNP attain the same maximum length (approximately 215 cm PCL for females and about 190 cm PCL for males). However, males larger than approximately 140-cm PCL and females larger than approximately 110-cm PCL in the ENP attain a greater weight-at-length than their same-sex counterparts in the WNP (Goldman and Musick 2006).Tanaka (1980) (see also Nagasawa 1998) states that maximum age from vertebral analysis of WNP salmon sharks is at least 25 years for males and 17 years for females, and von Bertalanffy growth coefficients are 0.17 and 0.14 for males and females, respectively. Goldman and Musick (2006) gave maximum ages for ENP salmon sharks (also from vertebral analysis) of 17 years for males and 30 years for females, with growth coefficients of 0.23 and 0.17 for males and females, respectively. It should be noted that salmon shark ages estimated from growth-zone counts in vertebral centra have yet to be independently validated, and as such all reported ages should be regarded as unconfirmed.

The reproductive mode of salmon sharks is lecithotrophic viviparity and includes an oophagous stage when embryos feed on eggs produced by the ovary (Tanaka 1986 cited in Nagasawa 1998, Gallucci et al. 2008, Conrath et al. 2014). Litter size is three to five pups, and litters in the WNP have been reported to be male-dominated 2.2:1 (Nagasawa 1998, Gallucci et al. 2008, Conrath et al. 2014). Salmon sharks appear to have a biennial reproductive cycle; mating occurs in the late summer and early fall and parturition occurs in the spring following a 9 to 10-month gestation period, after which females sharks enter a resting period of at least 14 months (Nagasawa 1998, Tribuzio 2004, Goldman and Musick 2006, Conrath et al. 2014). Size at parturition is between 60 and 65 cm PCL throughout the North Pacific (Tanaka 1980, Goldman and Musick 2006).

Literature Cited

Ali, M., A. Saad, C. Reynaud, and C. Capapé. 2012. Occurrence of basking shark, *Cetorhinus maximus* (Elasmobranchii: Lamniformes: Cetorhinidae), off the Syrian coast (eastern Mediterranean) with first description of egg case. Acta Ichthyologica Et Piscatoria 42:335-339.

Andrews, A. H., and L. A. Kerr. 2015. Validated age estimates for large white sharks of the northeastern Pacific Ocean: altered perceptions of vertebral growth shed light on complicated bomb Δ14C results. Environ. Biol. Fish. 98:971-978.

Barnett, A., J. M. Braccini, C. A. Awruch, and D. A. Ebert. 2012. An overview on the role of Hexanchiformes in marine ecosystems: biology, ecology and conservation status of a primitive order of modern sharks. J. Fish. Biol. 80:966-990

Beamish, R. J., G. A. McFarlane, K. R. Weir, M. S. Smith, J. R. Scarsbrook, A. J. Cass and C. C. Wood. 1982. Observations on the biology of Pacific hake, walleye pollock and spiny dogfish in the Strait of Georgia, Juan de Fuca Strait and off the west coast of Vancouver Island and United States, July 13-24, 1976. Can. MS Rep. Fish. Aquat. Sci. 1651:150p.

Bizzarro, J. J., A. B. Carlisle, W. D. Smith, and E. Cortes. 2017. Diet composition and trophic ecology of Northeast Pacific Ocean sharks. Pages 111-148 in S. E. Larson and D. Lowry, editors. Northeast Pacific Shark Biology, Research and Conservation, Part A.

Blackburn, D. G. 2015. Evolution of vertebrate viviparity and specializations for fetal nutrition: A quantitative and qualitative analysis. J. Morphol. 276:961-990.

Bonham, K. 1954. Food of the dogfish *Squalus acanthias*. Fish Res Paper. 1:25-36.

Campana, S. E., C. Jones, G. A. McFarlane, and S. Myklevoll. 2006. Bomb dating and age validation using the spines of spiny dogfish (*Squalus acanthias*). Environ. Biol. Fish. 77:327-336.

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

Carlisle, A. B., C. R. Perle, K. J. Goldman, B. A. Block, and J. M. Jech. 2011. Seasonal changes in depth distribution of salmon sharks (*Lamna ditropis*) in Alaskan waters: implications for foraging ecology. Can. J. Fish. Aquat. Sci. 68:1905-1921.

Carlisle, A. B., K. J. Goldman, S. Y. Litvin, D. J. Madigan, J. S. Bigman, A. M. Swithenbank, T. C. Kline, Jr., and B. A. Block. 2015a. Stable isotope analysis of vertebrae reveals ontogenetic changes in habitat in an endothermic pelagic shark. Proc. Biol. Sci. 282:20141446.

Castro, J.I., C.M. Woodley and R. L. Brudek. 1999. A preliminary evaluation of the status of shark species. FOA Fisheries Tech. Paper No. 380. FAO Rome, 72p.

Coffey, D. M., A. B. Carlisle, E. L. Hazen, and B. A. Block. 2017. Oceanographic drivers of the vertical distribution of a highly migratory, endothermic shark. Sci. Rep. 7:10434.

Conrath, C.L., C.A. Tribuzio, and K.J. Goldman. 2014. Notes on the reproductive biology of female salmon sharks in the eastern North Pacific Ocean. Trans. Am. Fish. Soc. 143:363-368.

Compagno, L.J.V. 1984. Sharks of the world: An annotated and illustrated catalogue of shark species known to date. FAO species catalogue vol. 4.

Corro-Espinosa, D., J. F. Marquez-Farias, and A. Muhlia-Melo. 2011. Size at maturity of the Pacific sharpnose shark *Rhizoprionodon longurio* in the Gulf of California, Mexico. Ciencias Marinas 37:201-214.

Cortes, E. 1999. Standardized diet compositions and trophic levels of sharks. J. Mar. Sci. 56:707-717.

Davis, B., D. L. VanderZwaag, A. Cosandey-Godin, N. E. Hussey, S. T. Kessel, and B. Worm. 2013. The Conservation of the Greenland Shark (*Somniosus microcephalus*): Setting Scientific, Law, and Policy Coordinates for Avoiding a Species at Risk. J. Internat. Wildlife Law Policy 16:300-330.

Doherty, P. D., J. M. Baxter, B. J. Godley, R. T. Graham, G. Hall, J. Hall, L. A. Hawkes, S. M. Henderson, L. Johnson, C. Speedie, and M. J. Witt. 2019. Seasonal changes in basking shark vertical space use in the north-east Atlantic. Mar. Biol. 166:129.

Dureuil, M., and B. Worm. 2015. Estimating growth from tagging data: an application to north-east Atlantic tope shark *Galeorhinus galeus*. J. Fish. Biol. 87:1389-1410.

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. 2002. Some observations on the reproductive biology of the sixgill shark *Hexanchus griseus* (Bonnaterre, 1788) from southern African waters. S. Afr. J. Mar. Sci. 24:359-363.

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

Flammang, B. E., D. A. Ebert, and G. M. Cailliet. 2008. Reproductive biology of deep-sea catsharks (Chondrichthyes: Scyliorhinidae) in the eastern North Pacific. Environ. Biol. Fish. 81:35-49.

Gallucci, V. F., R. J. Foy, S. M. O'Brien, A. Aires-Da-Silva, H. Nesse, B. Langseth, N. Vega, I. Taylor, and K. J. Goldman. 2008. Information from a pregnant salmon shark *Lamna ditropis* in the eastern North Pacific with observations on oophagous reproduction. J. Fish. Biol. 73:732-739.

Goldman, K.J. 2002. Aspects of age, growth, demographics and thermal biology of two Lamniform shark species. Ph.D. dissertation. College of William and Mary, School of Marine Science, Virginia Institute of Marine Science. 220 pp.

Goldman, K.J., S.D. Anderson, R.J. Latour and J.A. Musick. 2004. Homeothermy in adult salmon sharks, *Lamna ditropis*. Env. Biol. Fish. 71:403-411.

Goldman, K.J. and J.A. Musick. 2006. Growth and maturity of salmon sharks in the eastern and western North Pacific, with comments on back-calculation methods. Fish. Bull 104:278-292.

Goldman, K. J., and J. A. Musick. 2008. The biology and ecology of the salmon shark, *Lamna ditropis*. Pages 95-104 in M. D. Camhi, E. K. Pikitch, and E. A. Babcock, editors. Sharks of the open ocean: Biology, fisheries and conservation. Blackwell Publishing, Oxford, UK.

Gotshall, D. W., and T. Jow. 1965. Sleeper sharks (*Somniosus pacificus*) off Trinidad, California, with life history notes. Cal. Fish Game 51:294 -298.

Hansen, P. M. 1963. Tagging experiments with the Greenland shark (*Somniosus microcephalus* (Bloch and Schneider)) in Subarea 1.in North Atlantic Fish Marking Symposium, Woods Hole, MA.

Holden, M.J. 1974. Problems in the rational exploitation of elasmobranch populations and some suggested solutions. *In* Sea Fisheries Research (Harden Jones, FR ed.). pp. 117-137.

Hulbert, L., A. M. Aires-Da-Silva, V. F. Gallucci, and J. S. Rice. 2005. Seasonal foraging behavior and migratory patterns of female *Lamna ditropis* tagged in Prince William Sound, Alaska. J. Fish Biol. 67:490-509.

Hoenig, J. M. and S. H. Gruber. 1990. Life history patterns in the elasmobranchs: implications for fishery management. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt, Jr., S.H.)

Indian Ocean Tuna Commission. 2016. Blue shark supporting information. Available at http://www.iotc.org/sites/default/files/documents/science/species_summaries/english/Blue%20shark%20Supporting%20Information.pdf

Kaganovskaia, S. M. 1937. On the commercial biology of *Squalus acanthias*. Izv. Tikhookean. Nauch. Issled. Inst. Ryb. Khoz. Okeanogr. 10:105-115.

Ketchen, K. S. 1972. Size at maturity, fecundity, and embryonic growth of the spiny dogfish (*Squalus acanthias*) in British Columbia waters. J. Fish. Res. Bd. Can. 29:1717-1723.

Ketchen, K. S. 1986. The spiny dogfish (*Squalus acanthias*) in the northeast Pacific and a history of its utilization. Can. Spec. Publ. Fish. Aquat. Sci. 88:78p.

Koefoed, E. 1957. A uterine foetus and the uterus from a Greenland shark. Notes on the Greenland shark *Acanthorhinus carcharias* (Gunn). Report on Norwegian Fishery and Marine Investigations 11:8-12.

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.

Máquez-Farias, J. F., D. Corro-Espinosa, and J. L. Castillo-Géniz. 2005. Observations on the biology of the Pacific sharpnose shark (*Rhizoprionodon longurio*, Jordan and Gilbert, 1882), captured in southern Sinaloa, México. J. Northw. Atlantic Fish. Sci. 35:107-114.

Matta, M. E., C. A. Tribuzio, D. A. Ebert, K. J. Goldman, and C. M. Gburski. 2017. Age and growth of elasmobranchs and applications to fisheries management and conservation in the northeast Pacific Ocean. Pages 179-220 in S. Larson and D. Lowry, editors. Northeast Pacific Shark Biology, Research and Conservation Part A. Academic Press.

McClain, C. R., M. A. Balk, M. C. Benfield, T. A. Branch, C. Chen, J. Cosgrove, A. D. Dove, L. C. Gaskins, R. R. Helm, F. G. Hochberg, F. B. Lee, A. Marshall, S. E. McMurray, C. Schanche, S. N. Stone, and A. D. Thaler. 2015. Sizing ocean giants: patterns of intraspecific size variation in marine megafauna. PeerJ 3:e715.

McFarlane, G. A., and J. R. King. 2003. Migration patterns of spiny dogfish (*Squalus acanthias*) in the North Pacific Ocean. Fish. Bull. 101:358-367.

Mecklenburg, C.W., T.A. Anthony, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda Maryland 1037 pp.

Musick, J. A., G. Burgess, G. Cailliet, M. Camhi, and S. Fordham. 2000. Management of sharks and their relatives (Elasmobranchii). Fisheries 25:9-13.Nagasawa, K. 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean. Bulletin of the North Pacific Anadromous Fish Commission, No. 1:419-433.

Musick, J. A., and J. K. Ellis. 2005. Reproductive evolution of Chondrichthyans. In: Hamlett, W.C. (ed) Reproductive biology and phylogeny of Chondrichthyes: Sharks, batoids and chimaeras. Science Publishers, Inc, Enfield, New Hampshire, pp 45-79.

Nagasawa, K. 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus spp.*) in the North Pacific Ocean. Bulletin of the North Pacific Anadromous Fish Commission, No. 1:419-433.

Natanson, L. J., L. L. Hamady, and B. J. Gervelis. 2016. Analysis of bomb radiocarbon data for common thresher sharks, *Alopias vulpinus*, in the northwestern Atlantic Ocean with revised growth curves. Environ. Biol. Fish. 99:39-47.

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

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

Orlov, A. M., V. F. Savinykh, E. F. Kulish, and D. V. Pelenev. 2011. New data on the distribution and size composition of the North Pacific spiny dogfish *Squalus suckleyi* (Girard, 1854). Scientia Marina 76:111-122.

Orlov. A.M. and A.A. Baitalyuk. 2014. Spatial distribution and features of biology of Pacific sleeper shark *Somniosus pacificus* in the North Pacific. J. Ichthyology 54:533-553.

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.

Ormseth, O.A., P.D. Spencer. 2011. An assessment of vulnerability in Alaska groundfish. Fish. Res. 112:127-133.

Pratt, H., L., Jr. and J. G. Casey. 1990. Shark reproductive strategies as a limiting factor in directed fisheries, with a review of Holden's method of estimating growth parameters. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt, Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 97-109. NOAA Technical Report NMFS 90.

Ripley, W.E. 1946. The soupfin shark and the fishery. In The Biology of the Soupfin *Galeorhinus zyopterus* and Biochemical Studies of the Liver. State of California Department of Natural Resources Division of Fish and Game Bureau of Marine Fisheries Fish Bulletin No. 64.

Saunders, M.W. and G.A. McFarlane. 1993. Age and length at maturity of the female spiny dogfish (*Squalus acanthias*) in the Strait of Georgia, British Columbia, Canada. Environ. Biol. Fish. 38:49-57.

Sato, K., M. Nakamura, T. Tomita, M. Toda, K. Miyamoto, and R. Nozu. 2016. How great white sharks nourish their embryos to a large size: evidence of lipid histotrophy in lamnoid shark reproduction. Biol. Open 5:1211-1215.

Sigler M.F., L. Hulbert, C. R. Lunsford, N. Thompson, K. Burek, G. Corry-Crowe, and A. Hirons. 2006. Diet of Pacific sleeper shark, a potential Steller sea lion predator, in the north-east Pacific Ocean. J. Fish Biol. 69:392-405.

Smith, S. E., R. C. Rasmussen, D. A. Ramon, and G. M. Cailliet. 2008. The biology and ecology of thresher sharks (Alopiidae). Pages 60-68 in M. D. Camhi, E. K. Pikitch, and E. A. Babcock, editors. Sharks of the Open Ocean. Blackwell Publishing.

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. 1980. Biological investigation of *Lamna ditropis* in the north-western waters of the North Pacific. *In* Report of investigation on sharks as a new marine resource (1979). Published by: Japan Marine Fishery Resource Research Center, Tokyo [English abstract, translation by Nakaya].

Tanaka, S., T. Kitamura, T. Mochizuki, and K. Kofuji. 2011. Age, growth and genetic status of the white shark (*Carcharodon carcharias*) from Kashima-nada, Japan. Mar. Freshwat. Res. 62:548-556.

Tribuzio, C.A. 2004. An investigation of the reproductive physiology of two North Pacific shark species: spiny dogfish (*Squalus acanthias*) and salmon shark (*Lamna ditropis*). MS Thesis, University of Washington. 137pgs.

Tribuzio, C. A., Gallucci, V. F., and Bargmann, G. G. 2009. A survey of demographics and reproductive biology of spiny dogfish (*Squalus acanthias*) in Puget Sound, WA. In ' Biology and Management of Dogfish Sharks'. (Eds. V. F. Gallucci, G. A. McFarlane, and G. Bargmann) pp. 181-194. (American Fisheries Society: Bethesda, MD)

Tribuzio, C.A., G.H. Kruse and J.T. Fujioka. 2010b. Age and growth of spiny dogfish (*Squalus acanthias*) in the Gulf of Alaska: Analysis of alternative growth models. Fish. Bull. 102:119-135.

Tribuzio, C.A. and G. H. Kruse. 2012. Life history characteristics of a lightly exploited stock of *Squalus suckleyi*. J. Fish Biol. 80:1159-1180.

Tribuzio, C. A., W. W. Strasburger, and G. H. Kruse. 2017. Do abiotic and ontogenetic factors influence the diet of a generalist predator? Feeding ecology of the Pacific spiny dogfish (*Squalus suckleyi*) in the northeast Pacific Ocean. Environ. Biol. Fish. 100:685-701.

Weng, K.C., A. Landiera, P.C. Castilho, D.B. Holts, R.J. Schallert, J.M. Morrissette, K.J. Goldman, and B.A. Block. 2005. Warm sharks in polar seas: satellite tracking from the dorsal fins of salmon sharks. Science 310:104-106.

Weng, K. C., D. G. Foley, J. E. Ganong, C. Perle, G. L. Shillinger, and B. A. Block. 2008. Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. Marine Ecology Progress Series 372:253-264.

Williams, G. D., K. S. Andrews, D. A. Farrer, G. G. Bargmann, and P. S. Levin. 2011. Occurrence and biological characteristics of broadnose sevengill sharks (*Notorynchus cepedianus*) in Pacific Northwest coastal estuaries. Environ. Biol. Fish. 91:379-388.

Wischniowski, S. 2009. Technique development for age determination of the Pacific sleeper shark (*Somniosus pacificus*). IPHC Report of Assessment and Research Activities 2008: 389-392.

Wood, C. C., Ketchen, K. S., and Beamish, R. J. 1979. Population dynamics of spiny dogfish (*Squalus acanthias*) in British Columbia waters. Journal of the Fisheries Research Board of Canada 36, 647-656.

Yamamoto, T. and O. Kibezaki. 1950. Studies on the spiny dogfish *Squalus acanthias*. (L.) on the development and maturity of the genital glands and growth. Hokkaido Reg Fish Resour Res Rep. 3:531-538.

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.* J. Fish Biol. 70: 374-390.

IOTC-2023-WPEB19-32

Table 19B.1. Biological characteristics and depth ranges for shark species in Alaska waters. The life history data reported in this table are specific to the Northeast Pacific Ocean when available; however, some data sources are from other regions (e.g., North Atlantic). TL is total length with the tail in a natural position, TLext is total length with the tail extended, and PCL is pre-caudal length. Missing information is denoted by "?".

Scientific Name	Common Name	FMP	Maximum TL (cm)	Maximum Age (yr)	Age, Length at 50% Maturity	Feeding Mode	Fecundity	Depth Range (m)
Lamna ditropis	**Salmon shark**	**BSAI**	**310**[1]	**20**[2]	**♀6-9 yr, 165 cm PCL ♂3-5 yr, 124 cm PCL**[2]	**Predator**[3]	**4-5**[4]	**0-1864**[1]
Somniosus pacificus	**Pacific sleeper shark**	**BSAI, GOA**	**700**[5]	**?**	**♀370 cm TL**[6]	**Predator/Benthic/Scavenger**[7]	**?**	**0-≥2,000**[5]
Squalus suckleyi	**Pacific spiny dogfish**	**BSAI, GOA**	**160**[5]	**80-107**[8]	**♀36 yr, 97.3 cm TLext ♂21 yr, 74.5 cm TLext**[8]	**Predator/Benthic/Scavenger**[9]	**7-14**[8]	**0-1,244**[1]
Alopias vulpinus	Common thresher shark	GOA	640[1]	≥38[10]	303 cm TL[11]	Predator[11]	2-7[11]	0-366[1]
Apristurus brunneus	Brown cat shark	BSAI, GOA	71[1]	?	♀50.1 cm TL, ♂51.4 cm TL[12]	Benthic[13]	?	33-1,306[1]
Carcharodon carcharias	White shark	GOA	700[14]	≥30[15]	♀450 cm TL, ♂310 cm TL[16]	Predator[3]	6-10[17]	0-1,280[1]
Cetorhinus maximus	Basking shark	BSAI, GOA	1,227[14]	?	♀8.1-9.8 m TL, ♂4.0-5.0 m TL[5]	Plankton[3]	34[18]	0-1,500[19]
Galeorhinus galeus	Tope/soupfin) shark	GOA	195[5]	59[20]	♀17 yr, 155 cm TL, ♂12 yr, 121 cm TL[20]	Predator/Benthic[21]	16-54[21]	0-1,100[22]
Hexanchus griseus	Bluntnose sixgill shark	BSAI, GOA	550[14]	?	♀421 cm TL[23]	Predator[3]	22-108[23]	0-2,500[1]
Notorynchus cepedianus	Broadnose sevengill	GOA	296[24]	?	♀220-250 cm TL, ♂150-180 cm TL[25]	Predator/Benthic/Scavenger[5]	60-107[24]	0-570[22]
Prionace glauca	Blue shark	BSAI, GOA	380[1]	25[26]	♀5-7 yr, 194 cm TL, ♂4-7 yr, 201 cm TL[26]	Predator[3]	4-135[26]	0-350[1]
Rhizoprionodon longurio	Pacific sharpnose	BSAI	154[5]	?	♀92.9 cm TL, ♂100.6 cm TL[27]	Predator/Benthic[28]	1-12[28]	0-100[22]

[1] Stevenson et al. (2007)
[2] Goldman & Musick (2006)
[3] Cortes (1999)
[4] Gallucci et al. (2008)
[5] Compagno (1984)
[6] Ebert et al. (1987)
[7] Sigler et al. (2006)
[8] Tribuzio & Kruse (2012)
[9] Tribuzio et al. (2017)
[10] Natanson et al. (2016)
[11] Smith et al. (2008)
[12] Flammang et al. (2008)
[13] Mecklenburg et al. (2002)
[14] McClain et al. (2015)
[15] Andrews & Kerr (2015)
[16] Tanaka et al. (2011)
[17] Sato et al. (2016)
[18] Ali et al. (2012)
[19] Doherty et al. (2019)
[20] Dureuil & Worm (2015)
[21] Ripley (1946)
[22] Love et al. (2005)
[23] Ebert (2002)
[24] Barnett et al. (2012)
[25] Williams et al. (2011)
[26] Indian Ocean Tuna Commission (2016)
[27] Corro-Espinosa et al. (2011)
[28] Máquez-Farias et al. (2005)

Table 19B.2. Life history parameters for spiny dogfish, Pacific sleeper, and salmon sharks. Top: Length-weight coefficients and average lengths and weights are provided for the formula $W = aL^b$, where W = weight in kilograms and L = PCL (precaudal length in cm). Bottom: Length at age coefficients from the von Bertalanffy growth model, where L_∞ is PCL or the TL_{ext} (total length with the upper lobe of the caudal fin depressed to align with the horizontal axis of the body).

Species	Area	Gear type	Sex	Average size PCL (cm)	Average weight (kg)	a	b	N
Spiny dogfish	GOA	NMFS bottom trawl	M	63.4	2	1.40E-05	2.86	92
Spiny dogfish	GOA	NMFS bottom trawl	F	63.8	2.29	8.03E-06	3.02	140
Spiny dogfish	GOA	Longline	M	64.6	1.99	9.85E-06	2.93	156
Spiny dogfish	GOA	Longline	F	64.7	2.2	3.52E-06	3.2	188
Pacific sleeper shark	Central GOA	Longline	M	166	69.7	2.18E-05	2.93	NA
Pacific sleeper shark	Central GOA	Longline	F	170	74.8	2.18E-05	2.93	NA
Salmon shark	Central GOA	NA	M	171.9	116.7	3.20E-06	3.383	NA
Salmon shark	Central GOA	NA	F	184.7	146.9	8.20E-05	2.759	NA

Species	Sex	L_∞ (cm)	κ	t_0 (years)	M	Age at first Recruit
Spiny Dogfish	M	93.7 (TL_{ext})	0.06	-5.1	0.097	NA
Spiny Dogfish	F	132.0 (TL_{ext})	0.03	-6.4		
Pacific Sleeper Shark	M	NA	NA	NA	NA	NA
Pacific Sleeper Shark	F	NA	NA	NA		
Salmon Shark	M	182.8 (PCL)	0.23	-2.3	0.18	5
Salmon Shark	F	207.4 (PCL)	0.17	-1.9		

Sources: NMFS GOA bottom trawl surveys in 2005; Wood et al. (1979); Goldman (2002); Sigler et al (2006); Goldman and Musick (2006); and Tribuzio and Kruse (2012).

