# Assessment of the shark stock complex in the Bering Sea and Aleutian Islands

Cindy A. Tribuzio, Katy Echave, Cara Rodgveller, and Peter-John Hulson

November 2018

## EXECUTIVE SUMMARY

The shark complex (Pacific sleeper shark, spiny dogfish, salmon shark, and other/unidentified sharks) in the Bering Sea and Aleutian Islands (BSAI) is assessed on a biennial stock assessment schedule. In even years we present a full stock assessment document. BSAI sharks are a Tier 6 complex with the over fishing limit (OFL) based on maximum historical catch between the years 2003–2015 and acceptable biological catch (ABC) is 75% of OFL. This range of years was selected as a result of the 2016 assessment which identified issues in the accuracy of the catch data prior to 2003. The model numbering convention has been adopted beginning in this assessment, and the Tier 6 model used within this assessment will henceforth be termed Model 16.0. When Model 16.0 was adopted, the authors recommended that the time frame used for ABC and OFL specifications continue to be investigated by assessment authors as part of investigations into alternative methods to improve the stock assessment. No new assessment methods are presented in this assessment, but the authors have begun exploring the suite of data-limited methods now available.

## Summary of Changes in Assessment Inputs

*Changes to the input data*

1. Total catch for BSAI sharks is updated 2003–2018 (as of Oct 9, 2018)
2. International Pacific Halibut Commission (IPHC) longline survey relative population numbers (RPNs) are updated through 2017
3. Biomass estimates have been updated for the Aleutian Islands and eastern Bering Sea shelf trawl surveys through 2018

*Changes in assessment methodology*

None

## Summary of Results

For 2019–2020 we recommend the maximum allowable ABC of 517 t and an OFL of 689 t for the shark complex, which are the same as the previous assessment. Current catches are well below the recommended ABC because sharks are generally considered undesirable. Due to the 2 million ton cap in the BSAI, the total allowable catch (TAC) has been set well below the recommended ABC since the inception of the shark complex in 2011. Total shark catch in 2017 was 142 t and catch in 2018 was 94 t, as of October 9, 2018. The stock complex was not subject to overfishing last year, and data do not exist to determine if the complex is overfished.

ABC and OFL calculations and Tier 6 recommendations for 2019–2020. OFL = maximum shark catch from 2003–2015. ABC = OFL*0.75.

| Quantity | As estimated or *specified last* year for: 2018 | 2019 | As estimated or *recommended this* year for: 2019 | 2020 |
|---|---|---|---|---|
| Tier | 6 | 6 | 6 | 6 |
| OFL (t) | 689 | 689 | **689** | 689 |
| maxABC (t) | 517 | 517 | 517 | 517 |
| ABC (t) | 517 | 517 | **517** | 517 |
| **Status** | As determined *last* year for: 2016 | 2017 | As determined *this* year for: 2017 | 2018 |
| Overfishing | No | n/a | No | n/a |

# Summaries for Plan Team

| Species | Year | Biomass[1] | OFL | ABC | TAC | Catch[2] |
|---|---|---|---|---|---|---|
| Shark Complex | 2017 | NA | 689 | 517 | 125 | 142 |
| | 2018 | NA | 689 | 517 | 180 | 94 |
| | 2019 | NA | 689 | 517 | | |
| | 2020 | NA | 689 | 517 | | |

[1]The shark complex in the BSAI is a Tier 6 complex with no reliable estimates of biomass

[2]Catch as of October 9, 2018

# Responses to SSC and Plan Team Comments on Assessments in General

"*In an effort improve record keeping as assessment authors formulate various stock status evaluation models, the Plan Team has recommended a systematic cataloging convention. Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes are identified by the addition of a letter designation (e.g., 16.1a). The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time*." (SSC December 2016)

We have adopted the requested model naming conventions.

*"The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity."* (SSC, October 2017)

To facilitate a coordinated response to this request, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from stock assessment program leadership at the AFSC, have suggested that authors address it by using the previous year's Ecosystem Status Report (ESR) as follows:

> "No later than the summer of each year, the lead author of each assessment should review the previous year's ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where "severe decline" means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely, and if that decline was not anticipated in the most recent stock assessment, he or she should summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become available after the document is produced but prior to the October Council meeting of that year, the document should be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary."

*"Stock assessment authors are encouraged to work with ESR analysts to identify a small subset of indicators prior to analysis, and preferably based on mechanistic hypotheses."* (SSC October 2018)

The authors carefully reviewed the most recent ESR for the EBS and AI. Sharks are included as part of the non-target and discards indicator. There has been little change in discards or catch relevant to sharks.

*"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern."* (SSC October 2017)

Clarification during December 2017 SSC meeting and then re-clarified during June 2018 SSC meeting. In the interest of efficiency, the clarification from the December 2017 minutes is not included here. The relevant portion of the clarification from the June 2018 minutes reads as follows:

*"This request was recently clarified by the SSC by replacing the terms 'ecosystem status' and 'stock assessment status' with 'Ecosystem Status Report information' and 'Stock Assessment Information,' where the potential determinations for each will consist of 'Okay' and 'Not Okay,' and by issuing the following guidance:*

- *The SSC clarifies that 'stock assessment status' is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.*
- *Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the 'Okay' or 'Not Okay' determinations.*
- *The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.*

- *Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC."*

*"The Teams recommend that the terms 'current and future ecosystem condition' and 'current and future stock condition' be used in place of 'ESR information' and 'stock assessment information'."* (Plan Team September 2018)

*"The SSC recognized that because formal criteria for these categorizations have not been developed by the PT, they will not be presented in December 2018."* (SSC October 2018)

The iterative process described in the final bullet above was scheduled to begin at the September 2018 meeting of the Joint BSAI and BSAI Plan Teams. However, no formal criteria for these categorizations were developed by the Plan Teams in September 2018.