Appendix 19C. Supplemental Catch Data Summary

Introduction

This appendix summarizes spatial distribution and sources of fishery catches in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). Logbook, eLandings and fish ticket data are not included here. The format of this report is under development and should be considered a draft. Data are queried from the Alaska Regional Office Catch Accounting System (CAS) and queried through AKFIN. The results are based on total catch estimates and observer deployment information. Due to minor differences in observer strata assignments between CAS and what vessels log into the Observer Declare and Deploy System (ODDS), the total catch estimates may be slightly different from those values reported in the North Pacific Observer Program Annual Reports. Any differences are expected to be minor. Data prior to the 2013 Observer Program Restructure are not included in the analyses presented here due to structural changes in the North Pacific Observer Program.

Observer Deployment Performance

This section summarizes the projected and realized observer coverage rates since 2016 for all partial coverage trips (i.e., not specific to any fishery). Observer strata are defined in the North Pacific Observer Program Annual Reports as follows: Full Coverage - catcher/processors (with limited exceptions), motherships, catcher vessels that are participating in programs that have transferable prohibited species catch, catcher vessels using trawl gear that have requested full coverage for all fishing activity within the BSAI and inshore processors receiving or processing Bering Sea pollock. Partial Coverage - Catcher vessels fishing in federally managed groundfish or parallel fisheries, excepting when in full coverage, catcher vessels participating in the Pacific halibut or sablefish IFQ fisheries, catcher vessels participating in the CDQ fisheries or those < 46ft LOA using hook-and-line gear for groundfish, catch/processors that qualify for partial coverage; and shoreside or stationary floating processors that are not in the full coverage category. No Coverage/Selection - vessels < 40ft LOA, jig and exempted vessels

There are two Electronic Monitoring (EM) programs in effect: fixed-gear EM and trawl EM. The fixed-gear EM program includes both pot and hook-and-line vessels. Trips logged into ODDS for that program have a partial coverage selection rate, and if selected, the vessel must run the EM cameras for the trip duration. After the videos are submitted, 30% of recorded hauls are reviewed and catch is fully censused. There are no biological samples collected from fixed-gear EM trips. Vessels operating in the trawl EM program record all trips and all of the videos are reviewed, however, the review is for compliance monitoring only. Vessels operating in the trawl EM program are required to retain all catch (with limited exceptions) for shoreside sampling by observers at the plant.

For 2013 - 2015, the North Pacific Observer Program deployment strata included vessel level selection criteria and coverage rates are not comparable to current time series, therefore, not included in the table below. Full Selection trips are all assumed to be 100% covered and not reported in Table 19C.1. The Zero Selection trips are also not included. Values are from the Annual Deployment Plans and the Annual Reports, available on the NPFMC website. Not all observer strata were covered each year. For example, Hook-and-line (HAL) tender was only covered in 2017, in which a total of four trips were made and thus deemed not a useful stratum to include. In 2020, observer sampling was significantly impacted March-June due to the pandemic, resulting in minimal coverage during those months and reducing the annual realized coverage rates. The trawl EM EFP went into effect in 2020, in this strata all trips have 100% of video reviewed for compliance monitoring, and full retention is in effect. Observer sampling occurs shoreside with the target of all Trawl EM Exempted Fishing Permit (EFP) deliveries being observer sampled in the BSAI and 30% in the GOA. The below table only documents partial coverage rates.

Sources of Catch

This section summarizes how the data which are used to estimate total catch are collected, including gear type, observer strata and if a trip was monitored. All species-specific shark catches are combined for total complex catch in each of the relevant categories. Most shark catch occurs in the Central and Eastern GOA and is predominantly from hook and line (i.e., longline) fisheries (Figure 19C.1). Shark catches in the Western GOA have been increasingly more the result of pelagic trawl fisheries, and most of eastern Bering Sea catch is also from pelagic trawl fisheries. In contrast, shark catch in the Aleutian Islands is mostly from non-pelagic trawl fisheries. Proportion of catch from each observer strata is highly dependent on the region and gear, of note is the dominance of catch from partial coverage vessels and the inclusion of catch from EM vessels (Figure 19C.2). Lastly, much of the GOA catch comes from trips that are not monitored (Figure 19C.3). The results is that a global average of catch rates from a small volume of catch is used to estimate the unobserved catch.

Fishery Catches Outside of the Assessment

Shark catch occurs in fisheries or areas that are not included in the total catch estimates used for management or harvest specification. Given the broad spatial extent of the shark species, catches that occur within nearshore waters (i.e., "inside" waters, NMFS Areas 649 – Prince William Sound, and 659 – Southeast Alaska) and Alaska Department of Fish and Game (ADFG) fisheries likely impact the stocks in federal waters as well. In this section we report catches federally prosecuted fisheries occurring in NMFS Areas 649/659, the Pacific halibut and sablefish IFQ fisheries (Table 19C.2) and ADFG sport fishery harvest (Table 19C.3). Data on shark catch are not available from ADFG managed commercial fisheries, data on shark catch from ADFG sport fisheries were provided by S. Webster (ADFG, October 10, 2022). None of these catches count towards the TAC/ABC/OFL.

Spatial Distribution of Catch Estimates

All catch of shark species in the shark stock complexes in the BSAI and GOA Fishery Management Plan (FMP) areas is incidental. Spatial patterns in incidental shark catch therefore often reflect behavior of target groundfish fisheries, and are not necessarily indicative of areas of high shark biomass. Here we provide auxiliary information to the shark stock complex assessment about the spatial distribution of the shark catch in both FMP areas, with a focus on the three main species within the complex: Pacific sleeper shark (*Somniosus pacificus*), Pacific spiny dogfish (hereafter "spiny dogfish"; *Squalus suckleyi*), and salmon shark (*Lamna ditropis*).

Catch data recorded by fishery observers were downloaded on October 14, 2022 from the North Pacific Observer Program website and mapped to analyze the spatial distribution of catch of the three main species. It is important to note that not all catch is observed. Since 2001, observers have covered approximately 90% of the groundfish tonnage in the BSAI and 40% in the GOA. We present non-confidential catch weight data from target fisheries in the years 2003-2021 aggregated by 400 km^2 grid cells. We report these data in 5-year time blocks and by target fishery gear types relative to restructuring of the North Pacific Observer Program that occurred in 2013, which resulted in increased coverage on certain vessel types and in inside waters of the GOA (NMFS statistical reporting areas 649 and 659). The spatial distribution of observed catch of sharks in commercial fisheries varies for each of the three main species in the shark stock complex. In the BSAI FMP area, nearly all of the catch occurs in the Bering Sea subarea.

Pacific Sleeper Shark

Incidental catch of Pacific sleeper sharks within observed BSAI commercial fisheries primarily occurs in NMFS areas 517 and 521, along the outer edge of the eastern Bering Sea (EBS) shelf (Figure 19C.4). The largest incidental catches of Pacific sleeper shark tended to occur in hauls on the southern shelf as well as a few scattered hauls in the AI. However, the observed catches in NMFS areas 541-543, while rare, tended to be larger animals.

Due to confidentiality restrictions, the non-confidential observed bycatch of Pacific sleeper shark is limited (Figure 19C.4) and less informative in the GOA. Pacific sleeper shark are caught primarily in NMFS areas 620 and 630. Catch occurs predominantly within Shelikof Strait in the Central GOA and along the Alaska Peninsula.

The spatial extent of the Pacific sleeper shark catch has become changed since the beginning of the catch time series. Restructuring of North Pacific Observer Program resulted in more coverage of inside waters in the GOA longline sector (Figure 19C.5), but catches have become sparser in both FMP areas in general (Figure 19C.4). See the recent Pacific sleeper shark stock structure evaluation for more detail on the spatial distribution of the catch (Appendix 19A of this document).

Salmon Shark

Salmon shark incidental catch rate is higher in the Bering Sea than in the Aleutian Islands (Figure 19C.6). Salmon shark occur in a small number of hauls, with 94% of hauls in which salmon shark are observed reporting only one shark. Most of the catch occurs in NMFS areas 517 and 521 along the EBS shelf break and the shelf waters in the EBS outside of Bristol Bay in NMFS area 509. Each year since 2014 there has been a small number of hauls with large catches of salmon sharks in the southern Bering Sea, occurring near Unimak Pass or along the Alaska Peninsula (Figure 19C.6). Since Observer Program restructuring, there has also been an increase in observed catch of sharks on the southern Bering Sea shelf in the non-pelagic trawl sector (Figure 19C.7).

The amount of salmon shark bycatch within observed commercial fisheries in the GOA is small and rarely available as non-confidential data (Figure 19C.6). Therefore, it is difficult to make inferences about spatial patterns in the catch of salmon shark in the GOA.

Spiny Dogfish

Incidental catch of spiny dogfish within observed BSAI fisheries is less than both Pacific sleeper and salmon shark bycatch, with a slightly different spatial distribution (Figure 19C.8). Spiny dogfish bycatch occurs throughout the EBS shelf, generally along the shelf break and northwest from Unimak Pass; however, the majority of observed catch is farther south, near Unimak Pass and along the Alaska Peninsula.

Observed bycatch of spiny dogfish occurs predominately off Kodiak Island in the Central GOA (mostly area 630), with some catch spread along the shelf (Figure 19C.8). Following observer restructuring in 2013, more spiny dogfish have been observed in the Eastern GOA (NMFS area 650) and inside waters (NMFS areas 649 and 659) (Figure 19C.8), particularly in the longline sector (Figure 19C.9)

Catch of Other/Unidentified sharks

Observed bycatch of unidentified sharks within commercial fisheries is generally patchy and rare and has declined in recent years due to improved species identification. Hauls reporting catch of other/unidentified sharks are generally near the EBS shelf edge, with some larger hauls occurring near the southern end of the shelf (Figure 19C.10).

Reports of identified species other than the three primary species in the shark stock complex are extremely rare; one basking shark (*Cetorhinus maximus*) was recorded near the outer EBS shelf and one brown cat shark (*Apristurus brunneus*) was recorded near Unimak Pass (Figure 19C.11). Blue sharks (*Prionace glauca*) have also been reported from the GOA, particularly in NMFS area 650.

Tables and Figures

Table 19C.1. Expected observer coverage rate (from the Annual Deployment plans) and realized observer coverage rate (from the Annual Reviews, table 5 or 3.5 depending on version). HAL: hook-and-line, EM: electronic monitoring.

Year	HAL	HAL EM	HAL Tender	Pot	Pot EM	Pot Tender	Trawl	Trawl EM (GOA)	Trawl Tender
2016	15.4% (15.0%)	NA	NA	15.2% (14.7%)	NA	NA	28.3% (28.0%)	NA	NA
2017	11.1% (12.0%)	NA	25.0% (0.0%)	3.9% (7.7%)	NA	3.9% (5.3%)	17.6% (20.7%)	NA	14.3% (18.8%)
2018	17.3% (15.5%)	30.0% (22.7%)	NA	16.2% (15.5%)	NA	17.4% (29.0%)	20.2% (20.3%)	NA	16.7% (35.0%)
2019	17.7% (17.6%)	30.0% (31.8%)	NA	15.4% (14.0%)	30.0% (36.4%)	16.1% (29.5%)	23.7% (25.2%)	NA	27.1% (35.7%)
2020	15.4% (7.0%)	30.0% (30.0%)	NA	15.2% (9.0%)	30.0% (30.9%)	NA	19.6% (17.6%)	30.0% (32.1%)	NA
2021	15.1% (12.4%)	30.0% (27.4%)	NA	15.0% (16.5%)	30.0% (28.5%)	NA	16.1% (19.9%)	30.0% (32.9%)	NA

Table 19C.2. Estimated catch of Pacific sleeper shark and spiny dogfish in the inside waters of Prince William Sound (PWSI, NMFS area 649) and Southeast Alaska (SEI, NMFS area 659). These catch estimates do not count against the total allowable catch (TAC). Salmon shark and Other/Unidentified sharks are not included because catch is rare. Data are from the Alaska Regional Office Catch Accounting System (queried through AKFIN on Oct 13, 2020).

Species	Year	PWSI	SEI	Total
Pacific Sleeper Shark	2003	22.8	4.7	27.4
	2004	1.7	2.9	4.6
	2005	3.3	1.3	4.6
	2006	0.2	2.1	2.4
	2007	0.2	2.3	2.5
	2008	<0.1	1.9	1.9
	2009	1	0.5	1.5
	2010	7.2	4.3	11.5
	2011	0.5	1.6	2.1
	2012	0.2	2.8	3.0
	2013	45.6	107.5	153.1
	2014	30.1	10.2	40.3
	2015	33.1	14.9	47.9
	2016	40.8	7.1	47.8
	2017	309.1	2.7	311.7
	2018	9.4	42.1	51.5
	2019	5.6	15.3	20.9
	2020	2.5	5.7	8.2
Spiny Dogfish	2003	0.9	3.2	4.1
	2004	0.8	20.2	21.0
	2005	1.1	40.9	41.9
	2006	13.2	78.7	92.0
	2007	7.5	18.2	25.7
	2008	0.7	3.0	3.7
	2009	22.4	77.4	99.8
	2010	3.3	2.8	6.0
	2011	3.3	2.5	5.7
	2012	1.6	11.5	13.1
	2013	13.6	109.1	122.7
	2014	22.3	113.2	135.6
	2015	51.7	51.8	103.6
	2016	30.6	103.8	134.4
	2017	47.9	217.9	265.7
	2018	33.9	115.8	149.7
	2019	63.7	108.1	171.8
	2020	100.5	127.3	227.8

Table 19C.3. Estimated numbers of retained and discarded sharks in the Alaska Department of Fish and Game managed recreational fishery in the Gulf of Alaska. Estimates of total numbers, with discard rate in parentheses, are derived from the Statewide Harvest Survey. Salmon shark catch from the charter vessel fleet are all retained and numbers come directly from logbooks. Recreational catch of sharks does not count against the total allowable catch (TAC). Source: Sarah Webster, ADF&G. Note that these numbers have not been updated for this assessment.

	Sport Catch of All Sharks				Charter Catch of Salmon Shark			
Year	**Western**	**Central**	**Eastern**	**Total**	**Western**	**Central**	**Eastern**	**Total**
1998	0(0%)	10,865(95%)	4,767(96%)	15,632	0	84	122	206
1999	0(0%)	5,674(92%)	13,418(98%)	19,092	No data	No data	No data	
2000	0(0%)	9,217(95%)	16,515(98%)	25,732	0	99	76	175
2001	37(54%)	17,637(97%)	16,449(97%)	34,123	1	85	98	184
2002	0(0%)	7,429(95%)	4,767(95%)	12,196	0	90	110	200
2003	30(100%)	24,695(97%)	12,229(96%)	36,954	0	97	86	183
2004	37(100%)	16,659(98%)	9,630(96%)	26,326	1	56	103	160
2005	108(100%)	46,403(98%)	23,430(97%)	69,941	3	38	202	243
2006	0(0%)	39,092(99%)	19,878(98%)	58,970	1	37	246	284
2007	0(0%)	44,170(99%)	31,571(98%)	75,741	0	37	207	244
2008	410(100%)	23,163(98%)	29,427(99%)	53,000	0	13	81	94
2009	0(0%)	19,659(99%)	13,438(99%)	33,097	0	13	50	63
2010	13(100%)	18,710(98%)	11,050(100%)	29,773	0	7	20	27
2011	9(100%)	9,271(95%)	4,870(99%)	14,150	0	7	1	8
2012	7(100%)	6,638(98%)	6,611(99%)	13,256	0	10	11	21
2013	16(100%)	6,397(92%)	5,348(97%)	11,761	0	4	3	7
2014	0(0%)	15,278(91%)	14,832(95%)	30,110	0	5	17	22
2015	0(0%)	11,092(95%)	9,351(99%)	20,443	0	14	10	24
2016	0(0%)	11,307(98%)	5,103(100%)	16,410	0	7	3	10
2017	0(0%)	6,284(98%)	3,366(99%)	9,650	0	9	8	17
2018	0(0%)	12,679(97%)	5,174(99%)	17,853	0	8	6	14
2019	23(100%)	7,339(98%)	4,395(97%)	11,757	1	14	7	22

IOTC-2023-WPEB19-32

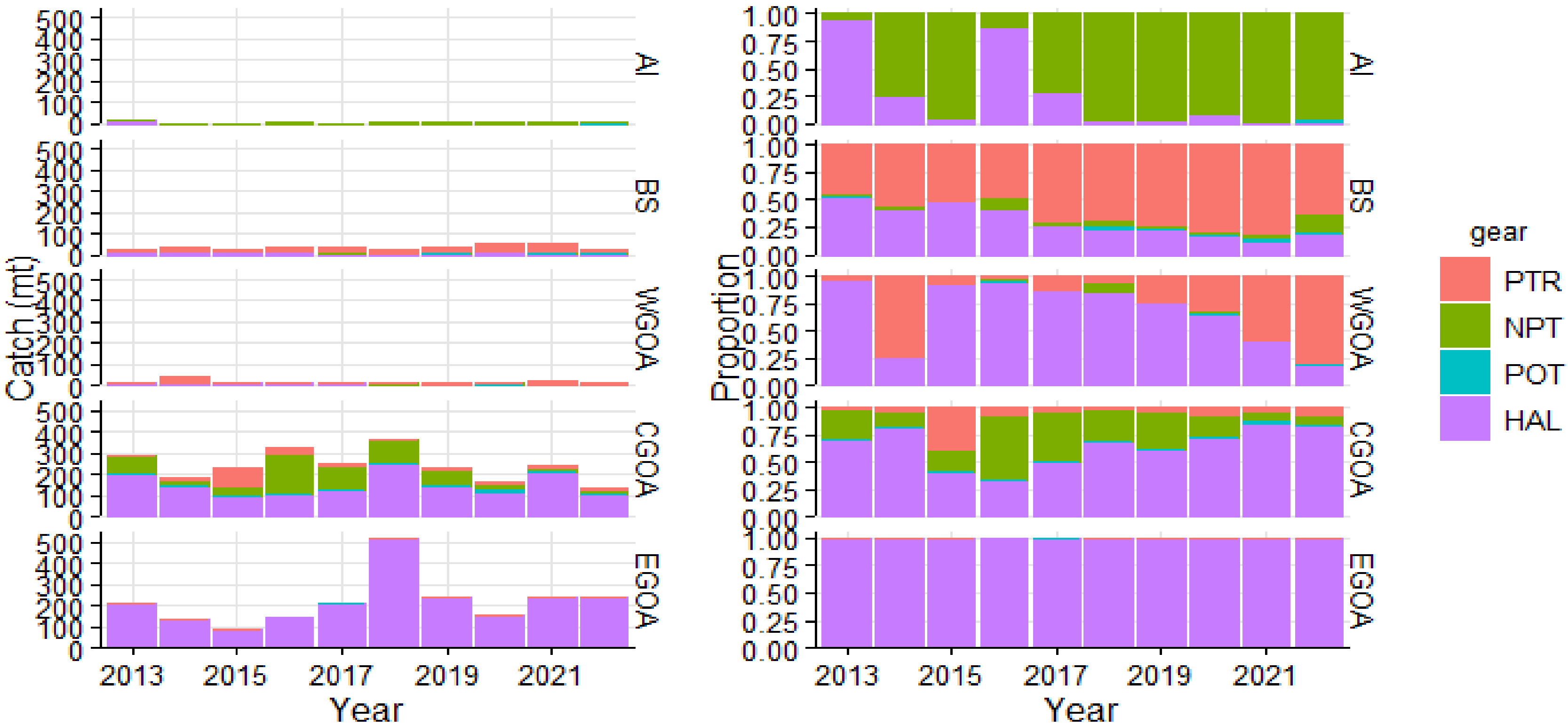


Figure 19C.1. Total catch estimates (mt) of Sharks in each management area. Colors represent the different gear types: HAL (hook and line), JIG (jig), NPT (non-pelagic trawl), POT (pot), PTR (pelagic trawl). Data queried October 8, 2022 through AKFIN

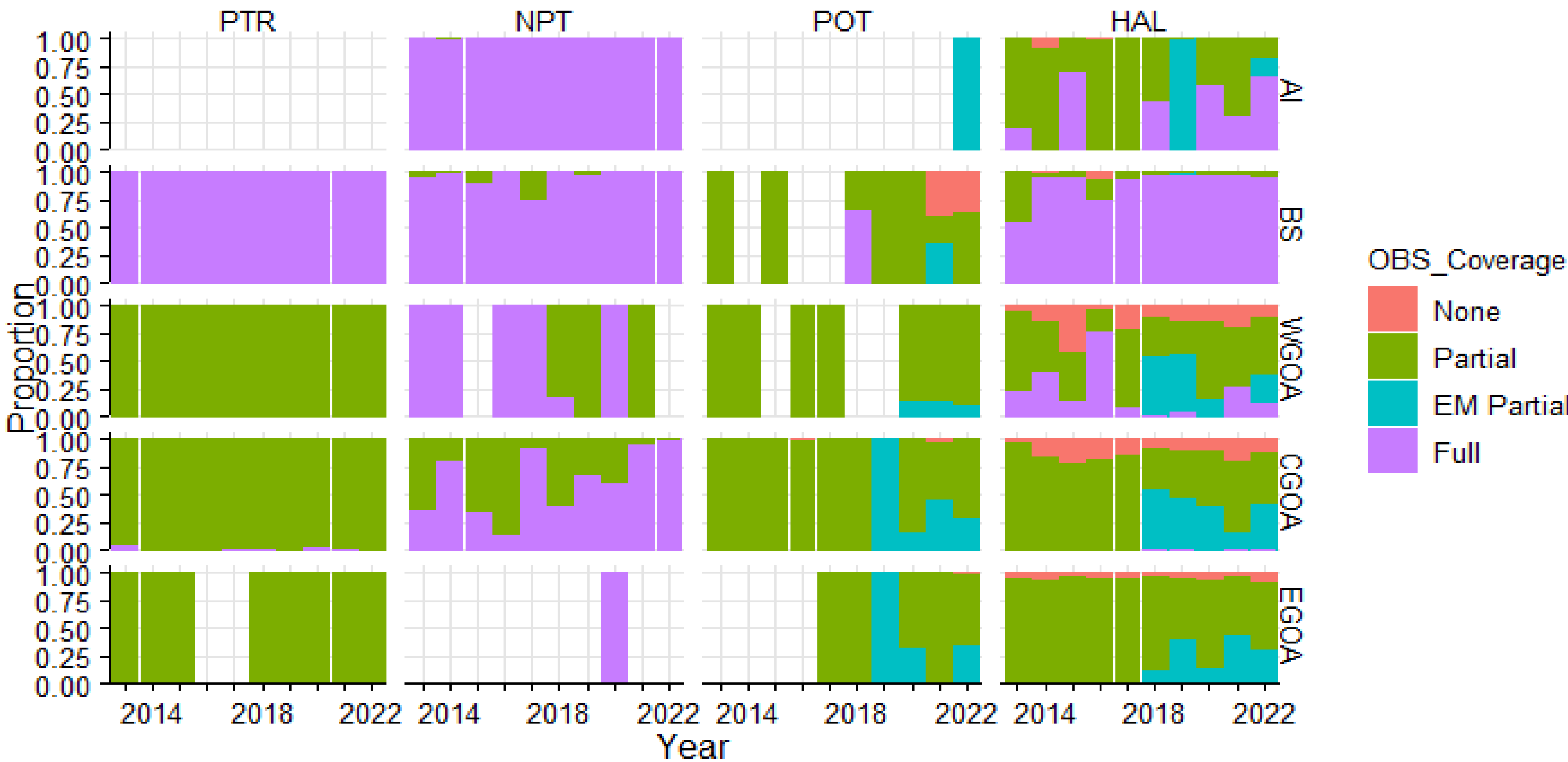


Figure 19C.2. Proportion of total catch (mt) of Sharks in each management area by observer coverage type. Data from jig fisheries has been removed due to scarcity.

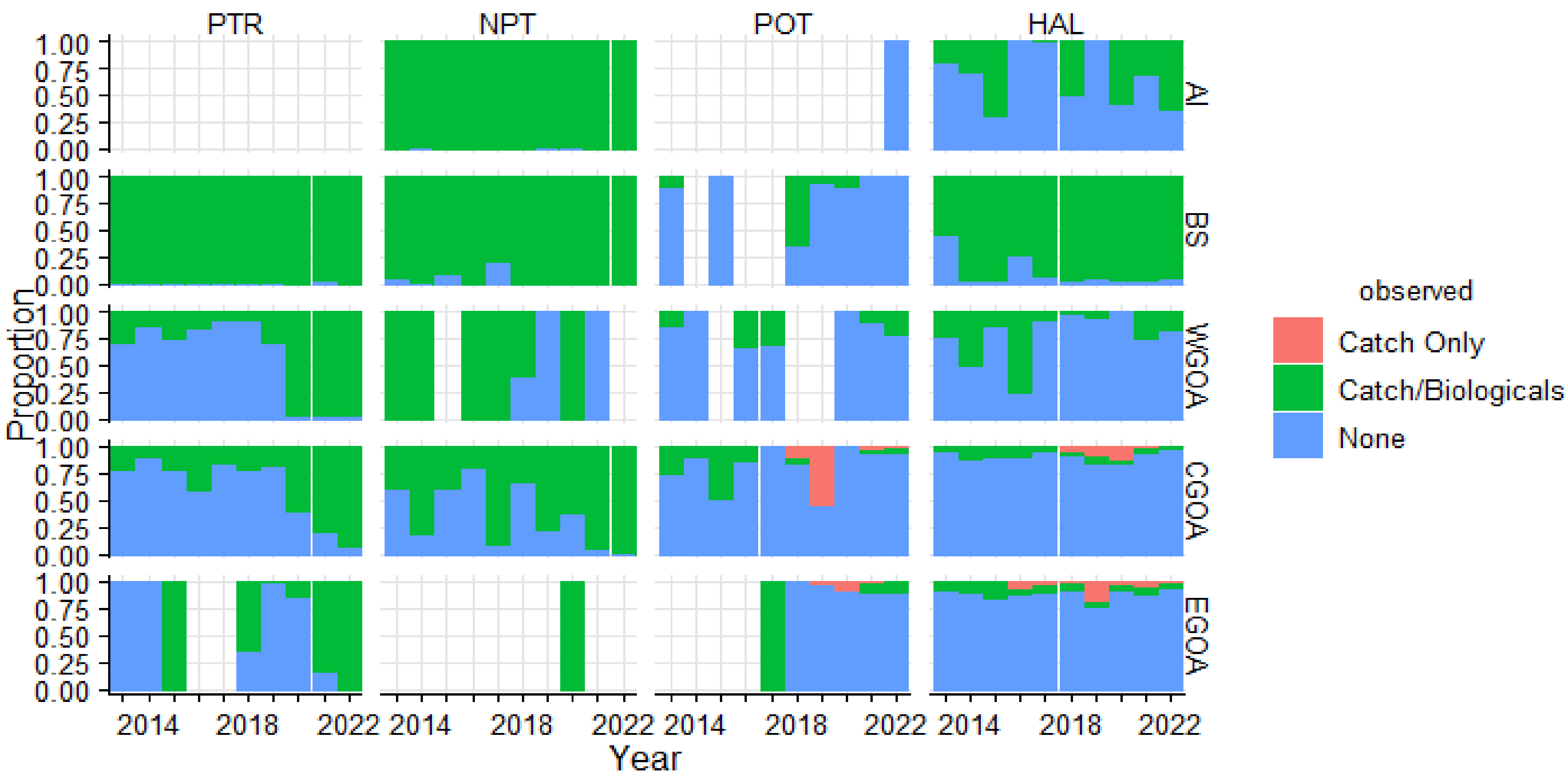


Figure 19C.3. Proportion of total catch of Sharks that is observed in each management area and gear type. Catch Only: monitoring in which only the catch is monitored and no biological data are recorded (i.e., fixed gear EM). Catch/Biologicals: observers monitor the catch, record biological data and take samples. None: catch for unobserved trips.

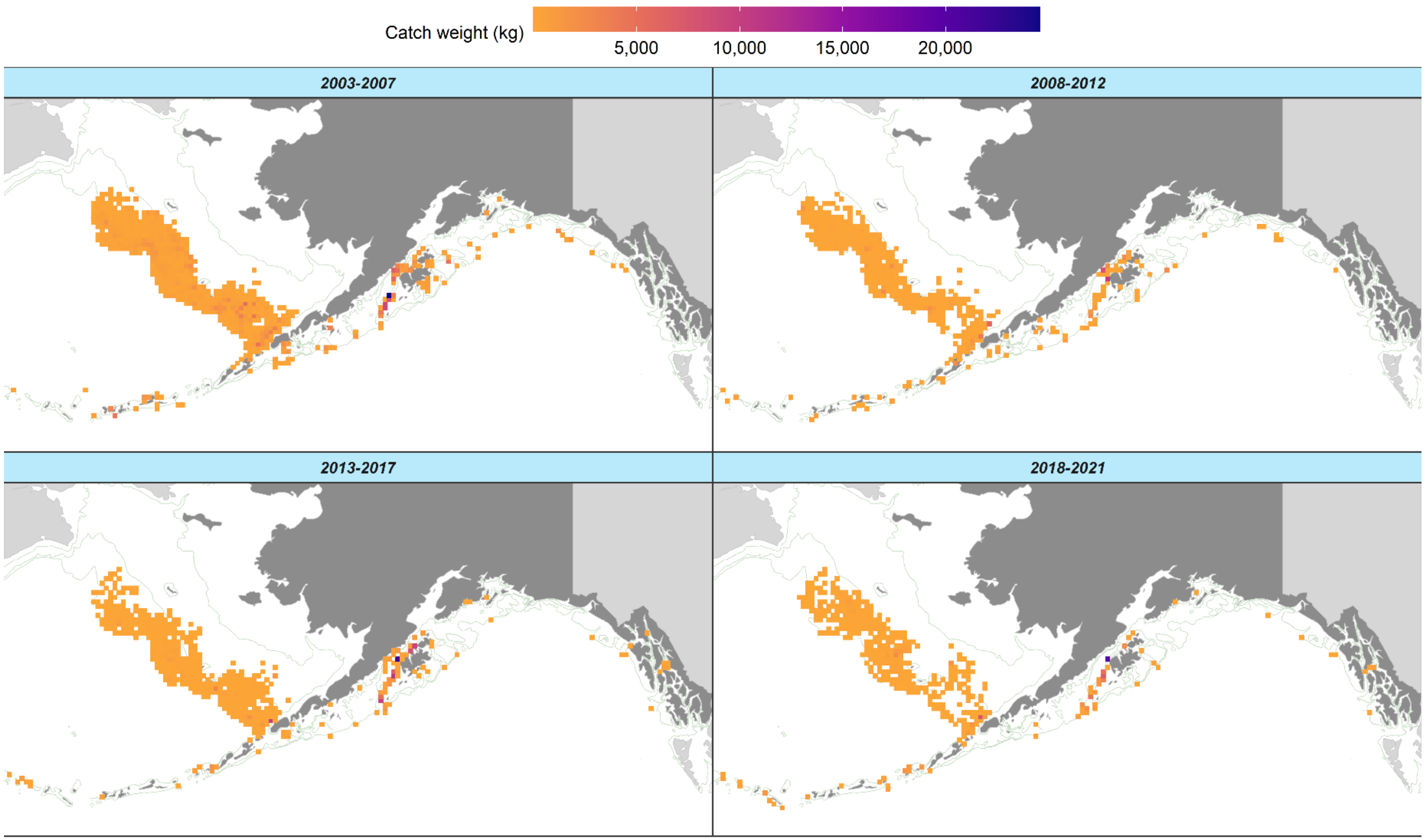


Figure 19C.4. Spatial distribution of observed Pacific sleeper shark fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid cell over 5-year catch periods. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

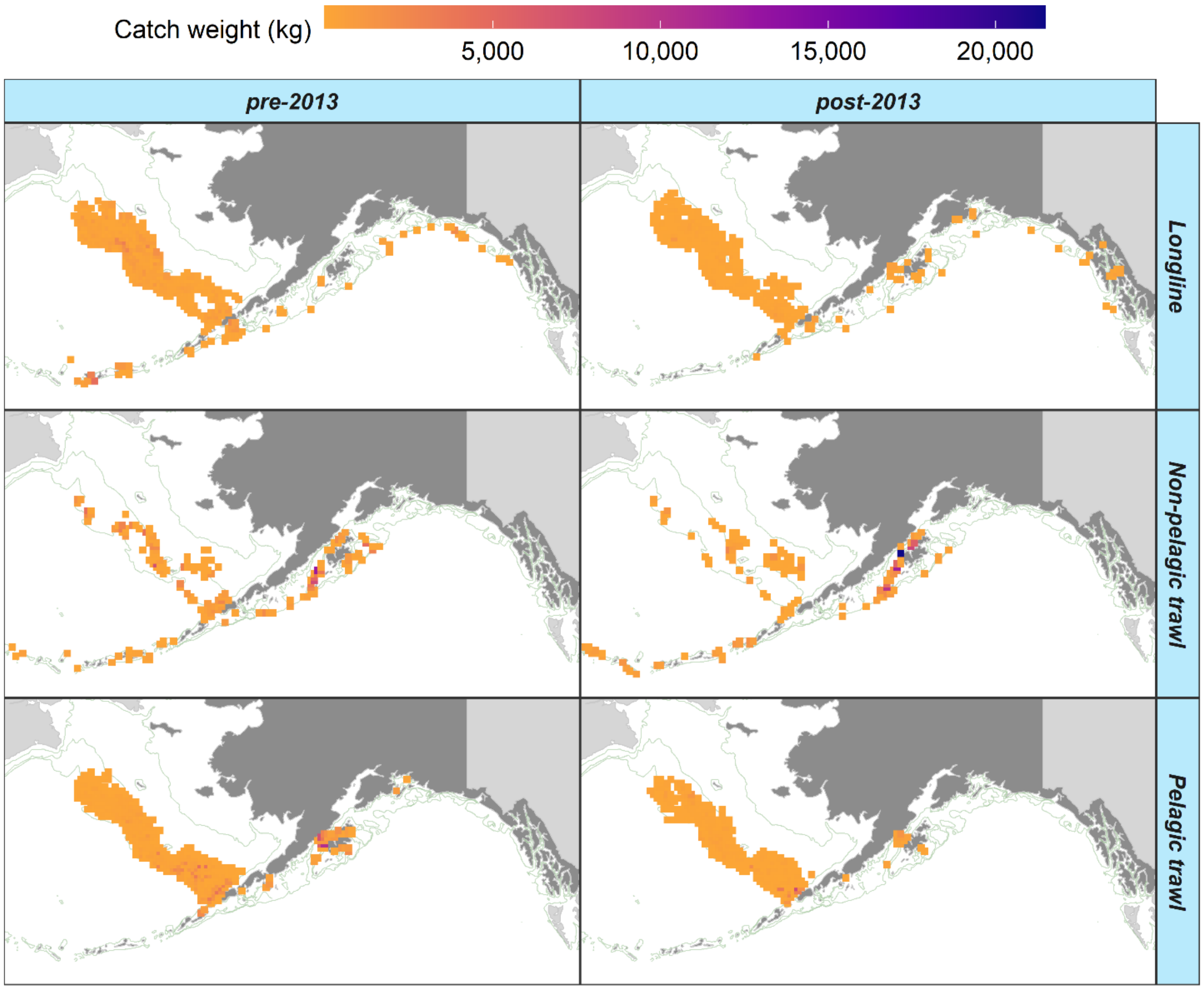


Figure 19C.5. Spatial distribution of observed Pacific sleeper shark fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid by gear type relative to restructuring of the North Pacific Observer Program in 2013, which resulted in increased observer coverage of vessels catching sharks. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

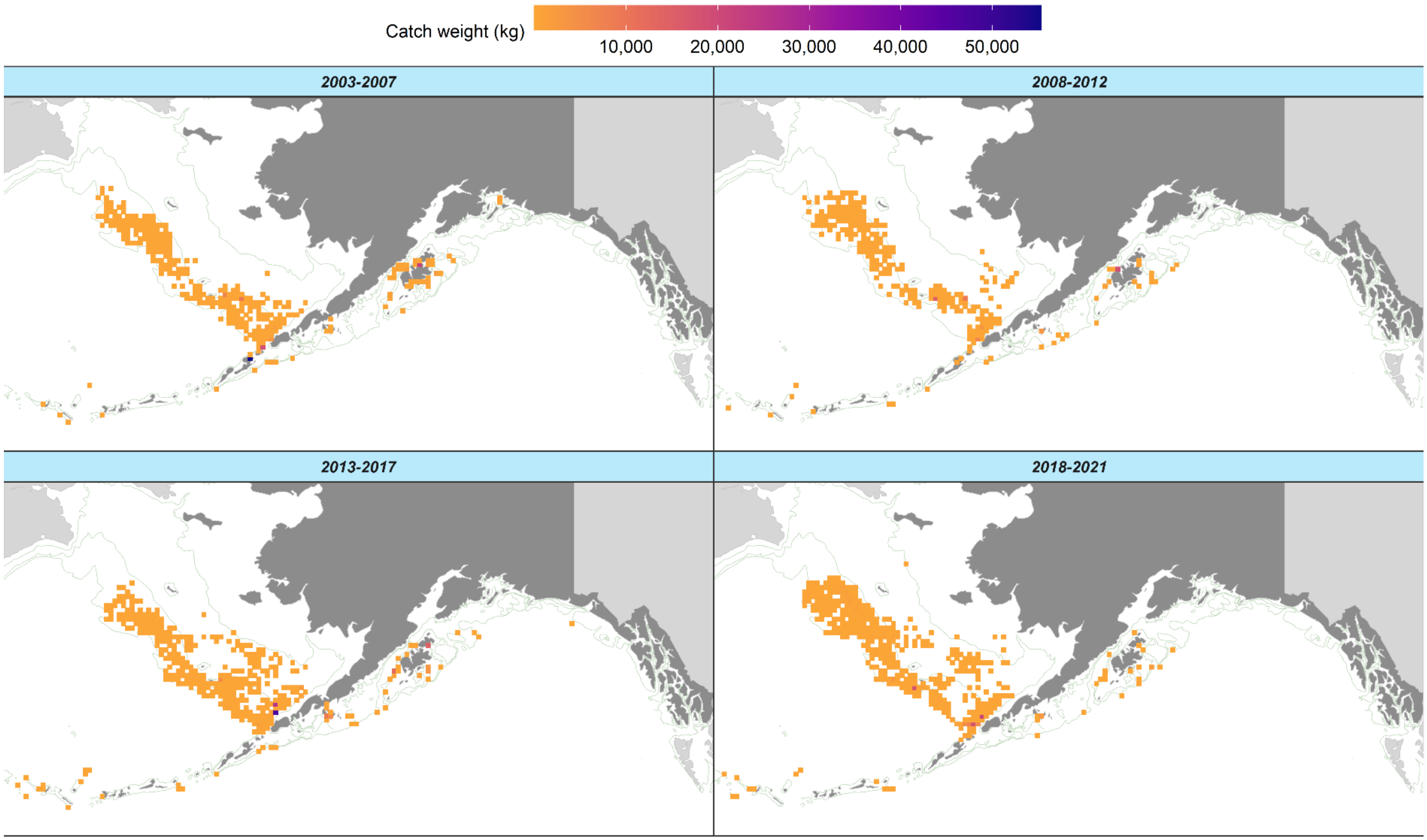


Figure 19C.6. Spatial distribution of observed salmon shark fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid cell over 5-year catch periods. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 ([http://www.afsc.noaa.gov/FMA/spatial_data.htm)](http://www.afsc.noaa.gov/FMA/spatial_data.htm).

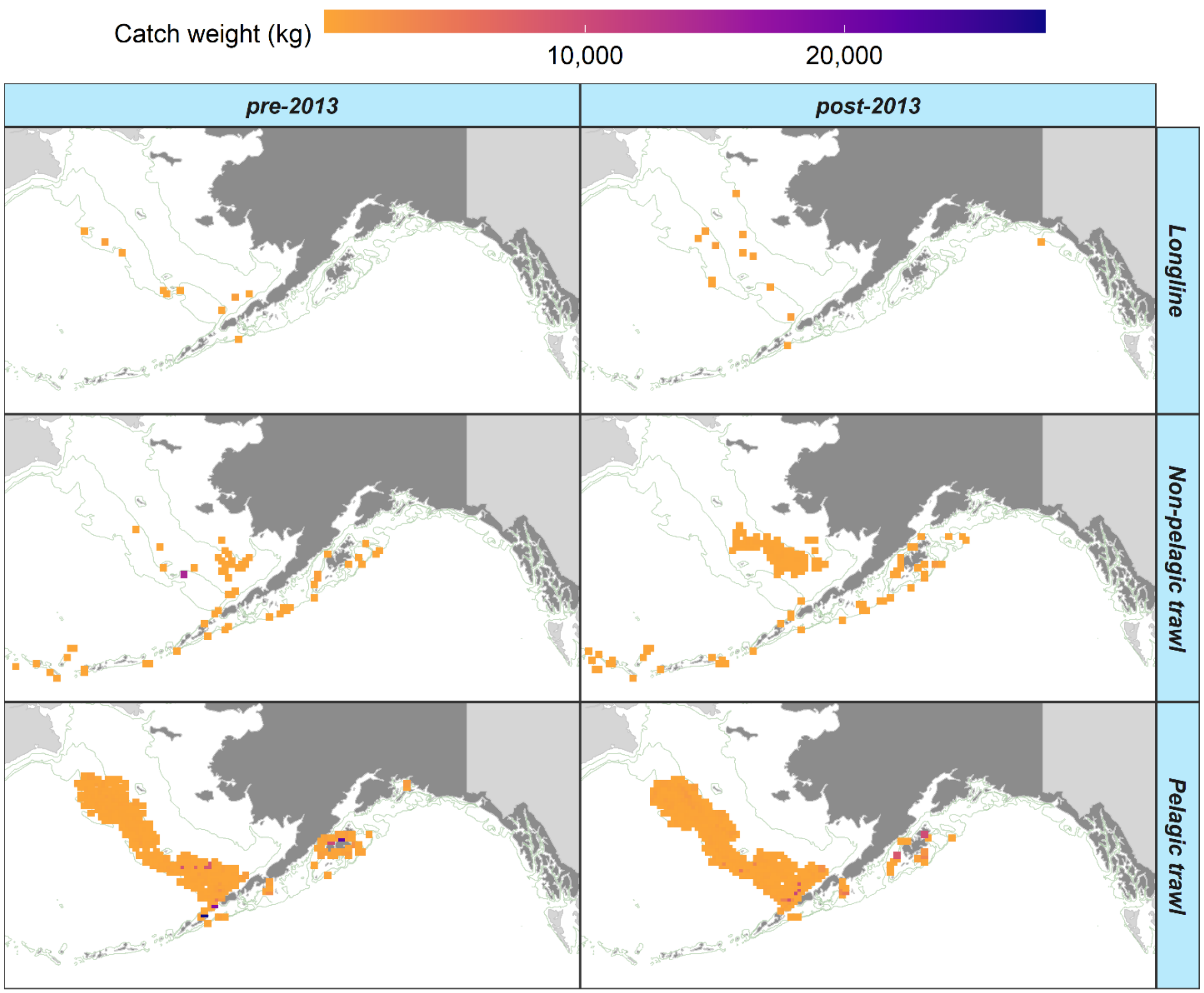


Figure 19C.7. Spatial distribution of observed salmon shark fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid by gear type relative to restructuring of the North Pacific Observer Program in 2013, which resulted in increased observer coverage of vessels catching sharks. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

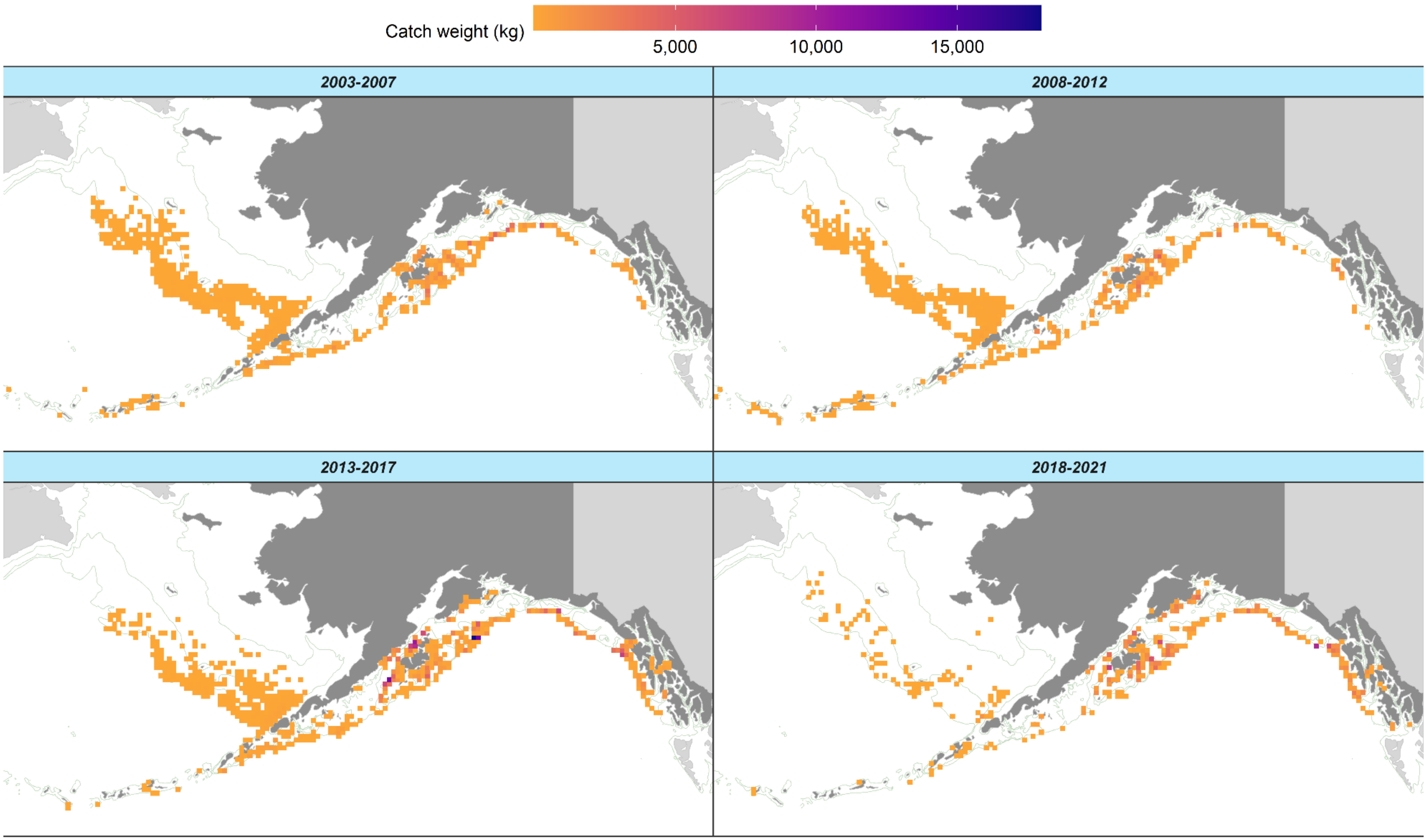


Figure 19C.8. Spatial distribution of observed Pacific spiny dogfish fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid cell over 5-year catch periods. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