*"The Team recommended that the authors simply report in words or a table whether catches exceed ABC as an indicator for "partial update" stocks.* (Plan Team November 2017)

Not applicable to this assessment

*"The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification."* (SSC December 2017)

Clarification: *"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."* (SSC June 2018)

Not applicable to this assessment

*"Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible."* (SSC December 2017)

Not applicable to this assessment

*"Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration."* (SSC December 2017)

Not applicable to this assessment

*"The Teams recommend that the appropriate use, or non-use, of new model based estimates in this assessment cycle be left to individual authors' discretion. The Teams further recommend that, if an author chooses to incorporate these into the assessment, the assessment should also contain appropriate comparative models and a full set of diagnostics."* (Plan Team September 2018)

*"The SSC supports the PT recommendation to make the use of model-based survey estimates at the individual author's discretion for 2018."* (SSC October 2018)

Not applicable to this assessment

*"The SSC also noted that, in order to save resources, authors should not conduct additional assessments beyond the prioritized schedule unless they specifically trigger one or more of the criteria identified."* (SSC October 2018)

Following the prioritized schedule, the BSAI shark complex stock assessment is scheduled to occur in even years. In odd years, the authors will review the criteria to determine if a full assessment is warranted.

## SSC and Plan Team Comments Specific to this Assessment

"*The Team recommends that the authors continue development of catch of sleeper sharks by numbers, if possible back to 2003, and examine the potential bias in average weight as applied to observed longline caught sleeper sharks.*" (PT November 2016)

Estimating catch by numbers back to 2003 is not possible within the Catch Accounting System (CAS) due to structural changes that occurred in 2010. It could be done as a separate program, outside of CAS, and the authors are working with staff at the Alaska Regional Office (AKRO) to complete this project. With regards to the potential bias in average weight in the observed longline fishery data, a special project is underway to investigate this and preliminary results were presented at the September 2018 Joint Groundfish Plan Team meeting. That document is included here as Appendix 20A.

"*The SSC recommends that the authors bring forward, in the next full assessment, harvest specification options discussed in the Plan Team (using the 2003-2015 time period), with a discussion of the tradeoffs between the methods and the management and conservation of BSAI sharks."* (SSC December 2016)

The alternative models discussed during the November 2016 Plan Team meeting were included in this assessment, see the "Description of Alternative Models" and "Model Evaluation" sections.

"*The SSC supports the Plan Team request to provide catch of sleeper sharks in numbers to better evaluate average weight and catch trends.*" (SSC December 2016)

See above comment

"*The SSC also requests the following for future assessments:*

- *Investigate the relationship between bottom temperature and catch trends, and*
- *follow the model numbering format*" (SSC December 2016)

Staff at the AKRO have begun a detailed spatial analysis of Pacific sleeper shark catch, which will include variables such as bottom temperature, cold-pool size, depth, etc. We have adopted the model-numbering format

"*The SSC also encourages further investigations to age sleeper sharks, which has not been possible to date. The author recommended several potential new methods for investigation.*" (SSC December 2016)

A pilot study is underway examining 14C in the eye lens, similar to a recent study on Greenland shark (Nielson et al. 2016). The Greenland shark study did not address a number of concerns about how well the eye lens uptakes and stores the 14C, thus the authors are collaborating with staff at the Age and Growth Program, as well as Dr. Allen Andrews at PIFSC and university faculty (TBD), to write a grant supporting an M.S. student to investigate appropriateness of this method for ageing.

"*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)

With regards to the two above comments, the authors have begun exploring the data-limited methods for Pacific sleeper sharks and plan to expand the analysis to the rest of the complex (both FMPs). The long-term plan is to examine the utility of the data-limited methods across the other Tier 5 and Tier 6 stocks.

# 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) (Figure 20.1). The three shark species most likely to be encountered in BSAI fisheries and surveys are the Pacific sleeper shark (*Somniosus pacificus)*, the salmon shark (*Lamna ditropis*), and the spiny dogfish (*Squalus suckleyi)*. In total eight species of sharks have been reported in the BSAI (Table 20.1).

*Squalus acanthias* is the scientific name that has historically been used for the spiny dogfish of the North Pacific and many areas of the world, however, the *S. acanthias* "group" is not monospecific and has a history of being taxonomically challenging. The North Pacific spiny dogfish were reclassified by Girard (1854) as *S. suckleyi*, but the description was vague and no type specimens were preserved, thus it remained *S. acanthias*. In a 2010 study, *S. suckleyi* was resurrected based on morphological, meristic, and molecular data (Ebert et al. 2010). This scientific name has subsequently been accepted by the American Fisheries Society naming committee. The spiny dogfish has been classified as *S. suckleyi* in the SAFE since 2010, but both names may be used to be consistent with data sources, which still use *S. acanthias* (e.g., RACEBASE survey data).

# General Distribution

### *Pacific Sleeper Shark*

The Pacific sleeper shark is the most commonly encountered shark in the BSAI ranging as far north as the Arctic Circle in the Chukchi Sea (Benz et al. 2004), west off the Asian coast and the western Bering Sea (Orlov and Moiseev 1999), south along the Alaska and Pacific coast and possibly as far south as the coast of South America (de Astarloa et al. 1999). However, Yano et al. (2007) reviewed the systematics of sleeper sharks and suggested that sleeper sharks in the southern hemisphere and the southern Atlantic Ocean were misidentified as Pacific sleeper sharks and are actually *Somniosus antarcticus*, a species of the same subgenera. Pacific sleeper sharks have been documented at a wide range of depths, from surface waters (Hulbert et al. 2006) to 1,750 m (seen on a planted grey whale carcass off Santa Barbara, CA, www.nurp.noaa.gov/Spotlight/Whales.htm), but this species can be found in relatively shallow waters at higher latitudes and in deeper habitats in temperate waters (Yano et al. 2007).