IOTC-2023-WPEB19-32

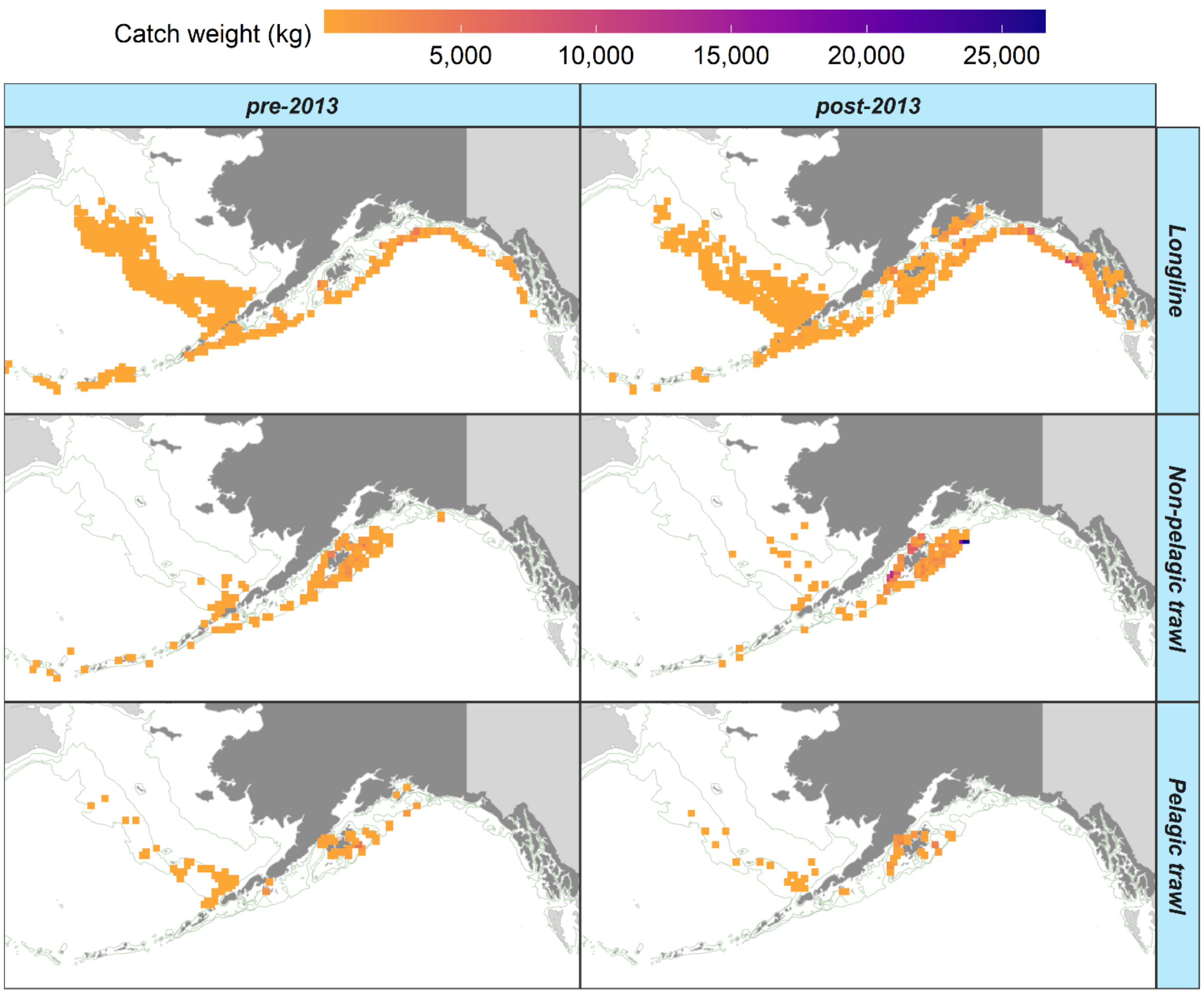


Figure 19C.9. Spatial distribution of observed spiny dogfish fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid by gear type relative to restructuring of the North Pacific Observer Program in 2013, which resulted in increased observer coverage of vessels catching sharks. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

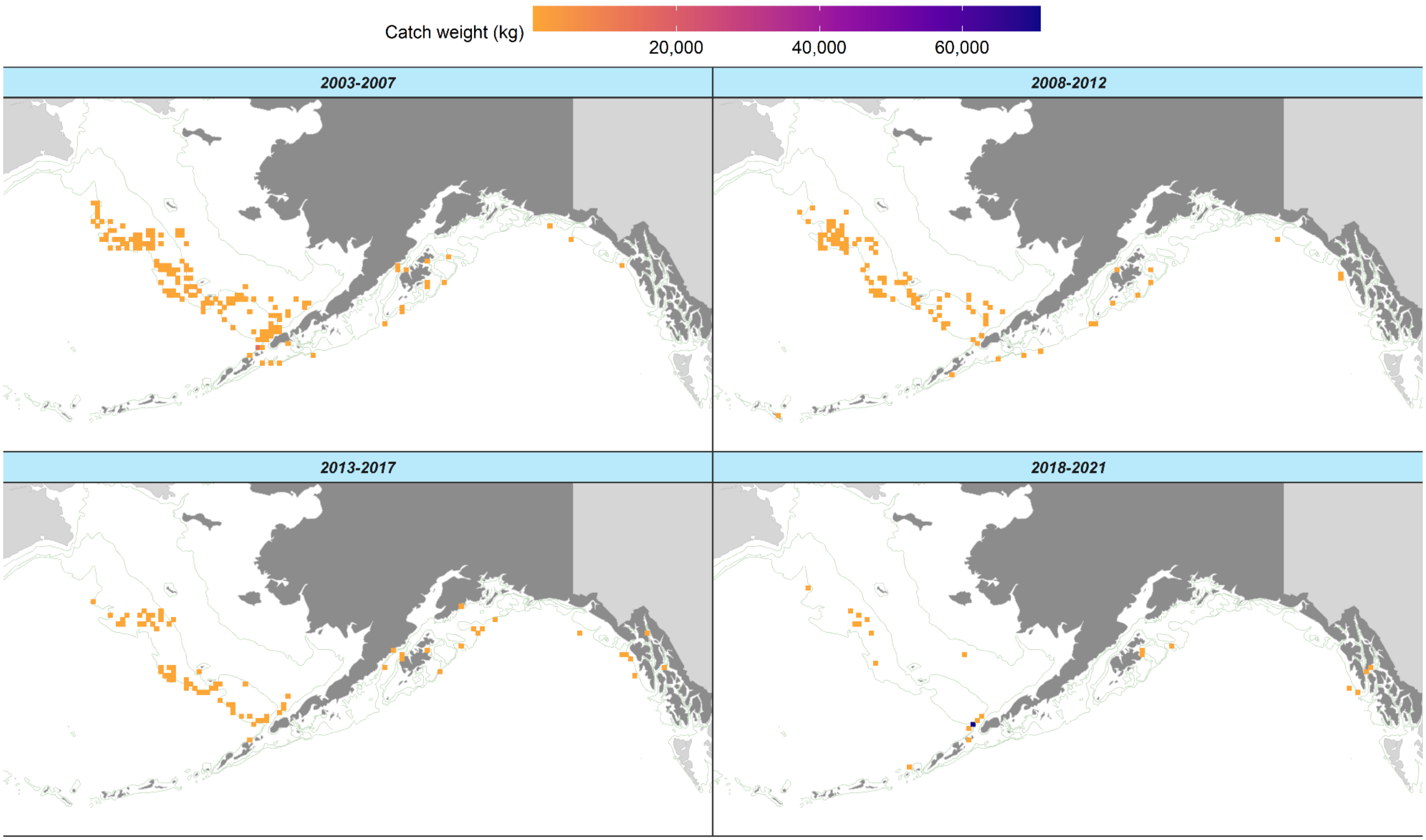


Figure 19C.10. Spatial distribution of observed unidentified shark catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid cell over 5-year catch periods. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

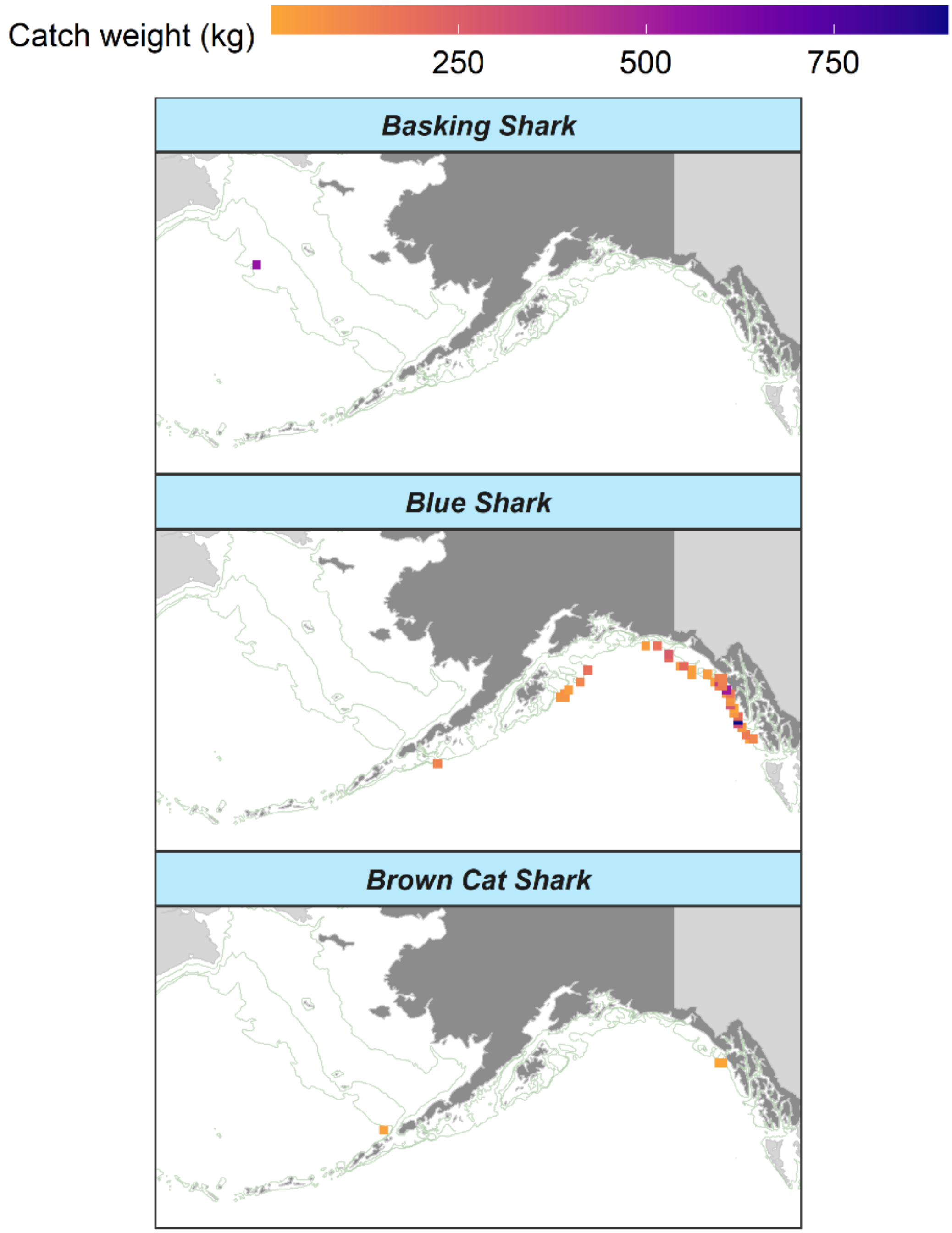


Figure 19C.11. Spatial distribution of observed other shark fishery catch in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan areas. Each square represents the average catch within each non-confidential 400 km^2 grid cell over the years 2003-2021. Grid cells with zero catch were not included for clarity. Data were provided by the Fisheries Monitoring and Analysis division website, queried October 14, 2022 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

Appendix 19D. Survey Biomass and Population Indices, Catch Distribution, and Length and Weights

Introduction

Data relevant to the shark stock complex are available from several fisheries-independent surveys in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) Fishery Management Plan (FMP) areas. With the exception of GOA Pacific spiny dogfish (hereafter "spiny dogfish"; *Squalus suckleyi*), a Tier-5 stock, survey data are not used to generate harvest specifications for any members of the shark stock complex. We present survey data for BSAI spiny dogfish and the two other primary members of the shark stock complex (Pacific sleeper shark *Somniosus pacificus* and salmon shark *Lamna ditropis*) as auxillary information to the assessment of the shark stock complex. We report results of trawl and longline surveys conducted by the Alaska Fisheries Science Center (AFSC), Alaska Department of Fish and Game (ADFG), and International Pacific Halibut Commission (IPHC). Data include abundance indices, length and weight distributions, and spatial distribution of the survey catch.

Trawl Surveys

AFSC Bottom Trawl Surveys-BSAI

Biomass estimates are available for shark species from NMFS AFSC bottom trawl surveys conducted in the BSAI on the eastern Bering Sea (EBS) slope (2002-2016; Table 19D.1, Figure 19D.1), the Aleutian Islands (AI) (1980-2022, Table 19D.2, Figure 19D.1) and the EBS shelf (1982-2022, Table 19D.3, Figure 19D.1. We do not include the earlier time series of the EBS slope survey (1979-1991) because the earlier time series used a different gear type, survey strata, and survey design; thus, the estimates are not comparable to the modern time series. The EBS shelf survey is annual, but the EBS slope and AI surveys take place as funding allows.

Sharks in the BSAI may not be sampled well by bottom trawl surveys. In many years, surveys fail to capture a single specimen of some shark species. As a result, the estimation procedure often produces a biomass of zero or biomass estimates with high levels of uncertainty, and trends in biomass estimates from trawl surveys are not informative. Spiny dogfish, for example, occurred in <1% of hauls in all BSAI surveys. The efficiency of bottom trawl gear varies by species, and trends in these biomass estimates should be considered, at best, a relative index of abundance for shark species until more formal analyses of survey efficiencies by species can be conducted. In particular, pelagic shark species, such as salmon sharks, are encountered by the trawl gear not while it is in contact with the bottom, but rather during gear deployment or retrieval, resulting in unreliable biomass estimates since the estimates are based, in part, on the amount of time the net spends in contact with the bottom. Although Pacific sleeper sharks are demersal, they are large animals that may be able to avoid bottom trawl gear or they may occupy depths outside those surveyed. As a result, biomass estimates are uncertain because the gear may not efficiently capture this species. These surveys are not informative for spiny dogfish because they are rarely caught in the trawl surveys of the BSAI. However, catches are reported in the observer data and in other surveys sampling the same area; differences in catch rates are likely due to gear differences, as spiny dogfish may be more susceptible to longline gear.

Pacific sleeper sharks are the most commonly caught shark species within BSAI surveys. They are most consistently caught on the EBS slope survey; however, the number of hauls with Pacific sleeper sharks has declined since 2008, with the lowest biomass estimate of the time series in 2016; no surveys of the EBS slope have been completed since that year (Table 19D.1, Figure 19D.1). Pacific sleeper sharks are also captured consistently in NMFS bottom trawl surveys in the AI (Table 19D.2), but biomass estimates in this area are based on a small number of hauls, and biomass estimates are generally lower than in the

EBS slope area (Figure 19D.1). Pacific sleeper sharks are not often caught during the annual EBS shelf survey, and biomass estimates are based on relatively few hauls (Table 19D.3, Figure 19D.1).

Spiny dogfish are rarely captured during any of the AFSC bottom trawl surveys in the EBS or AI. Resultant biomass estimates are often determined from a small number of hauls or are zero when no sharks are caught. During the EBS slope survey, spiny dogfish have only been caught in one haul (in 2008) and no other spiny dogfish have been caught since the new survey design in 2002 (Table 19D.1, Figure 19D.1). Spiny dogfish are caught sporadically in the AI (Table 19D.2, Figure 19D.1) and EBS shelf surveys (Table 19D.3, Figure 19D.1).

Salmon sharks are rarely caught in either the EBS or AI bottom trawl surveys, and therefore data are not shown.

AFSC Bottom Trawl Surveys-GOA

NMFS AFSC bottom trawl survey biomass estimates are available for the three primary shark species in the GOA (1984-2022, Table 19D.4). Bottom trawl surveys were conducted on a triennial basis in the GOA in 1984, 1987, 1990, 1993, 1996, and a biennial survey schedule has been used since the 1999 survey. The surveys covered all areas of the GOA to a depth of 1,000 m, with the following exceptions: the 1990, 1993, 1996, and 2001 surveys did not sample deeper than 500 m; the 2003, 2011, 2013, 2017 and 2019 surveys did not sample deeper than 700 m. Other important caveats are that the 2001 survey did not sample the Eastern GOA, thus removing an entire area of the estimation of biomass and the 2013, 2017 and 2019 surveys had a reduced number of stations, which likely increased uncertainty in biomass estimates. It is unlikely that these survey caveats would impact the estimation of shark biomass because most sharks are caught in strata shallower than 500 m, with the exception of the 2001 survey not sampling the Eastern GOA; however, it is important to note the potential for process error. Furthermore, the 1984 survey results should be treated with some caution, as a different survey design was used in the eastern GOA. In addition, much of the survey effort in 1984 and 1987 was by Japanese vessels that used a very different net design than the standard used by U.S. vessels in the years since, introducing an element of uncertainty regarding the standardization of these two surveys.

The efficiency of bottom trawl gear is not known for sharks. Hulson et al. (2016) used tagging data to investigate the availability of spiny dogfish to the survey gear and found that the species spends a large portion of time in near-surface waters (i.e., out of the range of the survey gear) during the summer. It is likely that the trawl survey biomass estimate for spiny dogfish is an underestimate and should be considered a minimum biomass. Pelagic species such as salmon shark are caught during net deployment and retrieval and thus trawl survey biomass estimates are unreliable. Pacific sleeper sharks are large animals and may be able to avoid the bottom trawl gear. Biomass estimates for Pacific sleeper sharks are often based on a small number of hauls and a small number of sharks within a haul. Consequently, these biomass estimates can be highly uncertain. For the purposes of this assessment, only the spiny dogfish biomass is used in harvest recommendations.

Trawl survey catch of spiny dogfish in the GOA is highly variable from year to year resulting in no obvious trend in biomass estimates (Table 19D.4, Figure 19D.2). The 2007 biomass estimate of 162,759 t was followed by a drop to 27,880 t in 2009, and the coefficients of variation (CVs) range from 0.12-0.74 (Table 19D.4, Figure 19D.2). The biomass estimate of spiny dogfish has declined from the near-record peak in 2013 of 160,384 t to 22,014 t (CV = 0.15) in 2019, its lowest value since 1990, but has since risen slightly to 32,319 in the 2021 survey.

Pacific sleeper sharks are caught in a small number of hauls during the GOA trawl survey each year. Biomass estimates from the GOA trawl survey are highly variable, and the bottom trawl survey is considered a poor indicator for this species (CVs range from 0.25-1.00). The highest biomass estimate

(70,933 t, CV = 0.57) occurred in 2015, followed by much lower values in 2017 (6,561) and 2019 (4,878); no Pacific sleeper sharks were caught in 2021 (Table 19D.4, Figure 19D.3).

Salmon shark catch is rare and variable in the GOA trawl survey, and biomass estimates often have confidence intervals overlapping zero (Table 19D.4).

ADFG Trawl Surveys

Abundance indices from two large mesh trawl surveys were provided by ADFG Southcentral Region: Kachemak Bay and Prince William Sound (1998-2019). The Kachemak Bay survey does not regularly encounter sharks. The Prince William Sound survey catches spiny dogfish semi-regularly and is included in this appendix. There was a large spike in spiny dogfish CPUE in 2016, but otherwise the catches have been relatively stable (Figure 19D.2).

Longline Surveys

International Pacific Halibut Commission (IPHC) Longline Surveys

The IPHC conducts a longline survey each year to assess Pacific halibut (*Hippoglossus stenolepis*). This fixed-station survey samples to depths of 500 m in the AI, EBS, and the GOA in inside and outside waters, as well as areas south of Alaska. More information about this survey can be found here. The IPHC survey is likely the most informative survey for the Pacific sleeper shark; it also reliably catches spiny dogfish. However, it rarely catches salmon sharks, and therefore data from the IPHC survey are not presented for that species. There was no survey conducted in the BSAI in 2020 due to COVID-19; data are updated through the 2021 survey (Table 19D.5).

Relative population numbers (RPNs) for spiny dogfish and Pacific sleeper shark were calculated from the raw survey data using the same historical methods as for the AFSC longline survey, the only difference being the depth stratum increments. An average CPUE, the number of sharks per effective hooks, was calculated by depth stratum for each FMP sub-area (e.g., EBS, AI, Central GOA, etc.). The CPUE was then multiplied by the area size of the stratum, using area sizes that are used to calculate biomass in the RACE trawl surveys. An FMP-wide RPN was calculated by summing the RPNs for all strata in the area and confidence limits estimated by bootstrap resampling of the stations within each region. Note that there are wide confidence intervals on the IPHC survey RPNs.

In the GOA FMP area, spiny dogfish IPHC RPNs have been increasing from the historic low in 2013 (Figure 19D.2). Pacific sleeper shark RPNs in the GOA declined steeply from 2001 through 2013 and dropped again in 2018 (Figure 19D.3).

Within the BSAI FMP area, almost all of the IPHC survey catch of sharks occurs in the Bering Sea and only limited catch occurs in the AI. For Pacific sleeper sharks, which are the primary shark species caught in the BSAI, EBS RPNs from the IPHC survey declined steeply from the late 1990s through 2004 and then remained at low levels since 2005 (Figure 19D.4). Spiny dogfish are not commonly caught in the IPHC survey in the BSAI, with no catch in the AI since the 2014 survey (Figure 19D.4).

The IPHC survey provides CPUE data coast-wide, allowing for regional comparisons of abundance trends, (i.e., BSAI, Canada = CAN, and the west coast of the U.S. = WC). Since 2013, the CPUE index for spiny dogfish in the BSAI has declined and leveled out, while it has increased in the GOA, where CPUE is higher (Figure 19D.5). The index in Canada showed a similar pattern as the GOA, but delayed. The WC has less catch and more uncertainty. The indices for Pacific sleeper shark in the BSAI and GOA have declined from a high in 2000 and 2003, respectively (Figure 19D.5), with a slight increase in the BSAI in 2017. Catches are less common in CAN, but the current index is well below the historical high in 2000. Catches along the WC are rare and no trends are apparent.

AFSC Longline Surveys

The AFSC annual longline survey has a standard series of fixed stations spaced 30-50 km apart along the continental slope (each station samples depths from 150-1,000 m) and in select cross-shelf gullies. The AFSC longline survey samples in the GOA in all years, in the EBS in odd years, and the AI in even years (survey protocol can be found here: https://www.fisheries.noaa.gov/resource/document/survey-protocol-alaska-sablefish-longline-survey). The U.S. time series starts in 1988, whereas the IPHC time series starts in 1998 and samples the continental shelf (Table 19D.5). Similar to the IPHC survey, the RPNs for spiny dogfish are variable and any trends are over short periods of time (e.g., the decline from 2006-2013, Figure 19D.2). They are caught regularly at a small number of stations. Catches of Pacific sleeper sharks in the GOA, or of any shark species in the BSAI FMP area, are rare on the AFSC longline survey and so those data are not presented.

ADFG Longline Surveys

Staff from the ADFG Southeast region provided data from two longline surveys: Chatham Strait and Clarence Strait. Further discussions will treat the Chatham Strait and Clarence Strait surveys as one Southeast Alaska (SEAK) inside waters survey. The spiny dogfish index in SEAK has trended downwards since 2009 (Figure 19D.2).

The SEAK longline survey trend for Pacific sleeper shark mirrors the long decline in the IPHC survey data. There was also a sharp decline in the 2017 AFSC bottom trawl survey (Figure 19D.3). The downward trend in Pacific sleeper shark survey indices indicates that either abundance is declining or sharks are becoming less available to the sampling gear. Some potential reasons could be that the number of immature sharks has declined, resulting in lower survey catch because smaller fish are likely more readily caught. Additionally, the depth distribution of the sharks may have changed making them less available to the surveys. One caveat with all three longline surveys is that hook competition has not been examined for sharks and so catch rates could fluctuate with the density of other species.

Length Distributions

Spiny Dogfish

The spiny dogfish length frequency data presented here are from the AFSC bottom trawl surveys (GOA, EBS shelf and slope and AI), AFSC and IPHC longline surveys and targeted research surveys. Length data for spiny dogfish are part of standard collections on the AFSC longline and trawl surveys, as well as being regularly collected on the IPHC longline survey.

Length frequency data from the AFSC trawl and IPHC and AFSC longline surveys are presented for GOA spiny dogfish in Figure 19D.6. Female length data show no significant difference in mean size between the surveys, however, the size distribution is shifted to larger animals on the IPHC and AFSC trawl surveys (Figure 19D.6). The IPHC survey samples the entire U.S. and Canadian West Coast, therefore providing coast-wide regional comparisons of size frequencies (Figure 19D.7). Females are smaller in the GOA and BSAI as compared to Canada and the U.S. West Coast, a trend is not seen in male length data (Figure 19D.7).

Pacific Sleeper Sharks

Length data are limited for Pacific sleeper sharks; therefore lengths for the BSAI and GOA are combined for each data source (Figure 19D.8, sexes combined). Genetic evidence suggests that the species is a continuous stock within the Pacific Ocean (Timm et al. in review) and therefore comparisons to other regions are valid. The authors have compiled length data for Pacific sleeper shark from standard and non-standard AFSC trawl surveys in the GOA and BSAI, the Northwest Fisheries Science Center (NWFSC) groundfish trawl survey off the U.S. West Coast, and International Pacific Halibut Commission (IPHC) longline surveys.

The length data compiled thus far show that small immature Pacific sleeper sharks (50-200 cm total length) are caught throughout their range along the North American coast. Within Alaska waters, they tend to be larger in the GOA than in the BSAI (Figure 19D.8), though most are still likely immature. In even years (BSAI surveys only) the AFSC trawl surveys catch smaller animals, many <100 cm; while in odd years (GOA survey included) the surveys catch larger animals, some >300 cm.

Distribution of Survey Catch

Spiny Dogfish

Due to the schooling nature of spiny dogfish, survey catch can be patchy, often with a small number of large spiny dogfish hauls. In Alaska waters, most of the survey catch occurs in the GOA; within the BSAI FMP area, spiny dogfish are caught more frequently in the AI subarea. The IPHC survey catches spiny dogfish regularly along the AI, but in small numbers. Spiny dogfish are rarely caught in the AFSC trawl or longline surveys in the BSAI, and catch distribution data within that FMP are not discussed here.

In the GOA, spiny dogfish have been caught primarily on the Fairweather grounds in northern Southeast Alaska and in Cook Inlet during the AFSC bottom trawl survey (Figure 19D.9). Spiny dogfish are commonly caught at many of the IPHC stations across the GOA, and in inside waters of Southeast Alaska and Prince William Sound (Figure 19D.10). Spatial distribution of spiny dogfish catch on the AFSC longline survey is more limited than the IPHC survey, due in part to fewer stations on the shelf (Figure 19D.11). They are often caught at gully stations outside of Prince William Sound, Yakutat Bay and Southeast Alaska. Spiny dogfish catches on the ADF&G longline survey in inside waters of Southeast Alaska occur primarily in Clarence Strait (Figure 19D.12).

Pacific Sleeper Shark

An examination of the spatial distribution of BSAI survey catches shows that Pacific sleeper shark are consistently caught in low numbers throughout the EBS shelf during the IPHC longline survey (Figure 19D.13) and NMFS trawl surveys, with rare scattered catches in the AI. The distribution of Pacific sleeper sharks spreads from Unimak Pass and follows the shelf break northwest beyond the Pribilof Islands, until approximately longitude 178°40’W.

The spatial distribution of Pacific sleeper shark catch on the GOA bottom trawl survey is generally limited to Shelikof Strait and areas southwest of Kodiak Island. The IPHC and AFSC longline surveys also catch Pacific sleeper sharks often in Shelikof Strait, as well as scattered stations across the shelf (Figure 19D.13). Catch of Pacific sleeper shark by the IPHC occurs most frequently in Prince William Sound and inside waters of Southeast Alaska. In contrast to spiny dogfish, Pacific sleeper sharks are caught primarily in Chatham Strait during the ADFG SEAK longline survey (Figure 19D.14).

Literature Cited

Hulson, P-J.F., C.A. Tribuzio, K. Coutre. In review. The use of satellite tags to inform the stock assessment of a data poor species: Spiny Dogfish in the Gulf of Alaska. Proceedings of the 2015 Lowell Wakefield Symposium.

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

Tables and Figures

Table 19D.1. AFSC Eastern Bering Sea (EBS) slope bottom trawl survey estimates of individual shark species total biomass (metric tons) with coefficient of variation (CV), and number of hauls. No surveys have been conducted on the EBS slope since 2016 (AKFIN, queried October 13, 2020).

		Spiny Dogfish			Pacific Sleeper Shark		
Year	**Survey Hauls**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls w/Catch**	**Biomass**	**CV**
2002	141	0	0	0	15	25,425	0.87
2004	231	0	0	0	24	2,282	0.34
2008	200	1	13	1	28	1,968	0.27
2010	200	0	0	0	19	833	0.27
2012	189	0	0	0	16	1,305	0.28
2016	175	0	0	0	5	251	0.49

Table 19D.2. AFSC Aleutian Islands (AI) bottom trawl survey estimates of individual shark species total biomass (metric tons) with coefficient of variation (CV), and number of hauls (AKFIN, queried October 4, 2022). There was no survey in 2020 due to the COVID-19 pandemic. Salmon sharks are caught infrequently during the AI survey and therefore data are not shown for that species. One very large Pacific sleeper shark was caught in a haul during the 2022 AI survey, but it was not included in the biomass estimate because it was a bad tow.

		Spiny Dogfish			Pacific Sleeper Shark		
Year	**Survey Hauls**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls w/Catch**	**Biomass**	**CV**
1980	127	0	0	0.00	0	0	0.00
1983	290	3	2	0.63	3	249	0.66
1986	383	6	14	0.50	12	1,995	0.36
1991	331	0	0	0.00	3	2,926	0.69
1994	380	9	47	0.37	3	374	0.64
1997	396	2	11	0.71	10	2,486	0.29
2000	419	3	25	0.62	3	2,638	0.57
2002	414	0	0	0.00	4	536	0.55
2004	419	0	0	0.00	2	1,017	0.96
2006	357	6	62	0.49	1	76	1.00
2010	418	0	0	0.00	1	74	1.00
2012	420	0	0	0.00	1	22	1.00
2014	410	2	23	0.71	0	0	0.00
2016	419	1	7	1.00	0	0	0.00
2018	420	0	0	0.00	2	100	0.65
2022	399	0	0	0.00	0	0	0.00

Table 19D.3. AFSC Eastern Bering Sea (EBS) shelf trawl survey estimates of individual shark species total biomass (metric tons) with coefficient of variation (CV) and number of hauls (AKFIN, queried October 4, 2022). There was no survey in 2020 due to the COVID-19 pandemic. Salmon sharks are caught infrequently during the AI survey and therefore data are not shown for that species.

		Spiny Dogfish			Pacific Sleeper Shark		
Year	**Survey Hauls**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls w/Catch**	**Biomass**	**CV**
1982	329	0	0	0	0	0	0
1983	353	2	381	0.83	0	0	0
1984	355	0	0	0	0	0	0
1985	353	1	46	1	0	0	0
1986	354	0	0	0	0	0	0
1987	343	3	213	0.6	0	0	0
1988	353	1	247	1	0	0	0
1989	354	0	0	0	0	0	0
1990	351	0	0	0	0	0	0
1991	352	0	0	0	0	0	0
1992	336	0	0	0	2	2,514	0.72
1993	355	0	0	0	0	0	0
1994	355	0	0	0	2	4,976	0.82
1995	356	0	0	0	1	1,001	1
1996	355	0	0	0	2	2,817	0.82
1997	356	1	36	1	0	0	0
1998	355	1	255	1	1	2,115	1
1999	353	0	0	0	2	2,071	0.71
2000	352	0	0	0	1	1,457	1
2001	355	0	0	0	0	0	0
2002	355	0	0	0	3	5,576	0.65
2003	356	0	0	0	1	727	1
2004	355	1	27	1	2	3,114	0.71
2005	353	0	0	0	2	1,687	0.76
2006	356	0	0	0	2	2,943	0.78
2007	356	0	0	0	0	0	0
2008	355	0	0	0	0	0	0
2009	356	1	70	1	0	0	0
2010	356	1	87	1	4	5,282	0.53
2011	356	0	0	0	1	763	1
2012	356	0	0	0	1	266	1
2013	356	0	0	0	0	0	0
2014	356	0	0	0	0	0	0
2015	356	1	91	1	2	2,583	0.85
2016	356	0	0	0	3	3,050	0.84
2017	356	0	0	0	1	1,301	1
2018	356	0	0	0	1	823	1
2019	356	0	0	0	0	0	0
2021	356	0	0	0	1	443	1
2022	356	2	159	0.76	2	7,686	0.92

Table 19D.4. AFSC Gulf of Alaska bottom trawl survey estimates of individual shark species total biomass (t) with coefficient of variation (CV) and number of hauls with catches of sharks. Data updated October 4, 2022 (RACEBASE, queried through AKFIN). There was no survey in 2020 due to the COVID-19 pandemic.

		Pacific Sleeper Shark			Salmon Shark		
Year	**Total # of Survey Hauls**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls w/Catch**	**Biomass**	**CV**
1984	929	1	163	1.00	5	7,849	0.52
1987	783	8	1,319	0.43	15	12,623	0.56
1990	708	3	1,651	0.66	13	12,462	0.30
1993	774	13	8,657	0.50	9	7,729	0.36
1996	807	11	21,101	0.36	1	3,302	1.00
1999	764	13	19,362	0.40	0	0	0.00
2001[*,#]	489	15	37,695	0.36	0	0	0.00
2003	809	28	52,116	0.25	2	3,613	0.71
2005	837	25	57,022	0.26	1	2,455	1.00
2007	816	15	41,849	0.41	2	12,340	0.75
2009	823	8	39,688	0.45	0	0	0.00
2011[$]	670	5	29,496	0.54	1	3,766	1.00
2013[$]	548	6	40,848	0.46	1	3,978	1.00
2015	771	6	70,933	0.57	2	5,931	0.88
2017[$]	536	1	6,561	1.00	0	0	0.00
2019[$]	541	1	4,878	1.00	0	0	0.00
2021	529	0	0	0.00	1	1,235	1.00

[#]Survey maximum depth was 500m
[$]Survey maximum depth was 700m
[*]Survey did not sample the Eastern Gulf of Alaska

Table 19D.5. Research survey catch of sharks 1977-2021 in the Gulf of Alaska. Alaska Fisheries Science Center (AFSC) longline (LL) and International Pacific Halibut Commission (IPHC) LL survey catches are provided in numbers prior to 2010. The IPHC survey catch numbers are estimated based on the subsample of observed hooks; catch weight is directly from survey fish tickets. Data were queried from AKFIN on October 27, 2022. ADFG sport fish harvest and AFSC acoustic trawl survey data are not yet available for 2021.

Year	AFSC Trawl Surveys (t) (Acoustic, Bottom)	AFSC LL Survey (#s)	AFSC LL Survey (t)	IPHC LL Survey (#s)	IPHC LL Survey (t)	ADF&G (t) (Sport, Research)
1977	0.14					
1978	1.44					
1979	1					
1980	0.86					
1981	2.23					
1982	0.36					
1983	1.03					
1984	3.12					
1985	0.96					
1986	1.38					
1987	3.55					
1988	0.27					
1989	0.87	751				
1990	3.52	583				
1991	0.15	2,039				
1992	0.12	3,881				
1993	5.03	2,557				
1994	0.43	2,323				
1995	0.57	3,882				
1996	3.48	2,206				
1997	0.52	2,822				
1998	0.58	7,701		42,361		
1999		1,185		21,705		
2000		1,212		29,257		
2001	0.45	1,726		34,227		
2002		1,576		22,028		
2003	7.36	2,372		68,940		
2004		1,964		48,850		
2005	7.13	3,775		44,082		
2006		6,593		41,355		
2007	14.06	3,552		34,023		
2008	0.73	3,606		24,655		
2009	4.03	4,709		29,299		
2010	0.07	2,622	6.18		391.48	9.65
2011	2.71	2,103	4.12		149.44	5.67
2012		1,835	5.30		187.30	6.06
2013	8.54	1,012	2.56		288.26	5.32
2014	1.94	2,843	8.09		147.92	14.69
2015	4.62	2,386	5.10		230.08	9.42
2016		2,259	4.86		318.16	4.64
2017	2.27	3,129	8.32		169.26	5.97
2018		811	2.11		129.22	10.01
2019	1.16	2,076	5.24		248.74	7.46
2020		3,257	8.05		121.13	5.84
2021	1.02	939	2.77		201.66	8.61

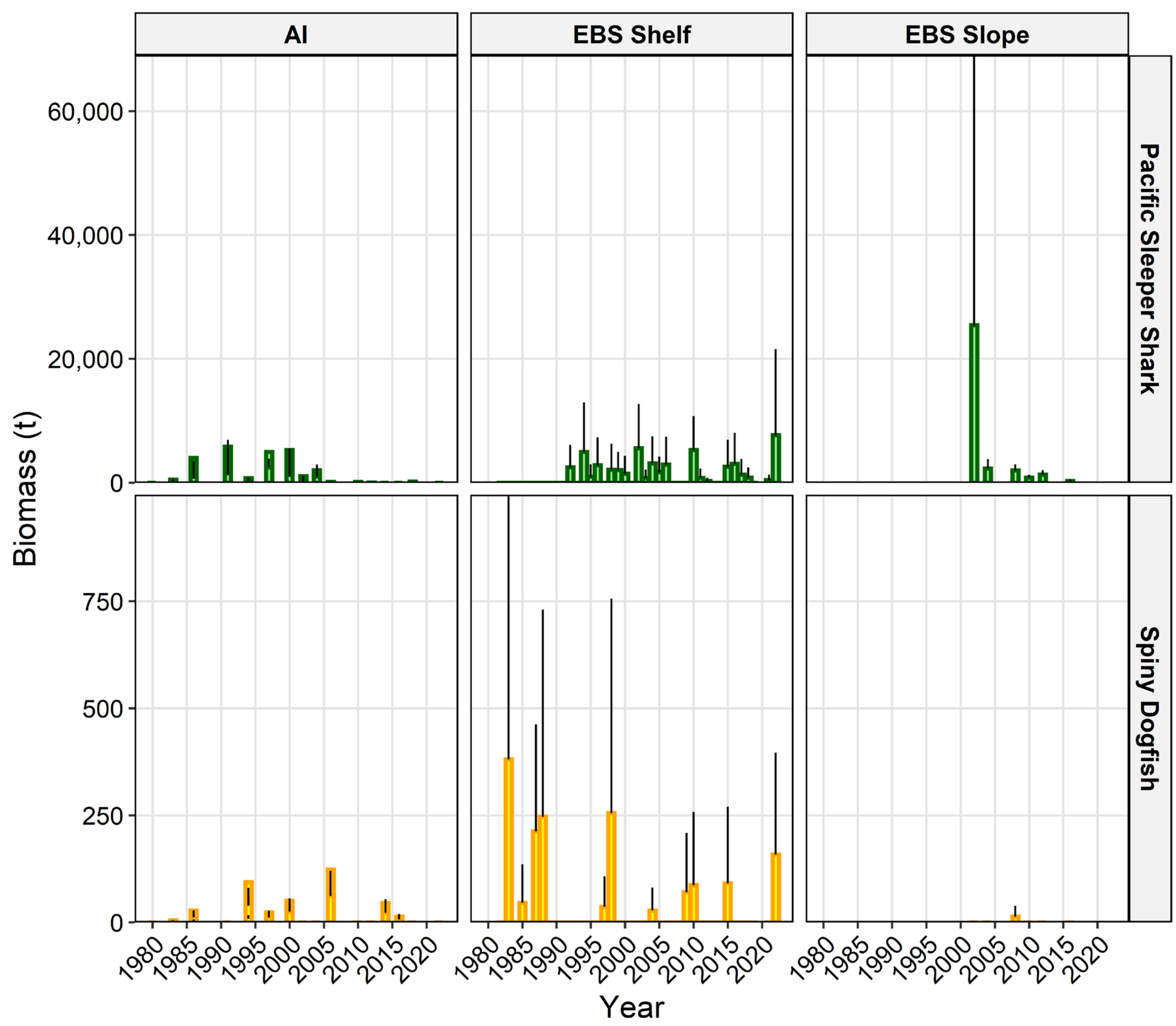


Figure 19D.1. Time series of biomass estimates (t) of Pacific sleeper shark and spiny dogfish in the AFSC eastern Bering Sea (EBS) slope, shelf, and Aleutian Islands (AI) bottom trawl surveys. Error bars are 95% confidence intervals. Scales on the y-axes differ for each species.

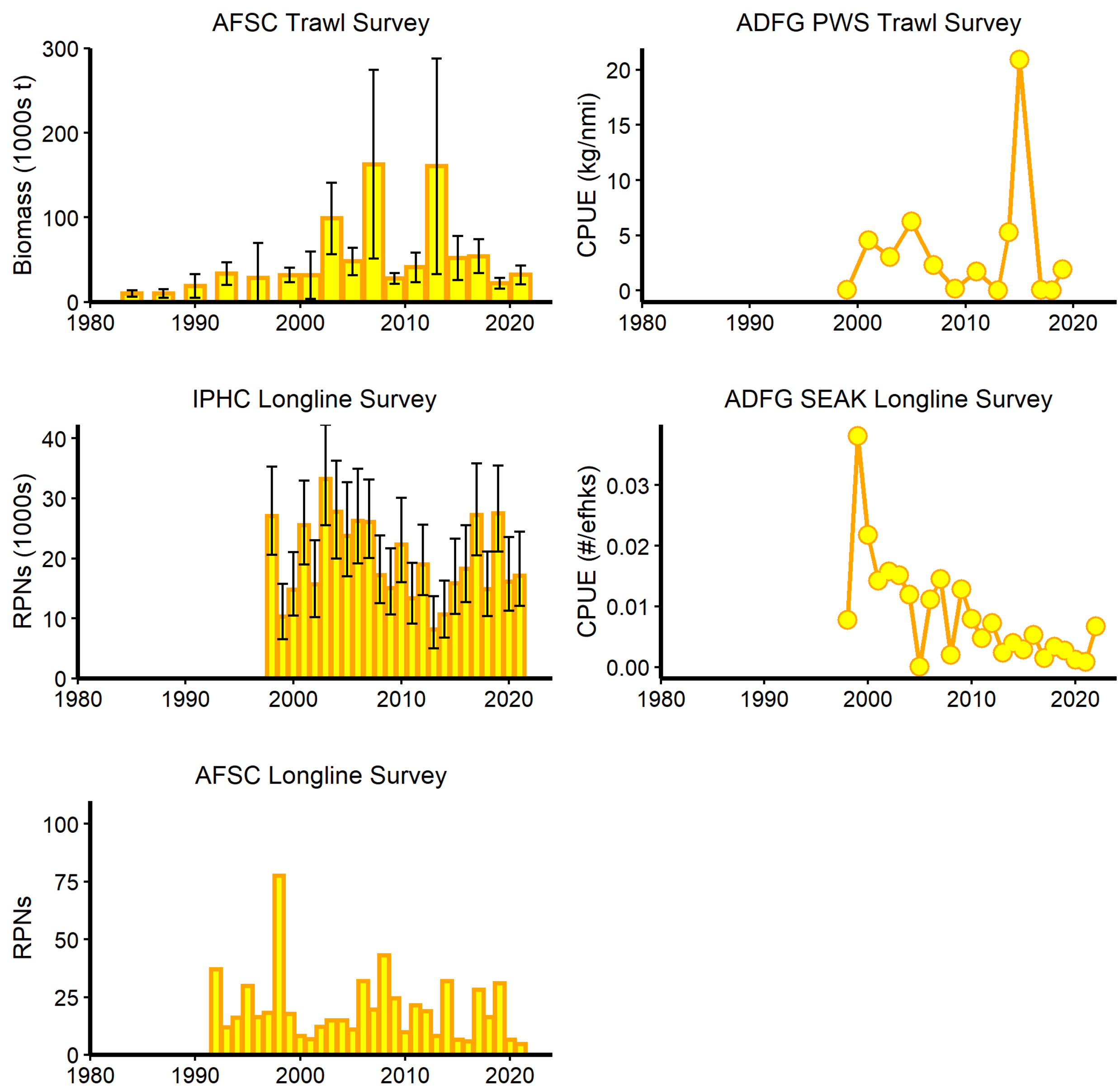


Figure 19D.2. Time series of survey indices available for spiny dogfish in the Gulf of Alaska. Catch per unit of effort (CPUE) is available for Alaska Department of Fish and Game (ADFG) trawl and longline surveys in Prince William Sound (PWS, kilograms per nautical mile) and Southeast Alaska (SEAK, number of fish/effective hooks), respectively. The Alaska Fisheries Science Center (AFSC) trawl survey provides an index of biomass (thousands of metric tons). The AFSC and International Pacific Halibut Commission (IPHC) longline surveys provide relative population numbers (RPNs).

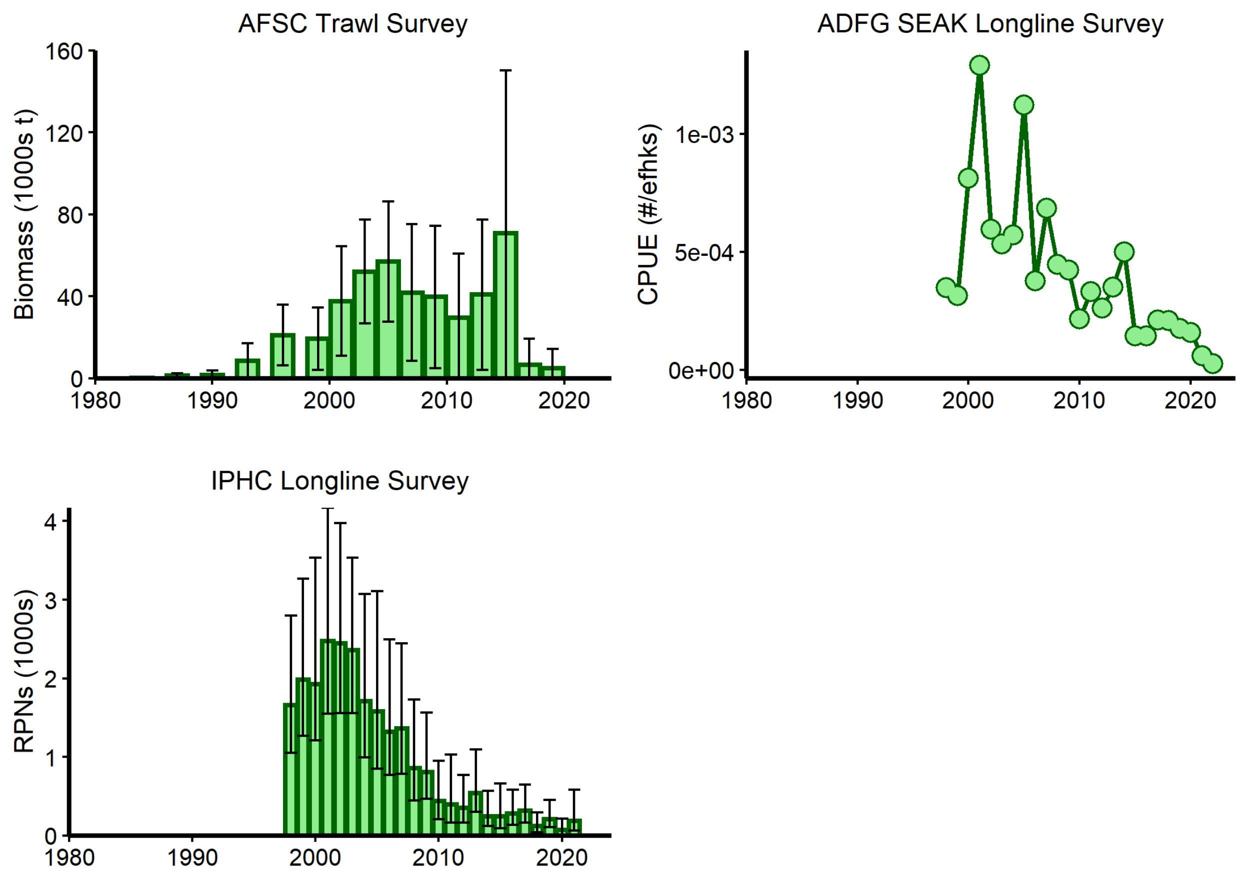


Figure 19D.3. Survey indices available for Pacific sleeper shark in the Gulf of Alaska. Catch per unit of effort (CPUE) is available for Alaska Department of Fish and Game (ADFG) surveys in Southeast Alaska (SEAK). The Alaska Fisheries Science Center (AFSC) trawl survey provides an index of biomass (thousands of metric tons). The International Pacific Halibut Commission (IPHC) longline survey provides relative population numbers (RPNs).