### *Salmon Shark*

Salmon sharks range in the North Pacific from Japan through the Bering Sea and Gulf of Alaska (GOA) to southern California and Baja, Mexico, and they are considered common in coastal littoral zones as well as inshore and offshore epipelagic waters (Mecklenburg et al. 2002). Salmon sharks tend to be more pelagic and surface oriented than the other shark species in the BSAI, spending 72% of their time in water less than 50 m depth (Weng et al. 2005). 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).

### *Spiny Dogfish*

Spiny dogfish occupy shelf and upper slope waters from the Bering Sea to the Baja Peninsula in the eastern North Pacific and south through the Japanese archipelago in the western North Pacific. They 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. Spiny dogfish inhabit both benthic and pelagic environments with a maximum recorded depth of 677 m (Tribuzio, unpublished data). Spiny dogfish are commonly found in the water column and in surface waters (Tribuzio, unpublished data).

# Evidence of Stock Structure

The stock structure of the BSAI and GOA shark complexes was examined and presented to the joint Plan Teams in September 2012 (Tribuzio et al. 2012). There is very little data available to evaluate whether different stocks exist among regions within the GOA or BSAI for any of the three species. Sharks are generally long-lived and slow growing. There is insufficient life-history data for any of the species to compare between or within the GOA and BSAI. Genetic studies conducted on spiny dogfish have indicated that there is no significant stock structure within the GOA or BSAI (Ebert et al. 2010, Verissimo et al. 2010).

Preliminary results of an ongoing genetics study of Pacific sleeper sharks detected two distinct mitochondrial lineages which are equally present across the range of the species (S. Wildes, NMFS, AFSC pers. comm.). Development of 7 novel microsatellite markers revealed low variability in this species. Only 2 markers resulted in allele frequency heterozygosity greater than 0.75 (Wildes, et al. in review). Staff are planning to identify additional nuclear markers with ddRAD sequencing and to examine close-kin mark-recapture methods to help estimate effective population size and anticipate results to inform the stock structure template for the species in 2019.

# Life History Information

There is little data specific to the BSAI region for any of the three primary shark species, thus GOA information is used as proxy. Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity. Therefore, 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 sharks were 3 of the 4 most vulnerable species (lower scores are less vulnerable), with salmon shark at 1.96, spiny dogfish at 2.10, and Pacific sleeper shark at 2.24, the most vulnerable of all species analyzed.

### *Pacific Sleeper Shark*

Sleeper sharks (*Somniosus* spp.) attain large sizes, most likely possess a slow-growth rate, and are likely long-lived (Fisk et al. 2002). Ages are not readily available because the cartilage in sleeper sharks does not calcify to the degree of many other shark species, and methods of ageing this species are under investigation. A Greenland shark (*Somniosus microcephalus*), the North Atlantic congener of the Pacific sleeper shark, sampled in 1999 was determined to have been alive during the 1950’s - 1970’s because it had high levels of DDT (Fisk et al. 2002). Additionally, an immature 220-cm Greenland shark (total length *TL* was measured from the tip of the snout to the upper lobe of the caudal fin) was estimated to be 49 years old using bomb radiocarbon isotopes in the eye lens (Nielson et al. 2016).

Data on the length of sleeper sharks are not prevalent because their large size makes handling difficult. The average length of *Somniosus* sp. captured in mid-water trawls in the Southern Ocean is 390 cm *TL* (range 150–500 cm, n=36, Cherel and Duhamel 2004). Large *Somniosus* sharks observed in photographs from deep water have been estimated at lengths up to 700 cm (Compagno 1984). The maximum lengths of captured Pacific sleeper sharks were 440 cm *TL* for females and 400 cm *TL* for males (Mecklenburg et al. 2002). Pacific sleeper sharks as large as 430 cm *TL* have been caught in the western North Pacific (WNP), where the species exhibits sexual dimorphism, with females being shorter and heavier (avg. length = 138.9 cm *TL*, avg. weight = 28.4 kg) than males (avg. length = 140 cm *TL*, avg. weight = 23.7 kg) (Orlov 1999).

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*, mature male Pacific sleeper sharks are in excess 397 cm *TL*, and the size at birth is approximately 40 cm *TL* (Gotshall and Jow 1965, Yano et al. 2007). The reproductive mode of sleeper sharks is thought to be aplacental viviparity. 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. Of two 74-cm sharks 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 35m depth 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). In summer 2005, an 85-cm *PCL* (pre-caudal length, measured from the tip of the snout to the dorsal pre-caudal notch, at the base of the tail) female was caught during the annual AFSC longline survey near Yakutat Bay and in spring 2009 another 85-cm *PCL* female was caught by a commercial halibut fisherman inside Chatham Strait in Southeast Alaska (Tribuzio unpublished data). Because of a lack of observations of mature and newly born sharks, and the absence of dates in literature, the spawning and pupping seasons are unknown for sleeper sharks.

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) surveys. There may be additional data available from the West Coast in the future; authors are working with staff at Monterey Bay Research Institute and Moss Landing Marine Labs to recover data that may be archived by those organizations. The length data compiled thus far show that small animals (50 – 200 cm total length) are caught coast wide; larger fish, those >200 cm *TL,* have never been recorded in the BSAI and animals up to 400 cm *TL* have been caught, in small numbers, in all other regions (Figure 20.2). 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 all young and 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 shark in any area comes from camera footage from deep water 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 that 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). Adult salmon sharks typically range in size from 180–210 cm *PCL* (Goldman and Musick 2006) in the eastern North Pacific and can weigh upwards of 220 kg. Length-at-maturity in the WNP has been estimated to occur at approximately 140 cm *PCL* for males and 170–180 cm *PCL* for females (Tanaka 1980), and these lengths correspond to approximate ages of five years and 8–10 years, respectively. Length-at-maturity in the eastern North Pacific (ENP) has been estimated to occur between 125–145 cm *PCL* (3–5 years) for males and between 160–180 cm *PCL* (6–9 years) for females (Goldman and Musick 2006). Tanaka (1980) (see also Nagasawa 1998) states that maximum age from vertebral analysis for WNP salmon shark is at least 25 years for males and 17 years for females, and growth coefficients are 0.17 and 0.14 for males and females, respectively. Goldman and Musick (2006) gave maximum ages for ENP salmon shark (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. 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).

The reproductive mode of salmon sharks is aplacental viviparity and includes an oophagous stage when embryos feed on eggs produced by the ovary (Tanaka 1986 cited in Nagasawa 1998). Litter size in the WNP is four to five pups, and litters have been reported to be male dominated 2.2:1 (Nagasawa 1998). Gestation times throughout the North Pacific appear to be nine months, with mating occurring during the late summer and early fall, and parturition occurring in the spring (Nagasawa 1998, Tribuzio 2004, Goldman and Musick 2006, Conrath et al. 2014). Salmon shark appear to have at least a two-year reproductive cycle, with an extended resting period between pregnancies (Conrath et al. 2014). Size at parturition is between 60 - 65 cm *PCL* in both the ENP and WNP (Tanaka 1980, Goldman and Musick 2006).

### *Spiny Dogfish*

Spiny dogfish have been relatively well studies and life-history parameters are available. Spiny dogfish grow to a maximum size of 160 cm in the ENP (Compagno 1984). Recent studies estimated ages-at-50% maturity to be 36 years for females and 21 years for males (Tribuzio and Kruse 2012), which is similar to estimates from BC 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, κ = 0.03 for females and 0.06 for males (Tribuzio et al. 2010b).

The mode of reproduction for spiny dogfish is aplacental viviparity. 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 occurred 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 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 in 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 centimeter in length (Ketchen 1972, Tribuzio et al. 2009, Tribuzio and Kruse 2012).

# Fishery

## Management History and Management Units

The shark complex is managed as an aggregate species group in the BSAI Fishery Management Plan (FMP). Prior to the 2011 fishery, sharks were managed as part of the “Other Species” complex, 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 87 (http://www.fakr.noaa.gov/sustainablefisheries/amds/95-96-87/amd87.pdf) to the BSAI 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 complex (and previously the Other Species complex) are set in aggregate (Table 20.2).

# Directed Fishery, Effort and CPUE

There are currently no directed commercial fisheries for shark species in federally- or state-managed waters of the BSAI.

# Discards

The estimated catch of sharks is broken into four groups: Pacific sleeper shark, spiny dogfish, salmon shark, and other/unidentified sharks. Nearly all incidental shark catch is discarded. Mortality rates of discarded sharks are unknown but are conservatively estimated in this report as 100%. Discard rates for sharks are presented in Table 20.3. Over the last 10 years, 100% of the catch has been discarded in the Aleutian Islands, and >95% in the Bering Sea, with the exception of other/unidentified sharks, which are discard at a lower rate (74% on average, <3 t retained on average). The reason for the lower discard rate of other/unidentified sharks is unclear. We surmise that much of the catch in the other/unidentified shark category is Pacific sleeper shark (Tribuzio et al. 2012), but that does not explain why the discard rate is lower for this category than other categories. About 4 t of sharks has been retained on average over the last 10 years (~3 t is Pacific sleeper shark), and nearly all is used for fishmeal (C. Tide, AKRO, pers. comm.).

# Historical Catch

Historical catches of sharks in the BSAI are composed entirely of incidental catch. Incidental shark catches by species is best summarized by two distinct time series: 1997–2002, estimated by staff at the AFSC using a pseudo-blend approach for 1997–2002 (Gaichas 2001, 2002), and 2003–present, estimated by the NMFS AKRO Catch Accounting System (CAS) (Table 20.4). The pseudo-blend approach used between 1997–2002 may not be comparable to estimates since 2003 due to the limited data available at that time and because it was a one-time analysis. Estimates generated by CAS are updated retroactively, as input data are error-checked and as improvements to CAS are made. Further, sharks were not always identified to species; thus, prior to 2003, there were high incidences of “unidentified sharks” in the observer records. Species identification has improved greatly since 2003 and “unidentified sharks” are now only a very small part of the shark catch.

Aggregate incidental catches of the shark management category from federally prosecuted fisheries for Alaska groundfish in the BSAI are tracked in-season by NMFS AKRO (Table 20.2 and Table 20.4). The restructured observer program went into effect in 2013. This restructuring increased observer coverage on vessels < 60 ft in length as well as incorporating those participating in the Pacific halibut IFQ fishery into the program. Thus, the catch time series beginning in 2013 may not be comparable to the catch time series prior for sharks because a large portion of shark catch originates from the vessels now included in the observer program. 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.