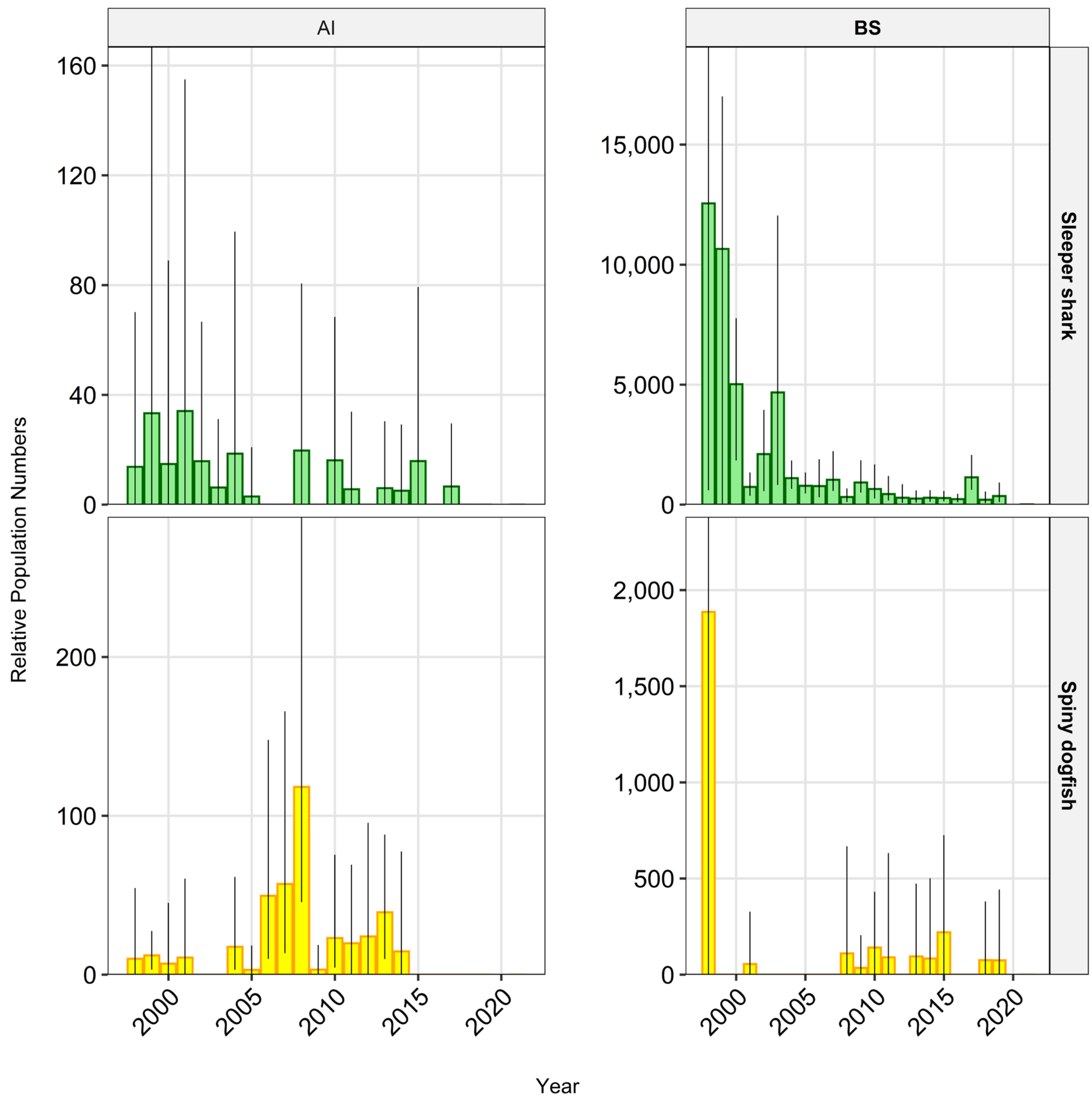


Figure 19D.4. Estimated relative population numbers with bootstrapped 95% confidence interval, where the unit was the station, from the IPHC annual longline survey in the Bering Sea (BS)/Aleutian Islands (AI) Fishery Management Plan area for Pacific sleeper sharks (top) and spiny dogfish (bottom). Scales on the y-axes differ for each species.

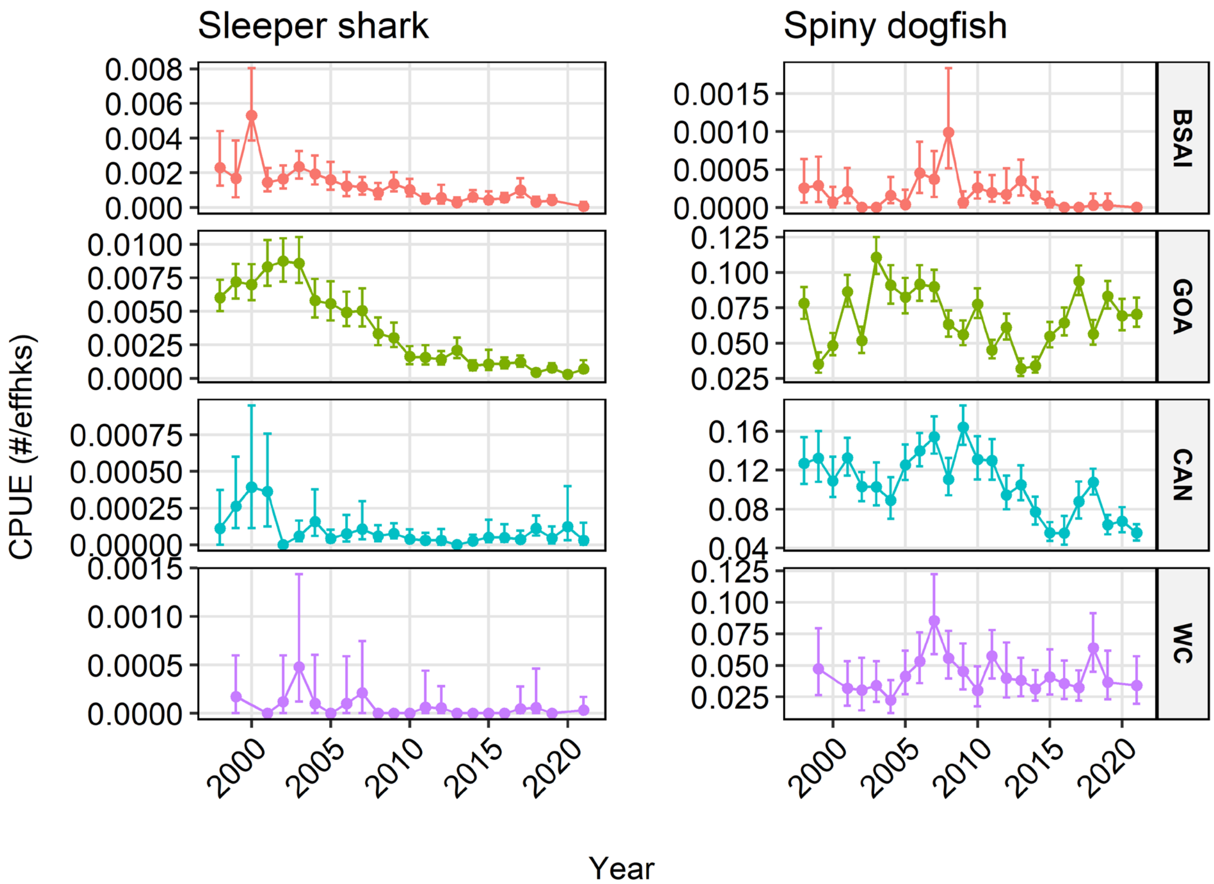


Figure 19D.5. Catch per unit of effort (CPUE) with bootstrapped 95% confidence intervals for each region (BSAI = Bering Sea and Aleutian Islands, GOA = Gulf of Alaska, CAN = British Columbia, Canada, and WC = the west coast of the United States) of the International Pacific Halibut Commission (IPHC) annual longline survey.

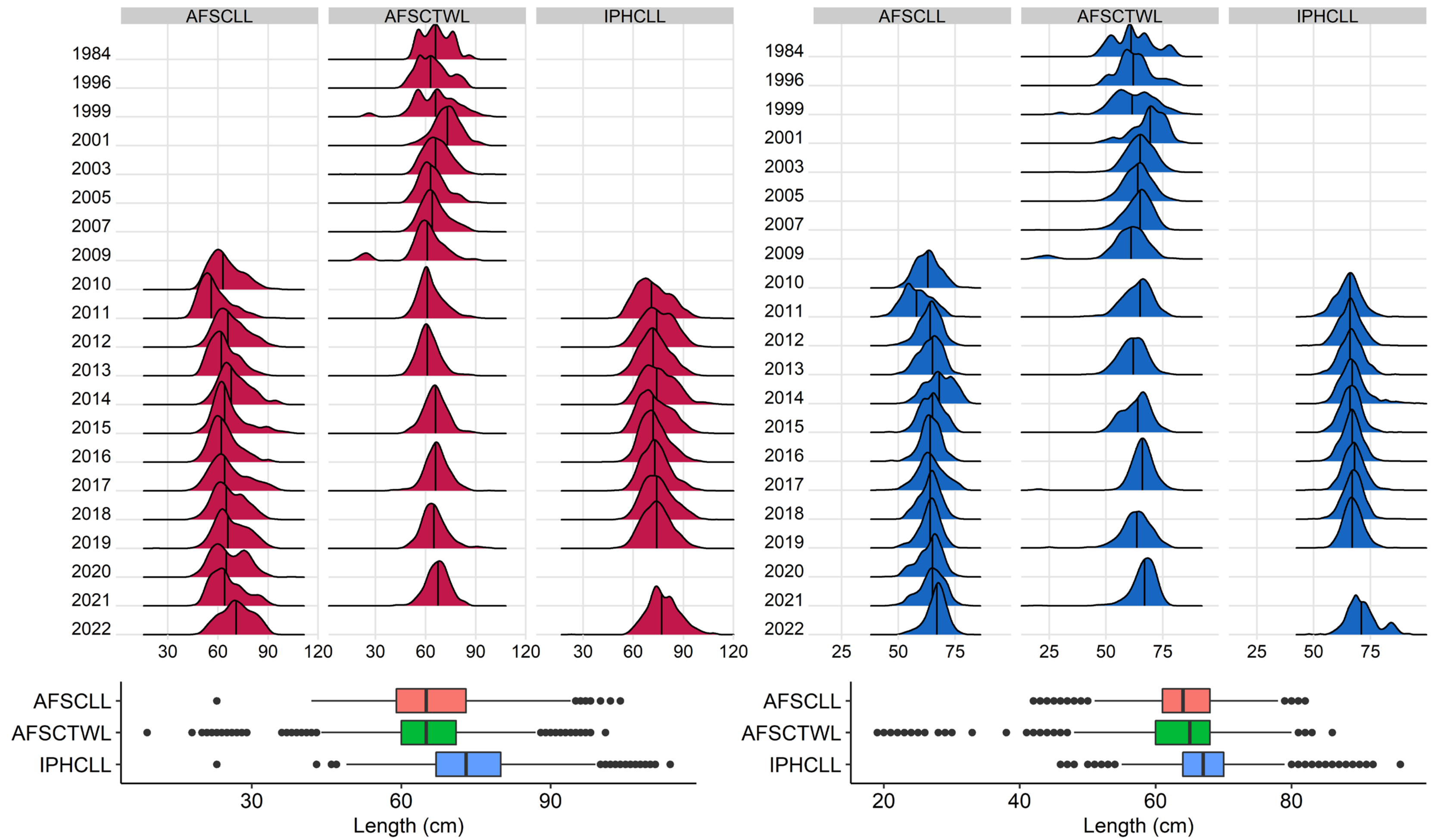


Figure 19D.6. Time series of observed length distributions for female (left) and male (right) spiny dogfish from the three primary surveys operating in the Gulf of Alaska: Alaska Fisheries Science Center longline survey (AFSCLL) and trawl survey (AFSCTWL), and the International Pacific Halibut Commission longline survey (IPHCLL). The bottom panel shows the overall median and interquartile ranges of the length data for each survey.

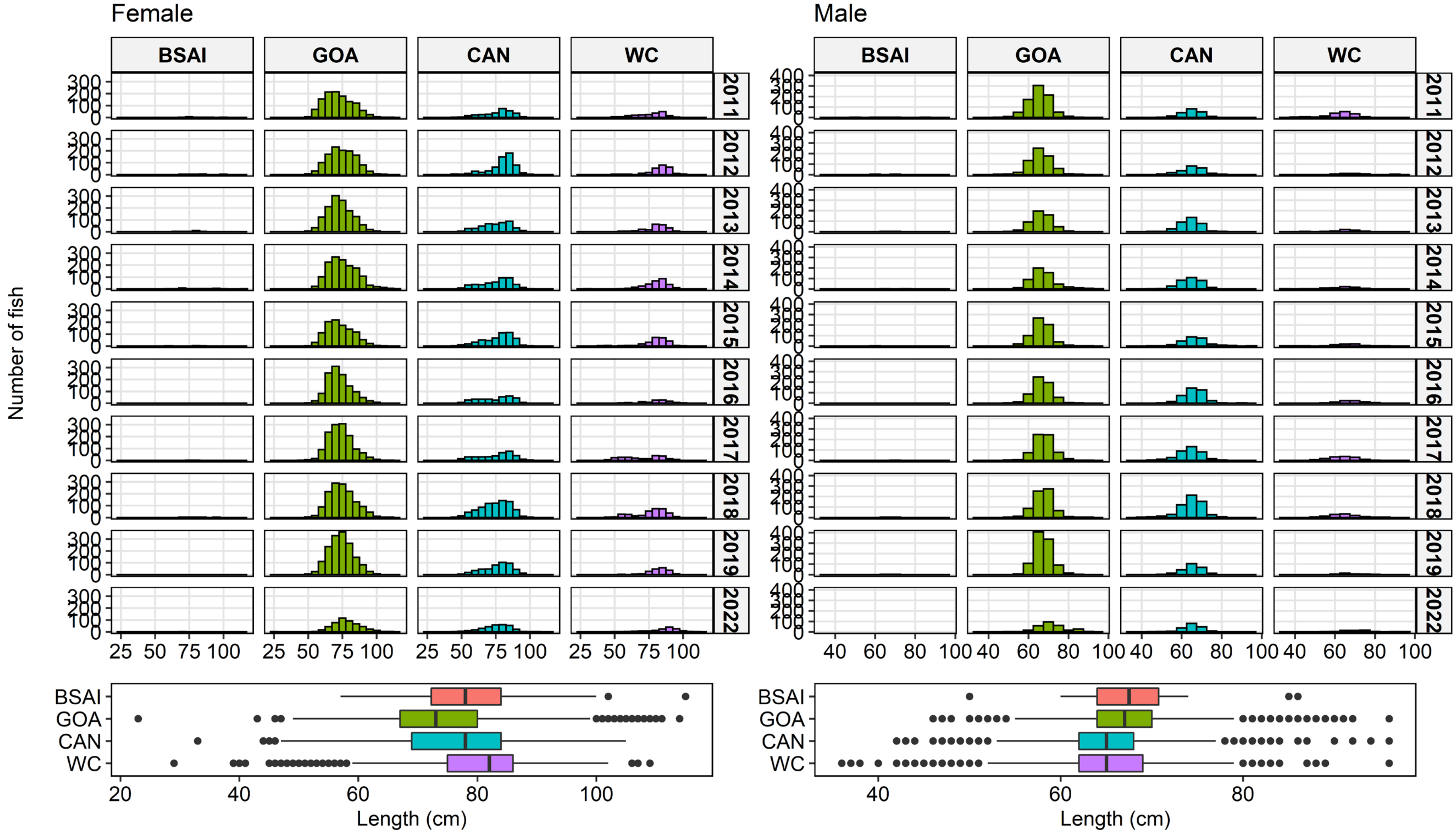


Figure 19D.7. Time series of observed length frequencies for female (left panel) and male (right panel) spiny dogfish sampled in the International Pacific Halibut Commission longline survey by region of capture. BSAI = Bering Sea and Aleutian Islands, GOA = Gulf of Alaska, CAN = Canadian west coast and WC = U.S. west coast. The bottom panel shows the overall median and interquartile ranges of the length data for each survey.

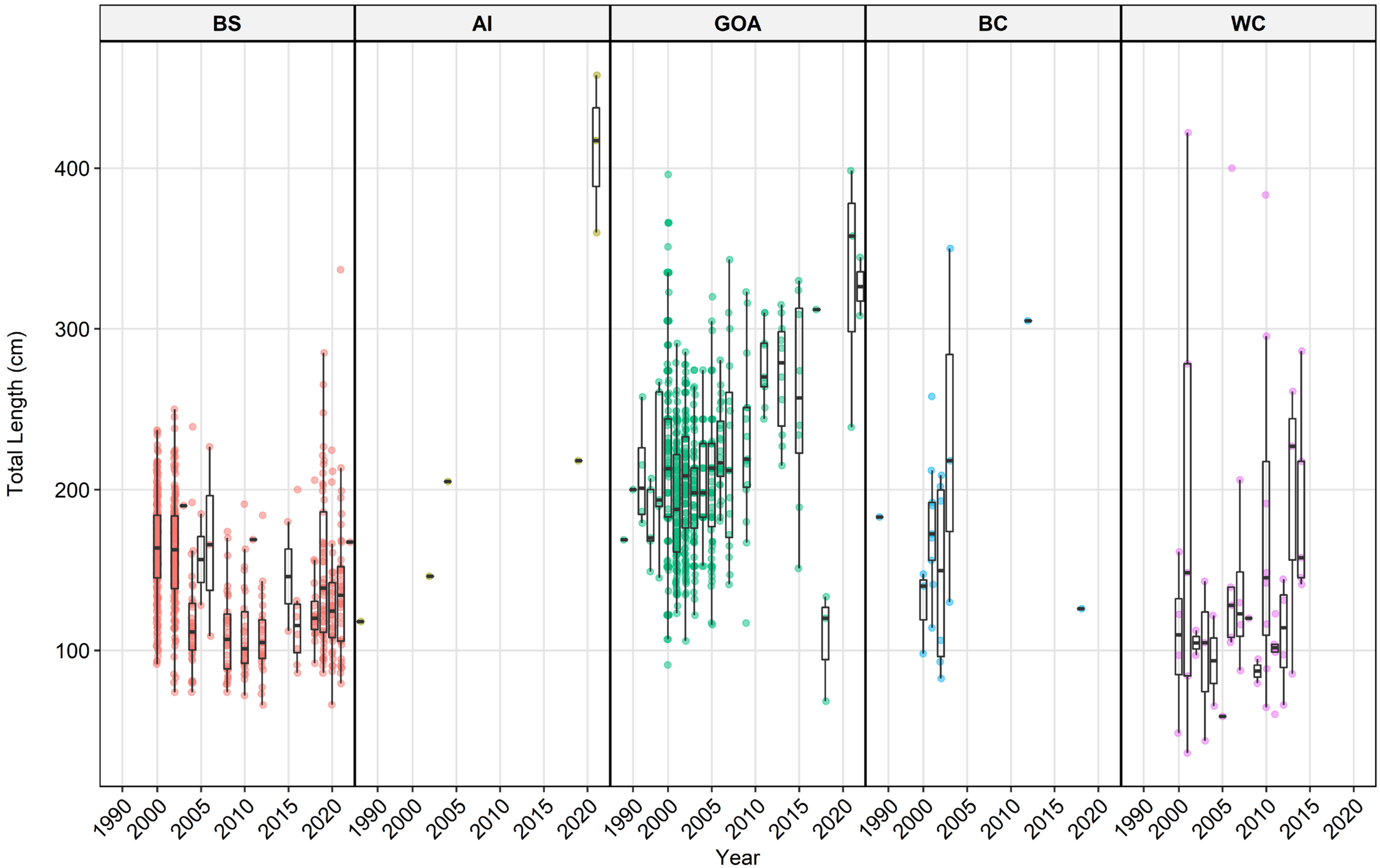


Figure 19D.8. Size distribution of Pacific sleeper shark collected in the Bering Sea (BS), Aleutian Islands (AI), Gulf of Alaska (GOA), and off British Columbia (BC) Canada, and the U.S. West Coast (WC). Data are compiled from standard NMFS groundfish trawl surveys, non-standard NMFS surveys (i.e., opportunistic sample collection), directed research surveys, and special projects on IPHC surveys.

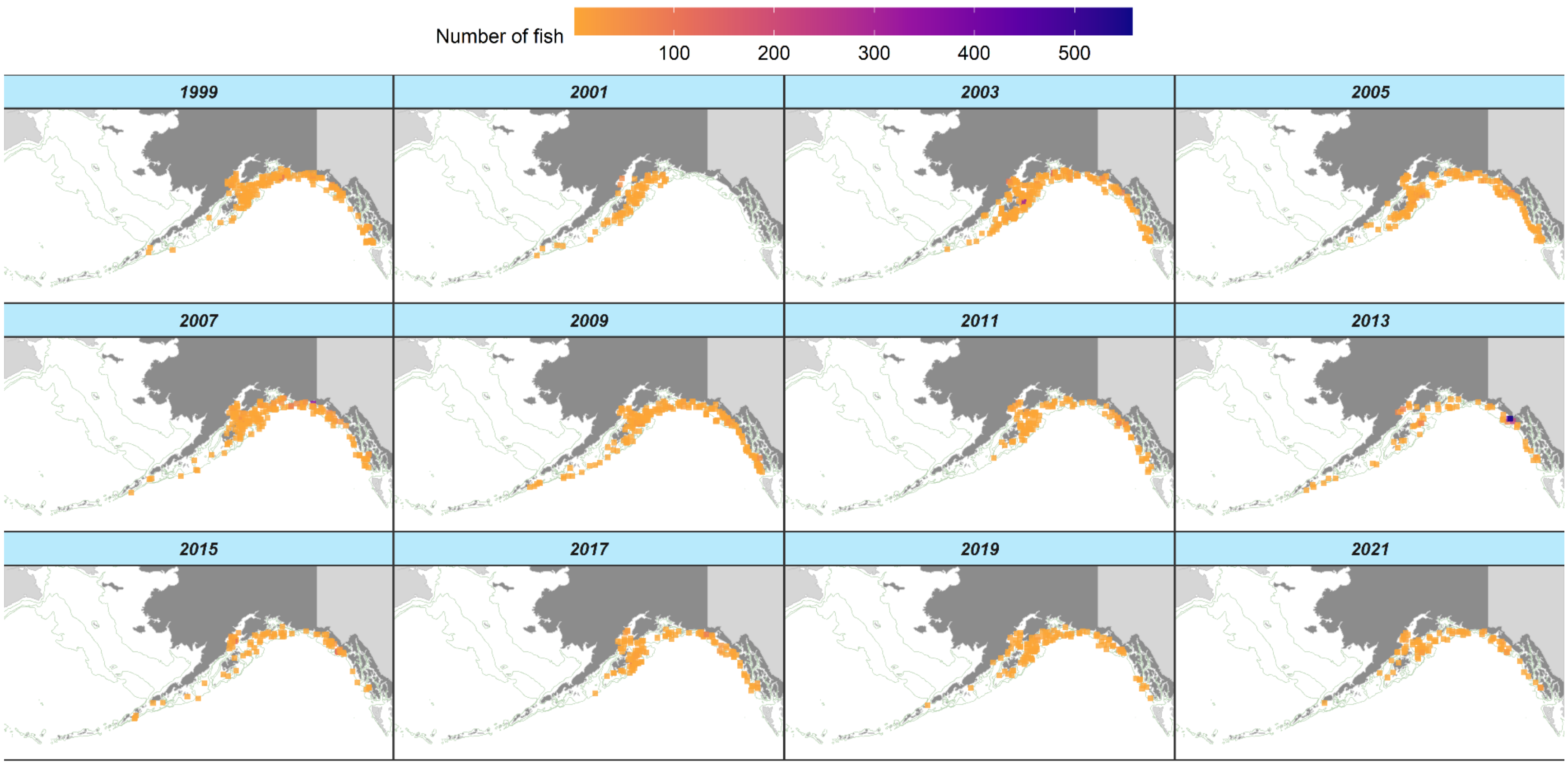


Figure 19D.9. Spatial distribution of the catch of spiny dogfish during the Alaska Fisheries Science Center biennial Gulf of Alaska (GOA) trawl surveys. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity. Note that the eastern GOA was not surveyed in 2001.

IOTC-2023-WPEB19-32

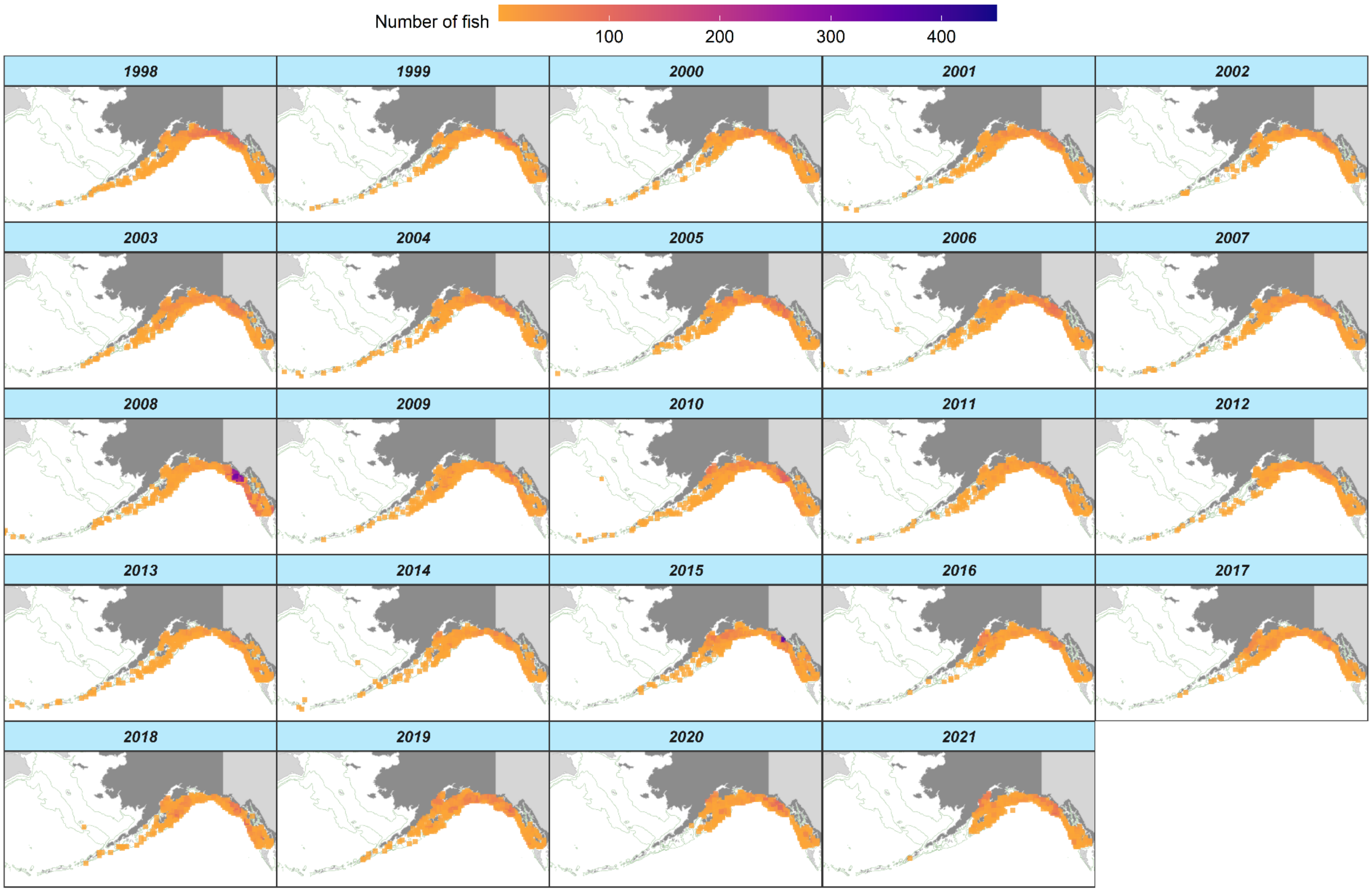


Figure 19D.10. Spatial distribution of the catch of spiny dogfish during the International Pacific Halibut Commission (IPHC) longline surveys in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan areas. Nearly all the spiny dogfish survey catch is in the GOA. Color represents the number of sharks caught. Each point represents one survey haul, and hauls with zero catch were removed for clarity.

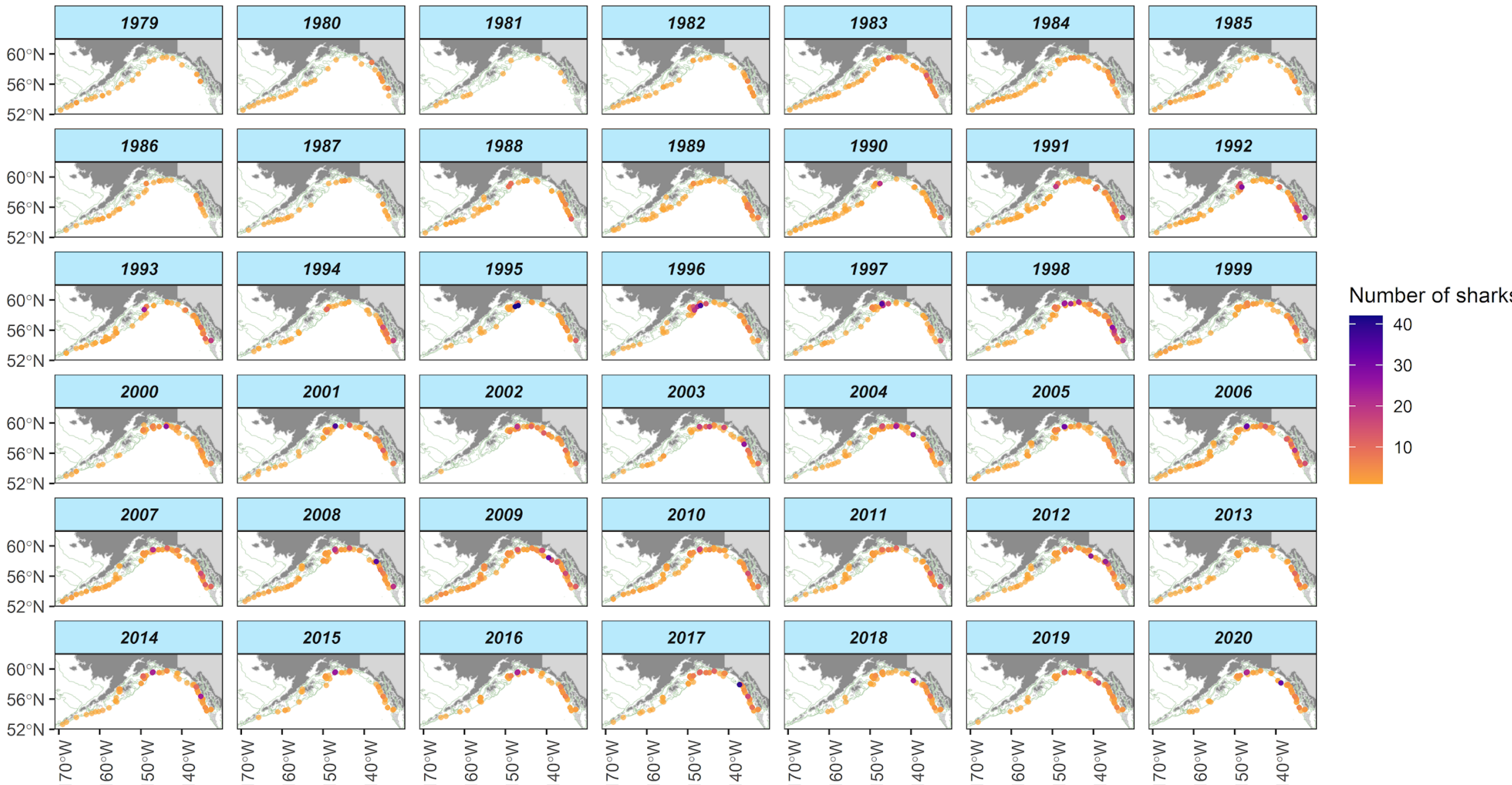


Figure 19D.11. Spatial distribution of the catch of spiny dogfish during the Alaska Fisheries Science Center longline surveys in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan areas. Color represents the number of sharks caught. Each point represents one survey haul, and hauls with zero catch were removed for clarity.

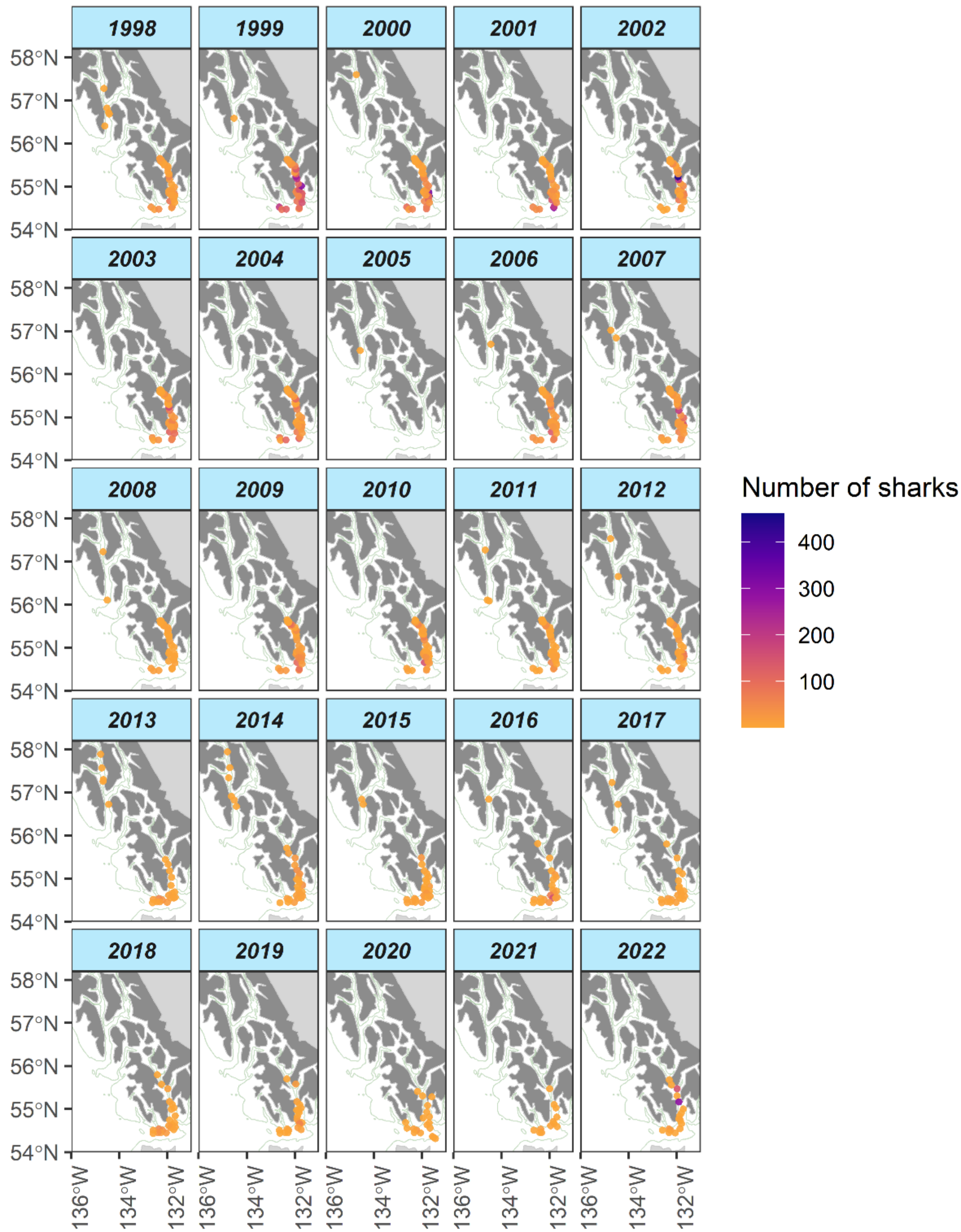


Figure 19D.12. Spatial distribution of the catch of spiny dogfish during Alaska Department of Fish and Game (ADFG) longline surveys in Southeast Alaska (Gulf of Alaska Fishery Management Plan area). Color represents the number of sharks caught. Each point represents one survey haul, and hauls with zero catch were removed for clarity.

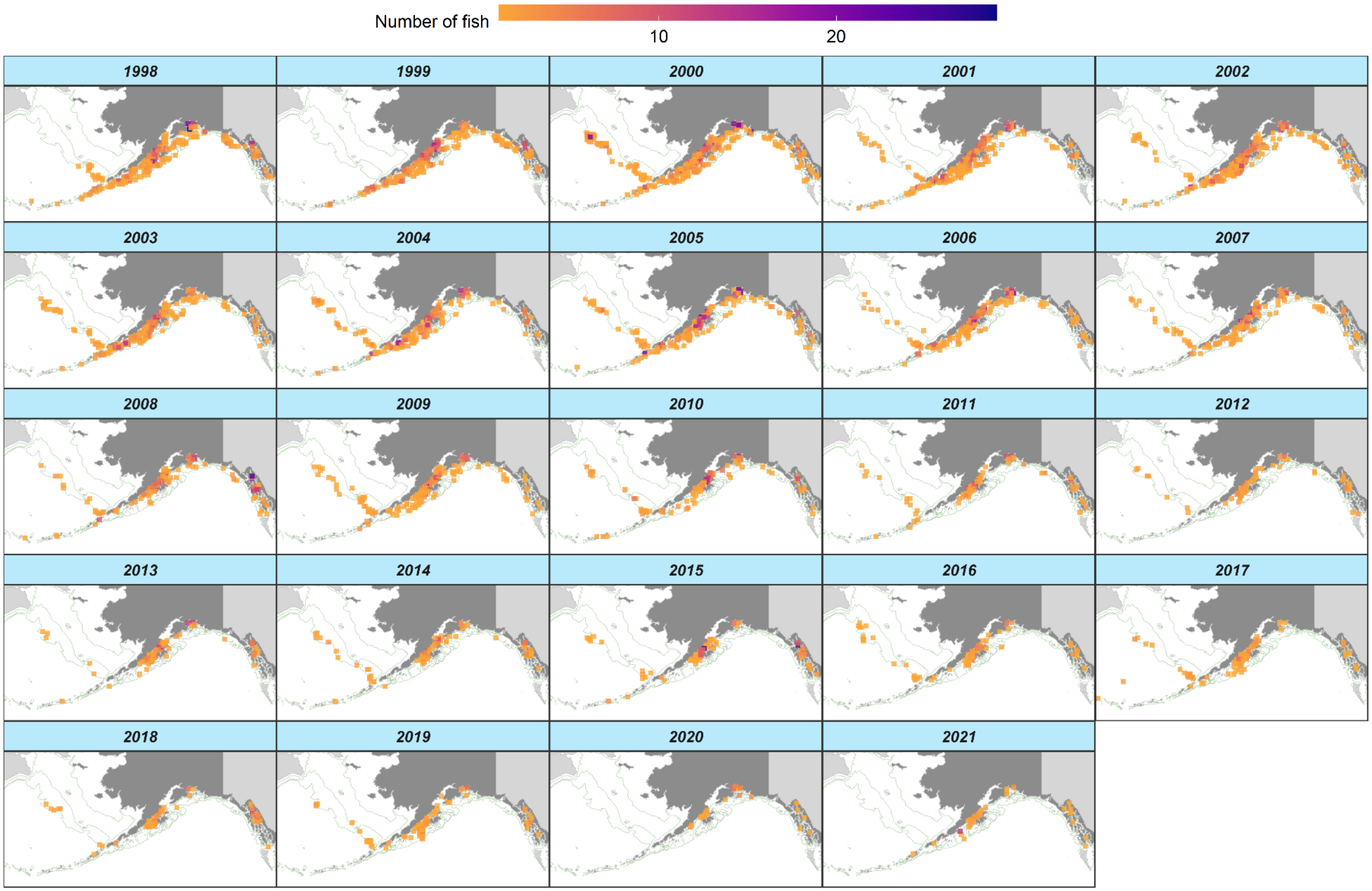


Figure 19D.13. Spatial distribution of the catch of Pacific sleeper shark during the International Pacific Halibut Commission (IPHC) longline surveys in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) Fishery Management Plan areas. Color represents the number of sharks caught. Each point represents one survey haul, and hauls with zero catch were removed for clarity.

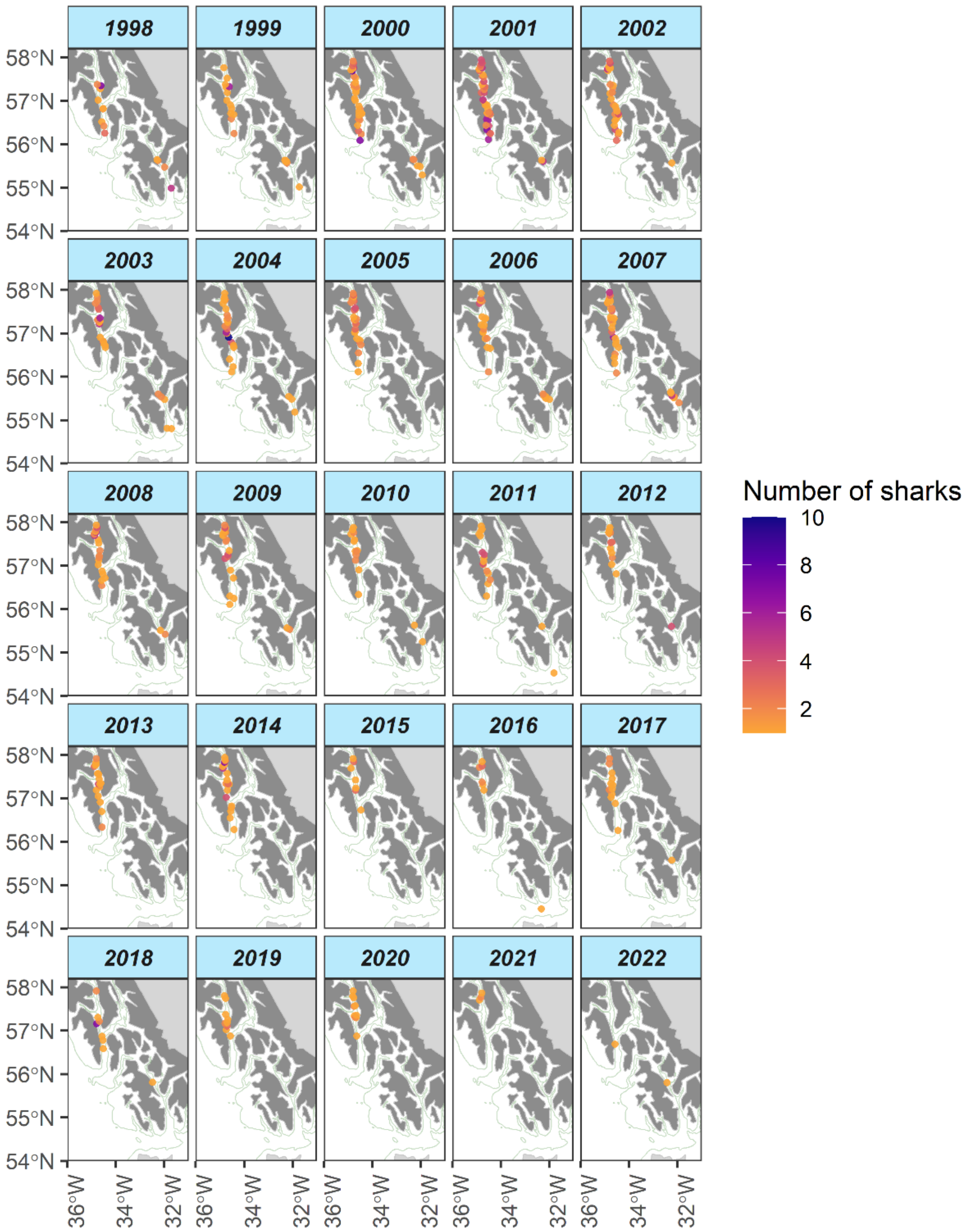


Figure 19D.14. Spatial distribution of the catch of Pacific sleeper shark during the Alaska Department of Fish and Game (ADFG) longline surveys in Southeast Alaska (Gulf of Alaska Fishery Management Plan area). Color represents the number of sharks caught. Each point represents one survey haul, and hauls with zero catch were removed for clarity.

Appendix 19E. Alternative Tier 6 Shark Stock Complex Models for the Bering Sea/Aleutian Islands and the Gulf of Alaska

EXECUTIVE SUMMARY

This document was presented to the Joint Groundfish Plan Teams in September 2022 and appended to this assessment for record.

The models for the Tier 6 components of the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) shark stock complexes are based on historical catch data. The Groundfish Plan Teams and the SSC have both requested explorations of data-limited assessment methods (DLMs) for these stocks. However, there are a number of considerations that need to be taken into account to apply DLMs to for some of the Tier 6 species, which cannot be remedied at this time.

This analysis examines the utility of two proposed models for Pacific sleeper sharks that focus on the most recent time series or utilize expert knowledge and accessory information. Additionally, an updated catch model is proposed for other/unidentified sharks in both FMPs and for spiny dogfish in the BSAI. This updated model reduces the influence of extreme or unlikely catch values due to rare occurrences or errors in the data series.

Introduction

There are two shark stock complexes in Alaskan waters: the Bering Sea/Aleutian Islands (BSAI) shark stock complex, which is comprised of all Tier 6 species; and the Gulf of Alaska (GOA) shark stock complex, which is comprised of Tier 5 spiny dogfish and the remaining species are all Tier 6. The Tier 5 GOA spiny dogfish are not included in the analysis reported here. The Tier 6 shark stock complexes in each of the Fishery Management Plans (FMPs) are assessed using historical catch data. However, the methodological approach of incorporating historical catch data for the Tier 6 species within the complexes is different between the FMPs. In the BSAI, the overfishing limit (OFL) is the maximum historical catch of all species within the complex. In the GOA the average catch is calculated for each species which are then summed to generate the OFL for the Tier 6 component of the complex. Different time series are used for each FMP due to limited availability of historical data (see previous assessments for details). Both the Plan Teams and the SSC have requested examinations of data-limited models (DLMs) for the shark stock complexes:

"The Teams encourage continued exploration of utilizing data limited methods for this assessment." (JGPT September 2018)

"The SSC agrees with the JGPT for continued exploration of utilizing data limited methods for this assessment. The SSC further recommends in addition to sharks, it would be helpful for the Plan Teams and other authors of Tiers 5 and 6 stocks to explore the increasing number of methods available for data limited situations." (SSC October 2018)

"The Team accepted the author's choice of OFL and ABC (the same as 2017 and 2018) and looks forward to the author's new analysis with a greatly expanded set of data-limited methods for 2020" (PT November 2018)

"For the next full assessment in 2020, the SSC looks forward to the authors' new analysis with a greatly expanded set of data-limited methods." (SSC December 2018)

The analysis presented in this document addresses the above requests as well as recommendations brought forward in the Pacific sleeper shark stock structure document. Additionally, an updated catch model is proposed for other/unidentified sharks in both FMPs and for spiny dogfish in the BSAI. This updated model reduces the influence of extreme or unlikely catch values due to rare occurrences or errors in the data series.