Historically, Pacific sleeper shark are the primary species of shark incidentally caught in the BSAI (Table 20.4, Figure 20.3). Pacific sleeper shark are caught primarily in the Pacific cod longline and the walleye pollock trawl fisheries (Table 20.5). Of note is that catch of Pacific sleeper sharks in the Pacific halibut target fishery increased from 1 t to 7 t, on average (Table 20.5) after 2013. Salmon shark are almost entirely caught in the walleye pollock fishery (Table 20.6), while spiny dogfish are predominantly caught in the Pacific cod longline fishery (Table 20.7).

The other/unidentified shark category is a difficult category to assess. Most of the "other" shark species are rare and likely anomalous. Since 2003, there has been one basking shark (*Cetorhinus maximus*), one brown cat shark (*Apristurus brunneus*) and six six-gill sharks (*Hexanchus griseus*) observed in the BSAI. Catch estimate for the "other" sharks cannot be separated from "unidentified" sharks, and so some portion of this category may actually be spiny dogfish, Pacific sleeper shark, or salmon shark. Incidental catch of other/unidentified sharks occurs primarily in the Pacific cod longline fishery and occasionally in the walleye Pollock trawl fishery (Table 20.8).

*Catch distribution:* Observer data was mapped to analyze spatial distribution of catch. Observers cover 90% of the groundfish tonnage in the BSAI. Data presented here represent non-confidential data aggregated by 400 $km^2$ grids from fisheries that occurred during 2014 – 2017 (data can be found here: http://www.afsc.noaa.gov/FMA/spatial_data.htm).

Incidental catch of Pacific sleeper sharks within observed BSAI commercial fisheries was relatively high along the western edge of the eastern Bering Sea (EBS) shelf (Figure 20.4). 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 Aleutians.

Salmon shark incidental catch in the Bering Sea is generally low, but occasional large catches occur (Figure 20.5). Most of the catch occurs along the EBS shelf, with a small amount in the southern Bering Sea near the Pribilof and Bering canyons and the shelf waters in the EBS outside of Bristol Bay. Each year since 2014 there have been a small number of hauls with large estimates of salmon sharks in the southern Bering Sea, occurring near Unimak Pass or along the Alaska Peninsula.

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 20.6). 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 other/unidentified sharks within commercial fisheries in the Bering Sea is generally patchy and has declined in recent years (Figure 20.7), owing to improved species identification. Hauls reporting catch of other/unidentified sharks is generally near the shelf edge, with some larger hauls occurring near the southern end of the shelf. During the years 2014–2017 only two "other" sharks were observed and identified to species, one basking shark and one brown cat shark.

# Data

Data for sharks were obtained from the following sources:

| Source | Data | Years |
|---|---|---|
| AKRO Catch Accounting System | Nontarget Catch | 2003 – 2018 |
| Improved Pseudo Blend (AFSC) | Nontarget Catch | 1997 – 2002 |
| NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual) | Biomass Index | 1979 – 2018 |
| NMFS Bottom Trawl Surveys –Eastern Bering Sea Slope (Historical) | Biomass Index | 1979 – 1991 |
| NMFS Bottom Trawl Surveys –Eastern Bering Sea Slope | Biomass Index | 2002 – 2016 |
| NMFS Bottom Trawl Surveys –Aleutian Islands | Biomass Index | 1980 – 2018 |
| NMFS Longline Surveys | Catch Numbers | 1989 – 2018 |
| IPHC Longline Surveys | Abundance Index | 1997 – 2017 |

# Fishery

Historical catch estimates for the shark complex are presented in Table 20.4, and species-specific estimates are shown in Tables 20.5–20.8.

### *Catch at Length (Fishery and Survey)*

A formal stock assessment population model does not exist for the shark complex or any of the component species in the BSAI; therefore, length frequency data are not used in the assessment specifications procedures. However, length data are available from surveys. The data presented here are from the AFSC bottom trawl surveys (GOA, EBS shelf, EBS slope and AI), AFSC and IPHC longline surveys, NWFSC trawl surveys on the U.S. West Coast (Pacific sleeper shark only) and targeted research surveys. Length data for spiny dogfish and salmon shark are rare in the BSAI, thus not presented in this assessment. A detailed description of the Pacific sleeper shark catch at length is included in the Life History section and Figure 20.2. Due to limited samples collected each year, and inconsistent surveys each year, there is not sufficient information to examine length frequencies over time for Pacific sleeper sharks.

# Survey

### *AFSC Trawl Survey Biomass Estimates*

Biomass estimates are available for shark species from NMFS AFSC bottom trawl surveys conducted in the BSAI on the eastern Bering Sea (EBS) slope (1979–1991 and 2002–2016; Table 20.9 and Figure 20.8), Aleutian Islands (AI, 1980–2018, Table 20.10 and Figure 20.8), and the EBS shelf (1979–2018, Table 20.11 and Figure 20.8). The EBS shelf survey is annual, but the EBS slope and AI 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 indicates 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 survey hauls for all of the 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. 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 surveys. 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.

Analysis of the EBS slope survey biomass time series is subject to the following caveats: the slope survey was standardized in 2002 to its current gear type, survey strata, and survey design. Because the survey stratification changed in 2002, biomass estimates are not comparable between the historical EBS slope survey (1979 – 1991) and the new slope survey (2002 – 2016). Consequently, surveys from 2002 – 2016 may be useful for estimating relative abundance of commonly encountered species, while surveys between 1979 and 1991 should only be used for identifying the relative distribution of species.