The current approach to assessing the Pacific sleeper shark in both the BSAI and GOA uses rudimentary catch scalars. The model assumes that fishery behavior 20+ years ago is representative of fishery behavior today and that trends in catch are representative of trends in abundance. The historical average catch and subsequent maximum catch approaches, as defined by Restrepo et al. (1998), were meant to be based on a time period with evidence of stable abundance. At this point, there are no data supporting the assumption that abundances are stable during either the Pacific sleeper shark catch or index time series. Current data are not included in either of the Pacific sleeper shark models, and in some cases, current catches are consistently and substantially lower than historical catches. It is unlikely that historical fishery behavior adequately represents current fishery behavior or even data quality, and recent data need to be incorporated into the assessment model. Following the assumption that catch trends are representative of abundance also suggests that the current trends in catch need to be taken into consideration for the assessment model. Pacific sleeper shark are non-targeted and primarily discarded, however, they are generally not actively avoided either. Further, the IPHC survey index shows a similar trend to catch of Pacific sleeper shark, suggesting that the assumption that catch trends may represent abundance trends is not unreasonable. Lastly, the buffer between OFL and ABC is meant to be informed by expert judgement if quantitative data are not available (Restrepo et al. 1998, Berkson et al. 2011). Restrepo et al. (1998) recommended buffers from 25% - 75% and, based on simulations of more data informed species, recommended a default buffer of 75% *for stocks judged to be above* B_{MSY}. This buffer is meant to be based on the stock status relative to B_{MSY}, as informed by qualitative or quantitative information, and account for uncertainty in the OFL estimator. The current NPFMC Tier 6 models adopted the 75% buffer. These type of assessment frameworks have a high risk of resulting in overfishing (e.g. Carruthers et al. 2014) and may be improved upon by using contemporary data-limited methods (DLMs).

Two DLMs for Pacific sleeper shark are reviewed, the Only Reliable Catch Series (ORCS) model (Berkson et al. 2011, later updated and refined by Free et al. 2017) allows for qualitative information to be used in the assessment model. In this framework the assessor averages the scores of several stock attributes to determine the stock status as: underexploited, fully exploited or overexploited. The OFL is calculated from the catch statistic appropriate to the stock status multiplied by a scalar selected based on the percentile value that satisfies the risk tolerance. Additionally a constant catch (CC) method is explored that provides stability to data-limited OFLs while accounting for recent trends in catch. The CC method OFLs are scaled most recent 5-year mean catch (Geromont and Butterworth 2015). The CC methods assume that catch data are known without error and that trends in catch data reflect trends in species abundance (Geromont and Butterworth 2015).

Catch estimates of rare species such as other/unidentified sharks or BSAI spiny dogfish are sensitive to the occasional "large haul" which results in large and unlikely estimated catch. For example, in 2006, there were two hauls which reported unusually high catches of unidentified sharks and resulted in an annual estimated catch well outside the range for that species category (Figure 19E.1). By using the 90th percentile of the catch time series instead of the maximum historical values it is possible to avoid the influence of "large hauls".

Analytic Approach

Model Structure

The status quo models for the BSAI and GOA Tier 6 shark stock complexes are described below. The entire complex models are included here because the BSAI model does not consider the individual species. The time series of estimated catch is *C* of species *s*. The BSAI model is 16.0 and the GOA model is 11.0, signifying the first year each of those models went into effect. The more recent and abbreviated time series in the BSAI is due to substantial concerns regarding the accuracy of catch estimates prior to 2003.

FMP	Tier 6 Model	OFL	Equation
BSAI	16.0	Max complex catch 2003–2015	$OFL = max(C_{2003-2015})$
GOA	11.0	Sum of species specific mean catch from 1997–2007	$OFL = \sum_{1}^{s} \bar{C}_{1997-2007}$

Description of Alternative Models

Pacific sleeper shark models

The below models are intended for use in both FMPs and are named by the species, PSS for Pacific sleeper shark, year, and model number. The Only Reliable Catch Series (ORCS) model (Berkson et al. 2011; later updated and refined by Free et al. 2017) is based on an assessor evaluated score for a number of stock attributes (Table 1). These scores are then averaged to determine the stock status as: underexploited, fully exploited or overexploited. The OFL is calculated from the catch statistic appropriate to the stock status multiplied by a scalar selected based on the percentile value that satisfies the risk tolerance (Table 2). The model structure is as follows:

Model	OFL	Equation
PSS22.0	Refined ORCS	$OFL = \begin{cases} s * C_{under}, C_{under} = \text{ } ith\ observation = 0.9(n_{all\ years} + 1) \\ s * C_{fully}, C_{fully} = \text{ } ith\ observation = 0.25(n_{prev\ 10yrs} + 1) \\ s * C_{over}, C_{over} = \text{ } ith\ observation = 0.1(n_{all\ years} + 1) \end{cases}$

where *C* represents catch statistics for under, fully, and overexploited status, *s* is the risk tolerance scalar from Table 2 and *n* is the number of years in the time series. Pacific sleeper shark in each FMP were given conservative and liberal scores for each attribute then the stock status determined from the mean score. In this analysis, the percentile scalar that should promote a 50% probability of overfishing if the stock status is correctly identified was chosen.

In the constant catch (CC) model (Geromont and Butterworth 2015) the OFL is a scaled most recent 5-year mean catch with the scalar reduced as risk aversion increases. The model structure is as follows:

Model	OFL	Equation
PSS22.1	CC1: OFL is average historical catch from recent 5 years	$OFL = x\bar{C}, x = 1\ and$ $\bar{C} = \frac{\sum_{y=t-4}^{t} C_y}{5}$
PSS22.2	CC2: OFL is 90% of average historical catch from recent 5 years	Same as 22.1 with $x = 0.9$
PSS22.3	CC3: OFL is 80% of average historical catch from recent 5 years	Same as 22.1 with $x = 0.8$
PSS22.4	CC4: OFL is 70% of average historical catch from recent 5 years	Same as 22.1 with $x = 0.7$
PSS22.5	CC5: OFL is 60% of average historical catch from recent 5 years	Same as 22.1 with $x = 0.6$

Other/unidentified sharks and BSAI spiny dogfish

Using the 90^{th} percentile of the catch time series instead of the maximum historical values will avoid undue influence from large or misreported hauls. The model BSAI22.0 would be applied to other/unidentified sharks and spiny dogfish in the BSAI and the GOA22.0 model would be only for other/unidentified sharks in the GOA. The years of the historical catch time series are maintained from previous assessments, i.e., BSAI is from 2003 – 2015 and the GOA is from 1997 – 2007.

FMP	Model	OFL	Equation
BSAI	BSAI22.0	90th Percentile of historical catch 2003 - 2015	$OFL = ith\ observation = 0.9(n+1)$ Where n is number of years
GOA	GOA22.0	90th Percentile of historical catch 1997 -2007	

Results

Model Evaluation

Pacific sleeper shark models

The current Tier 6 models are different between the FMPs and the two FMPs treat the complexes differently, therefore any model evaluation must consider the full complement of Tier 6 species. In the BSAI Tier 6 model (16.0) the OFL equals the maximum historical catch of the full complex, whereas the GOA model (11.0) is the summed species-specific OFLs, which are equal to the mean catches for the individual Tier 6 species. Results of the Tier 6 models from the most recent assessment are below.

FMP	Tier 6 Model	OFL	ABC
BSAI	16.0	689	517
GOA	11.0	570	427

About a decade ago, a NOAA working group evaluated catch-only stock assessments and provided guidance based on DLMs available at that time (Berkson et al. 2011). While the DLM resources available today are substantially expanded from those available to Berkson et al. (2011), the guidance is still relevant. In cases where depletion-based stock reduction or depletion-corrected average catch are not available, the ORCS approach is warranted. The time series of catches for the Tier 6 sharks in Alaska are too short for any of the depletion estimators. The ORCS approach follows the concept of “pretty good yield” (Hilborn 2010) and assigns stocks to one of three exploitation categories using evidence-based scoring (Table 19E.1), then calculates and OFL by using statistically supported catch metrics and scalars (Table 19E.2, Free et al. 2017). The ORCS approach was reviewed and updated with extensive simulation testing, resulting in the refined ORCS (Free et al. 2017).

For this analysis, Pacific sleeper shark were scored in each FMP with both liberal and conservative scores. In all cases, the mean score placed the species in the “Fully Exploited” category, regardless of liberal or conservative approaches to scoring. For the remaining discussion only one score per FMPs will be referenced. Because Pacific sleeper sharks were “Fully Exploited” in both FMPs, an OFL was calculated for each FMP using the 25th percentile of the most recent 10 years of catch and a default scalar that should promote 50% probability risk of overfishing assuming the stock status was correctly identified. The 75% ABC buffer was retained in this analysis assuming that because all stocks were considered “Fully Exploited” they are at or above B_{MSY}. This assumption is worth revisiting should this model proceed, given the low productivity of the stock. See Table 19E.3for the detailed results. The refined ORCS summary results are below.

FMP	Model	OFL	ABC
BSAI	PSS22.0	117	88
GOA	PSS22.0	197	148

The CC models also assume that catch trends represent abundance trends, but go further to assume that annual changes in catch are not due to noisy data and catches are known without error (Geromont and Butterworth 2015). The first two assumptions are reasonable for Pacific sleeper shark, however, preliminary ongoing research has demonstrated that catch is likely not known without error. Catch estimates are likely underestimated due to the challenges of accurately weighing such large species (K. Fuller unpublished data, Tribuzio et al. 2020). The summarized CC model results are below:

FMP	Model	OFL	ABC
BSAI	PSS22.1	59	44
	PSS22.2	53	40
	PSS22.3	47	35
	PSS22.4	41	31
	PSS22.5	35	26
GOA	PSS22.1	134	100
	PSS22.2	121	91
	PSS22.3	107	80
	PSS22.4	94	70
	PSS22.5	80	60

Other/unidentified sharks and BSAI spiny dogfish

Using the 90th percentile of the historical times series for GOA and BSAI other/unidentified sharks and BSAI spiny dogfish, results are:

FMP	Model	OFL	ABC
BSAI	BSAI22.0 (Other)	55	41
	BSAI22.0 (Spiny)	20	15
GOA	GOA22.0 (Other)	123	92

Recommendations

For the full 2022 assessment we recommend bringing forward the below Tier 6 models:

Species	FMP	Model
Pacific sleeper shark	BSAI	16.0 (Status Quo) PSS22.0
	GOA	11.0 (Status Quo) PSS22.0
Other/unidentified sharks	BSAI	16.0 (Status Quo) BSAI22.0
	GOA	11.0 (Status Quo) GOA22.0
Spiny dogfish	BSAI	16.0 (Status Quo) BSAI22.0

The CC models for Pacific sleeper shark are not recommended because of the assumption that catch is known without error, and because those models do not take into account accessory information.

The status quo harvest recommendations from the 2020 full assessments are below. The BSAI total Shark Complex maximum, OFL and ABC are not the sum of the species, but the value for the complex in aggregate. The species-specific values are shown for comparison.

BSAI	Pacific sleeper shark	Salmon shark	Other/Unidentified shark	Spiny dogfish	Total shark Complex*
Tier	6	6	6	6	6
Model	16.0	16.0	16.0	16.0	
Maximum Catch (t)	421	199	305	24	689
OFL	421	199	305	24	689
ABC	315	149	229	18	517

The GOA Shark stock complex harvest recommendations are the sum of the individual species recommendations and spiny dogfish is a Tier 5 species.

GOA	Pacific Sleeper Shark	Salmon Shark	Other/Unid Sharks	Spiny Dogfish	Total Complex
Tier	6	6	6	5	5/6
Model	11.0	11.0	11.0	15.3A	
Mean Catch (t)	312	70	188		
OFL	312	70	188	4,436	5,006
ABC	234	53	141	3,327	3,755

Based on the data from the 2020 full assessments, the proposed alternative model harvest recommendations are below. In this case, all Tier 6 species are using the same methods and the same approaches to complexes across both FMPs.

BSAI	Pacific sleeper shark	Salmon shark	Other sharks	Spiny dogfish	Total Complex
Tier	6	6	6	6	6
Model	PSS22.0	16.0	BSAI22.0	BSAI22.0	
Stock Status	Fully Expl.				
Catch Statistic	53.99				
50th Percentile Scalar	2.16				
OFL	117	199	55	20	451
ABC	88	149	41	15	293

GOA	Pacific sleeper shark	Salmon shark	Other sharks	Spiny dogfish	Total Complex
Tier	6	6	6	5	5/6
Model	PSS22.0	11.0	GOA22.0	15.3A	
Stock Status	Fully Expl.				
Catch Statistic	53.99				
50th Percentile Scalar	2.16				
OFL	197	70	123	4,436	4,826
ABC	148	53	92	3,327	3,620

One of the recommendations that came out of the Pacific sleeper shark stock structure document was to separate the GOA spiny dogfish ABC from the Tier 6 species ABCs within the GOA Shark stock complex assessment. The stock structure document discussed separating the Pacific sleeper shark ABC from the rest of the BSAI species, however, it is confounded with other/unidentified sharks because many of the unidentified sharks are believed to be Pacific sleeper shark; therefore, separation is not recommended in that FMP. The proposed GOA spiny dogfish and Tier 6 ABCs based on the 2020 full assessment are below and catch relative to the status quo ABC and the below alternative ABCs are in Figure 19E.2.

GOA	Spiny Dogfish	Tier 6	Total Complex
OFL			4,826
ABC	3,327	293	3,620

References

Berkson, J., L. Barbieri, S. Cadrin, S. L. Cass-Calay, P. Crone, M. Dorn, C. Friess, D. Kobayashi, T. J. Miller, W. S. Patrick, S. Pautzke, S. Ralston, M. Trianni. 2011. Calculating Acceptable Biological Catch for Stocks That Have Reliable Catch Data Only (Only Reliable Catch Stocks – ORCS). NOAA Technical Memorandum NMFS-SEFSC-616, 56 P.

Carruthers, T.R. and A.R. Hordyk. 2018. The data-limited methods toolkit (DLMtoo): An R package for informing management of data-limited populations. Methods in Ecology and Evolution. 00:1-8. DOI: 10.1111/2041-210X.13081

Free, C.M., O.P. Jensen, J. Wiedenmann, and J.J. Deroba. 2017. The refined ORCS approach: A catch-based method for estimating stock status and catch limits for data-poor stocks. Fisheries Research. 193:60-70.

Geromont, H. F., and D. S. Butterworth. 2015. Generic Management Procedures for Data-Poor Fisheries: Forecasting with Few Data. ICES Journal of Marine Science: Journal Du Conseil 72 (1). 251-61.

Hilborn, R. 2010. Pretty good yield and exploited fishes. Marine Policy. 34:193-196.

Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson–Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31, 54 p.

Tables and Figures

Table 19E.1. ORCS Table of attributes used in this analysis. Adapted from Table 1, Free et al. (2017).

		Stock status[a]		
#	Attribute	Underexploited (1)	Fully exploited (2)	Overexploited (3)
1	Status of assessed stocks in fishery	<10% overfished	10–25% overfished	>25% overfished
2	Behavior affecting capture	----------	No aggregation behavior	Exhibits aggregation behavior
3	Discard rate	Discards <10% of catch	Discards 10–25% of catch	Discards >25% of catch
4	Targeting intensity	Not targeted	Occasionally targeted	Actively targeted
5	M compared to dominant species[b]	Higher mortality rate	Equivalent mortality rates	Lower mortality rate
6	Occurrence in catch	Sporadic *(in <10% of efforts)*	Common *(in 10–25% of efforts)*	Frequent *(in >25% of efforts)*
7	Value (US$/lb, 5-year mean)	<$1/lb	$1-$2.25/lb	>$2.25/lb
8	Recent trend in catch	Increasing last 5 years	Stable last 5 years	Decreasing last 5 years
9	Habitat loss	No time in threatened habitats	Part time in threatened habitats *(full time in partially threatened habitats)*	Full time in threatened habitats
10	Recent trend in effort	Decreasing last 5 years	Stable last 5 years	Increasing last 5 years
11	Recent trend in abundance index	Increasing last 5 years	Stable last 5 years	Decreasing last 5 years
12	Proportion of population protected	Most of resource is protected *(size limits AND time/space closures)*	Some of resource is protected *(size limits OR time/space closures)*	None of resource is protected *(no size limits or time/space closures)*

[a] In the original ORCS approach, stock status is estimated as the mean of the TOA scores (<1.5=underexploited; 1.5–2.5=fully exploited; >2.5=overexploited).

[b] Removed ambiguity of score descriptions in the original table and specified that M's must differ by >20% to be considered different.

Table 19E.2. Status-specific historical catch statistics and potential status-specific catch scalars for relating the best catch statistic to the overfishing limit (OFL). The 50th percentile scalars should promote a 50% probability of overfishing if stock status is correctly identified. The other, more conservative scalars may be useful for buffering against classification uncertainty. From Table 3 in Free et al. 2017.

		OFL Scalars								
Stock status	Catch statistic	50th	45th	40th	35th	30th	25th	20th	15th	10th
Underexploited	90th percentile, whole time series	1.90	1.78	1.62	1.53	1.41	1.34	1.29	1.11	0.88
Fully exploited	25th percentile, previous 10 years	2.16	1.84	1.77	1.57	1.41	1.22	1.15	1.02	0.85
Overexploited	10th percentile, whole time series	1.56	1.53	1.49	1.00	0.52	0.51	0.50	0.45	0.41

Table 19E.3. ORCS results for the BSAI

		BSAI		GOA	
	Attribute Description	Cons	Lib	Cons	Lib
1	Status of assessed stocks in fishery	3	1	3	1
2	Behavior affecting capture	2	2	2	2
3	Discard rate	3	3	3	3
4	Targeting intensity	1	1	1	1
5	M compared to dominant species	3	2	3	2
6	Occurrence in catch	3	1	3	1
7	Value	1	1	1	1
8	Recent trend in catch	2	1	3	2
9	Habitat loss	2	1	2	1
10	Recent trend in effort	3	2	3	2
11	Recent trend in abundance index	2	3	2	3
12	Proportion of population protected	3	3	3	3
Mean Score		2.33	1.75	2.42	1.83
Stock Status		Fully Exploited			
Catch Statistic		53.99		91.02	
Scalar		2.16		2.16	
OFL		117		197	
ABC		88		148	

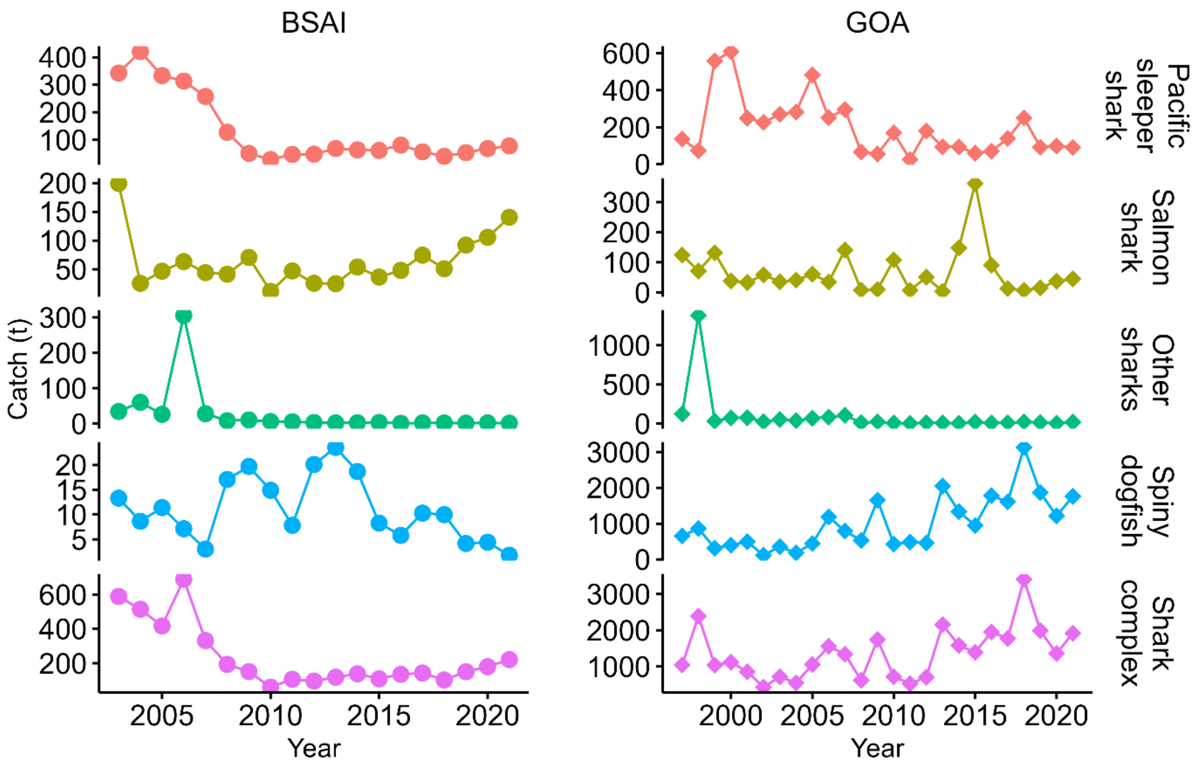


Figure 19E.1. Estimated catch (metric tons) time series for each of the shark species or species groups in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA).

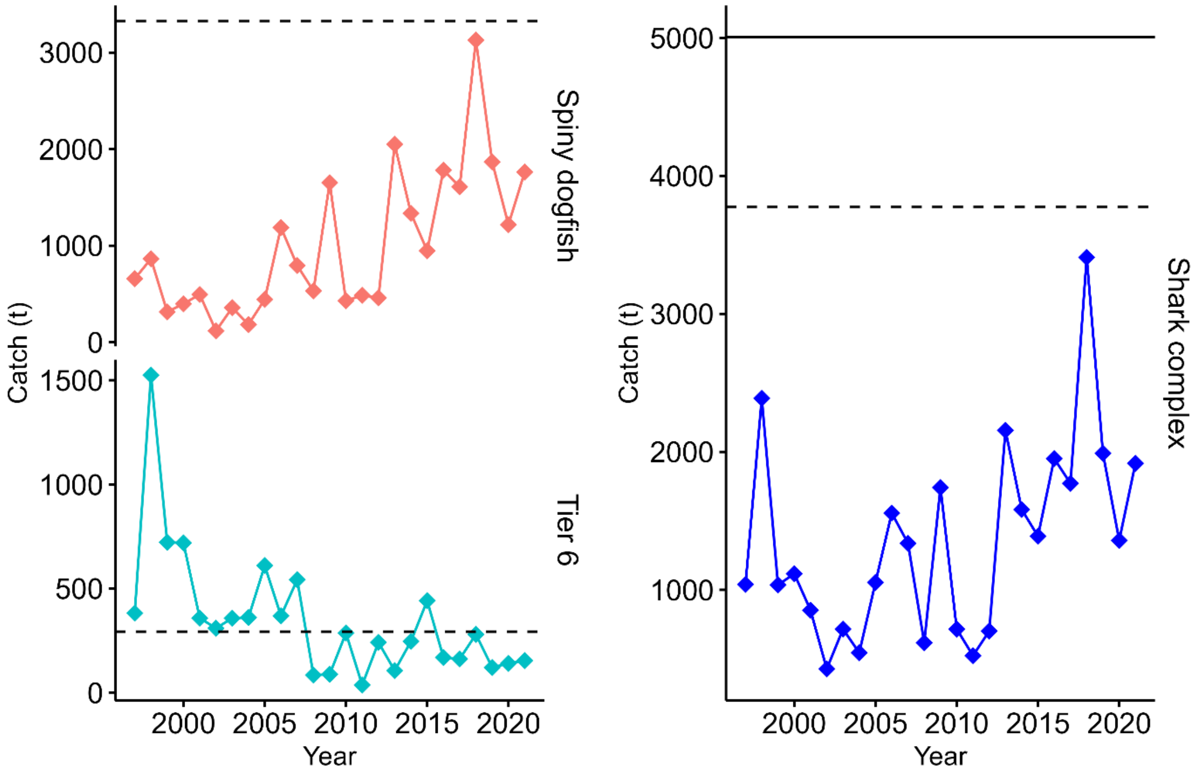


Figure 19E.2. Estimated catch times series of the proposed GOA sub-complex ABC groups: spiny dogfish and Tier 6 sharks (left panel) and the total shark complex (right panel). The solid line is the status quo ABC and the dashed lines represent the sub-complex ABCs (left) and the sum of the two sub-complex ABCs (right). The majority of the Tier 6 catch in the GOA is Pacific sleeper shark.