Pacific sleeper sharks are the most commonly caught of all shark species within BSAI surveys. They are most consistently caught on the annual EBS slope survey; however, the number of hauls with Pacific sleeper sharks has declined since 2008 and with the lowest biomass estimate of the time series in 2016 (Table 20.9 and Figure 20.8). Pacific sleeper sharks are also captured consistently in NMFS bottom trawl surveys in the AI, 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 (Table 20.10 and Figure 20.8). Pacific sleeper sharks are not often caught during the annual EBS shelf survey (Table 20.11 and Figure 20.8).

Spiny dogfish and salmon shark are rarely captured during any of the NMFS bottom trawl surveys in the EBS or AI. Resultant biomass estimates are often determined from a small number of hauls or to be 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 20.9 and Figure 20.8). Spiny dogfish are caught sporadically in the AI (Table 20.10 and Figure 20.8) and EBS shelf surveys (Table 20.12 and Figure 20.8). Salmon shark have never been caught in the EBS slope survey (Table 20.9). One salmon shark was caught in 2002 in the AI survey (Table 20.10 and Figure 20.8) and one in 1988 in the EBS shelf survey (Table 20.11 and Figure 20.8).

### *Longline Surveys*

The IPHC conducts a longline survey each year to assess Pacific halibut. This is a fixed station survey that samples down to 500 m in the AI, EBS, and the GOA, as well as areas south of Alaska. More information on this survey can be found in Soderlund et al. (2009). Total catch of sharks in the IPHC survey is presented in Table 20.13.

Relative population numbers (RPNs) for spiny dogfish and Pacific sleeper shark were calculated using the same methods have been used historically for the AFSC longline survey, with the only difference being the depth stratum increments. An average CPUE, as the number of sharks per effective hooks, was calculated by depth stratum for each FMP sub-area (e.g., east Yakutat, west Yakutat, central GOA, etc.). The CPUE was then multiplied by the area size of that stratum. A FMP-wide RPN was calculated by summing the RPNs for all strata in the area and confidence limits estimated by bootstrap resampling the stations within each region. Area sizes used to calculate biomass in the RACE trawl surveys were utilized for IPHC RPN calculations.

For Pacific sleeper sharks, which are the primary shark species caught in the BSAI, RPNs from the IPHC survey have declined steeply since the late 1990s and have remained at low levels since 2005 (Figure 20.9). The 2017 RPN was much greater than recent years, although the confidence intervals were still overlapping. Spiny dogfish are not commonly caught, with no catch the last two surveys. Salmon shark are extremely rare in the IPHC survey, thus the RPNs do not provide useful information. Almost all of the IPHC survey catch of sharks occurs in the Bering Sea and only limited catch occurs in the AI.

The AFSC longline survey samples stations in the EBS in odd years and the AI in even years (survey protocol can be found here: http://www.afsc.noaa.gov/ABL/MESA/pdf/LSprotocols.pdf). Overall shark catch is low on the AFSC longline survey. For this reason, RPNs from the AFSC longline survey are not presented for the BSAI. The AFSC longline survey samples fewer stations with longer sets along the slope, whereas the IPHC survey samples many stations with less gear set at shallower depths across the shelf. The AFSC longline survey likely does not sample shark habitat as well as the IPHC longline survey.

### *Distribution of Catch in Surveys*

An examination of the spatial distribution of survey catches shows that Pacific sleeper shark are consistently caught in low numbers throughout the EBS shelf in the IPHC longline survey (during years 2012–2017, Figure 20.10) and NMFS trawl surveys (Figure 20.11) 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.

In contrast, spiny dogfish catch is mostly distributed throughout the Aleutian chain (Figure 20.12). The IPHC survey catches spiny dogfish regularly out the Aleutian chain, but in small numbers. Spiny dogfish are rarely caught in the AFSC trawl or longline surveys in the BSAI and are not included here.

# Analytic Approach

## Model Structure

Sharks in the BSAI are managed under Tier 6 (harvest specifications based on the historical catch or alternatives accepted by the Science and Statistical Committee). The assessment began using the maximum of the catch history from 1997– 007 to determine OFLs for the 2011 fishery (the 2010 stock assessment). The OFL for the BSAI is based on the maximum of the shark complex catch, as determined by the Plan Team (November 2010, https://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Groundfish/BSAI1110minutes.pdf) and supported by the SSC (December 2010, https://www.npfmc.org/wp-content/PDFdocuments/minutes/SSC1210.pdf). This approach differs from the GOA shark assessment where the OFL for each species is calculated, then summed for the complex OFL.

The model currently used was accepted for the 2016 stock assessment, 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 instead of the 1997–2007 time series because data inaccuracies were identified in the early portion of the time series. The current time series only utilizes catch estimates from the CAS.

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

## Description of Alternative Models

The SSC requested that this assessment include harvest specification options as were discussed during the November 2016 Plan team meeting, using the 2003–2015 time period. The only alternative that the Team discussed was setting the OFL at the upper end of the 99% confidence limit of the mean catch ($C$), assuming a normal distribution and n-1 degrees of freedom, where n = 13 years. We are also including the mean catch and a 95% confidence limit, for comparison. The alternative models begin with the number 18, because we are deeming switching from maximum to mean a major change. The models based on the confidence intervals of the mean are considered minor changes to Model 18.0.

| Alternative Models | OFL | Equation |
|---|---|---|
| 18.0 | Mean catch 2003 – 2015 | $OFL = \bar{C}_{2003-2015}$ |
| 18.1 | 99% upper confidence interval of the mean catch 2003 – 2015 | $OFL = \bar{C}_{2003-2015} + t_{0.01,12} * stdev(\bar{C}_{2003-2015})$ |
| 18.2 | 95% upper confidence interval of the mean catch 2003 – 2015 | $OFL = \bar{C}_{2003-2015} + t_{0.05,12} * stdev(\bar{C}_{2003-2015})$ |

# Parameter Estimates

Although a model is not used to provide stock assessment advice for BSAI sharks, we provide estimates of life-history parameters where available (Table 20.14). Estimates are not available for BSAI stocks, and thus, GOA or North Pacific values are used as a proxy. Parameters include weight at length, length at age, natural mortality (*M*), maximum age, and age at first recruitment. Weight at length and average length parameters were derived from directed research projects (all three species) and standard survey collections (spiny dogfish only).

# Results

# Model Evaluation

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

Catch history 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. Given that, using a model based on the maximum historical catch (Model 16.0) has a high risk of overfishing. However, the species in the complex are “undesirable”, and it is unclear if current catch rates are sustainable or not. Therefore, choosing the most conservative model (Model 18.0) may not be necessary at this time.

Models 18.1 and 18.2 should not be considered further because they are based on the assumption that catch data are normally distributed. Catches are either bi-modal or heavily skewed, resulting in estimated OFLs that can be greater than the maximum catch.

# Harvest Recommendations

We recommend Model 16.0 for the 2019–2020 harvest specifications. While catch history scalars are a high risk for data-limited species management, choosing a different catch scalar method, such as Model 18.0, will have minimal impact on catch rates because current catches are well below current ABCs and below the most conservative ABC examined in this assessment. Further, it is unclear at this time if there is a conservation concern, thus we recommend maintaining the current assessment method pending evaluation of data-limited assessment methods and results of ongoing research projects.

Tier 6 options by species and total of all species (t) and recommendations for 2019–2020 (in bold).

| Species | Spiny dogfish | Pacific sleeper shark | Salmon shark | Other/Unidentified shark | Total shark Complex |
|---|---|---|---|---|---|
| **Maximum Catch** | 24 | 421 | 199 | 305 | 689* |
| **Model 16.0 OFL** | 24 | 421 | 199 | 305 | **689** |
| **Model 16.0 ABC** | 18 | 315 | 149 | 229 | **517** |
| | | | | | |
| Average Catch | 14 | 166 | 53 | 38 | 270 |
| Model 18.0 OFL | 14 | 166 | 53 | 38 | 270 |
| Model 18.0 ABC | 10 | 125 | 40 | 28 | 203 |
| | | | | | |
| 99% Confidence Interval | 32 | 604 | 196 | 289 | 1,122 |
| Model 18.1 OFL | 32 | 604 | 196 | 289 | 1,122 |
| Model 18.1 ABC | 24 | 453 | 147 | 216 | 842 |
| | | | | | |
| 95% Confidence Interval | 27 | 479 | 155 | 217 | 878 |
| Model 18.2 OFL | 27 | 479 | 155 | 217 | 878 |
| Model 18.2 ABC | 20 | 359 | 116 | 163 | 658 |

*The complex total is based on the maximum catch of the whole complex, not the sum of the individual species maximums.

The shark complex is a prime example of “data-limited stocks”. The field of data-limited assessment methods has expanded substantially in recent years in response to MSA and the requirements to set ACLs for all managed stocks. Studies have shown that the simple catch-based metrics used by the NPFMC Tier 6 are the poorest performing of the data-limited methods (DLMs), with a high likelihood of overfishing a stock, > 90% probability of overfishing for long-lived teleost stocks (e.g., Carruthers et al. 2014). While using DLMs to determine an ABC is useful, efforts need to be put in to exploring appropriate threshold limits, which are likely a species by species problem. The current Tier 6 “box” assumes that fishing at the mean or maximum historical catch is sustainable and not at a rate that could cause overfishing. Uncertainty is simply incorporated by assuming that a 25% reduction from the assumed sustainable fishing rate is sufficient. These rates are not informed by biology, nor has there been any examination on the potential for these rates to be truly sustainable.

Staff at AFSC have begun evaluating the DLMs and Tier 6 assumptions for the assessed data-limited stocks. The Pacific sleeper shark is the first species in the shark complexes in which we are exploring Tier 6 alternatives and DLMs. We anticipate bringing forward alternative assessment methods for the next full assessment.

# Ecosystem Considerations

The ecosystem considerations for the BSAI shark stock complex are summarized in Table 20.15.

# Ecosystem Effects on Stock

### *Pacific sleeper shark*

Pacific sleeper sharks were once thought to be sluggish and benthic because their stomachs commonly contain offal, cephalopods, and bottom dwelling fish such as flounder (*Pleuronectidae*) (e.g., Yang and Page 1999). In contrast, another diet analysis documented prey from different depths in the stomachs of a single shark, such as giant grenadier (*Albatrossia pectoralis*) and pink salmon (*Oncorhynchus gorbuscha*), 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 sluggish and benthic oriented as once thought. Recent research using stable isotope concentrations in both liver and muscle tissue determined that Pacific sleeper sharks likely get a significant portion of their energy from lower trophic prey (i.e., Pacific herring and walleye pollock; Schauffler et al. 2005) and that they also feed on prey from a wide variety of trophic levels (Courtney and

Foy, 2012). 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 orca. One study observed two events between the 'offshore' ecotype of orcas and Pacific sleeper sharks, where they killed the shark and ate the liver only (Ford et al. 2011). In each event multiple shark prey were identified 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 in the diving range of the orca. Incidents of Stellar 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 foraging (J. Moran, NMFS, AFSC pers. comm.). Data suggests that most of the Pacific sleeper sharks caught in the BSAI and GOA are immature and there is no information on spawning, mating, or gestation, so it remains unknown how the fishery affects their recruitment.

### *Salmon Shark*

Salmon sharks are opportunistic feeders, sharing the highest trophic level of the food web in subarctic Pacific waters 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* sp.) and rockfishes (family Sebastes) and even other sharks (Sano 1962, Hart 1973, Compagno 1984, Nagasawa 1998). The species is a significant seasonal predator of returning salmon in some areas (e.g. Prince William Sound), but the species is broadly dispersed across the North Pacific Ocean and likely does not have an overall significant impact on prey species. Salmon shark are endothermic, which enables them to have a broad thermal tolerance range and inhabit highly varying environments. Because of this ability, they can adapt to changing climate conditions and prey availability. Salmon sharks generally mate in the fall and give birth the following spring. Much of the salmon shark catch in the BSAI occurs in the summer months after spawning.

### *Spiny dogfish*

Previous studies have shown spiny dogfish to be opportunistic feeders that are not wholly dependent on one food source (Alverson and Stansby 1963). Small dogfish are limited to consuming smaller fish and invertebrates, while the larger animals will 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 the 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. The primary predators of spiny dogfish are other sharks, but data suggest other potential predators could be orcas, lingcod and halibut (Tribuzio, unpublished data). It is not well known if fishing activity occurs when and where sharks spawn. Spiny dogfish have an 18 – 24 month gestation; 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 species that generally have the greatest shark catches, 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 also 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, making effective management of sharks extremely difficult. Gaps include inadequate catch estimation (e.g., large unmeasurable species), unreliable biomass estimates, lack of fishery size frequency collections, and a lack of life history information (e.g., age and maturity). It is essential to continue to improve the collection of biological data on sharks by fisheries observers and surveys. Future shark research priorities will focus on the following areas:

1. Catch estimation for large, hard to measure species.
    a. Actions: Investigating catch by numbers for Pacific sleeper sharks and exploring management options.
2. Define the stock structure and migration patterns (i.e. tagging studies, genetics)
    a. Actions: Continued tagging of spiny dogfish with pop-off satellite archival tags; investigating population genetics of Pacific sleeper shark.
3. Explore ageing methods for difficult to age species
    a. Actions: Began sample collection for an examination of new ageing methods for Pacific sleeper shark, such as eye lens radio carbon and vertebra microchemistry.

# Acknowledgments

We gratefully acknowledge the following individuals for their timely and efficient work in providing bottom trawl survey and catch data for shark species: Wayne Paulson for Aleutian Islands; Robert R. Lauth for the eastern Bering Sea shelf, and Jerry Hoff for Bering Sea slope. Eric Soderlund (IPHC) and Aaron Ranta (IPHC) provided IPHC longline survey data. Sarah Gaichas provided catch estimates for 1997-2002; and Bob Ryzner, Rob Ames, and Niels Leuthold (AKFIN, Pacific States Marine Fisheries Commission) provided a user friendly portal to access Catch Accounting System data and multiple AFSC survey data sources.

# 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.

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.

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

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

Bright, D.B. 1959. The occurance and food of the sleeper shark, *Sominus 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.

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.

Castro, J. I. 1983. The sharks of Northern American waters. Texas A&M Univ Press, College Station, TX. 180p.

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.

Cherel, Y., and G. Duhamel. 2004. Antarctic jaws: cephalopod prey of sharks in Kerguelen waters. Deep-Sea Res. 51:17-31.

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

Compagno, L.V.J., 1990. Shark exploitation and conservation. *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. 391-414. NOAA Technical Report NMFS 90.

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.

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

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.

de Astarloa, J. M. D., D. E. Figueroa, L. Lucifora, R. C. Menni, B. L. Prenski, and G. Chiaramonte. 1999. New records of the Pacific sleeper shark, *Somniosus pacificus* (Chondrichthyes: Squalidae), from the southwest Atlantic. Ichthyol Res. 46:303-308.

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., 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 Pacfici, with comments on the *Squalus acanthias* subgroup (Squaliformes: Squalidae). Zootaxa. 2612:22-40.

Eschmeyer, W.N., E.S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston: 336 pp.

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. Ecology 83: 2162-2172.

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.

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.

Gilmore, R.G. 1993. Reproductive biology of lamnoid sharks. Env. Biol. Fish. 38:95-114.

Girard, C.F. 1854. Characterstics of some cartilaginous fishes of the Pacific coast of North America. Proceedings of the Natural Sciences of Philadephia. 7:196-197.

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. December 2004.

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.

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

Hart, JL. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada (Bull. 180), Ottawa, Canada. 749 pp.

Hoenig, J. M. (1983). Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin* 82, 898–903.

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.

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.

Hulbert, L., M. Sigler, and C. R. Lunsford. 2006. Depth and movement behavior of the Pacific sleeper shark in the north-east Pacific Ocean. J. of Fish Biol. 69:406-425.

ICES Demersal Fish Committee. 1997. Report of the study group on elasmobranchs. ICES CM/G: 2, 123p.

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 Canada. 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.

Last, P.R., and J.D. Stevens. 1994. Sharks and rays of Australia. CSIRO, Australia. 513 p.

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

Mooney-Seus, M. L., and G. S. Stone. 1997. The forgotten giants: giant ocean fishes of the Atlantic and the Pacific. Ocean Wildlife Campaign, WA, USA. New England Aquarium, Boston. 64p.

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.

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.

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

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

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. 54:533-553.

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.

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.

Ruttenberg BI, Hamilton SL, Walsh SM, Donovan MK, Friedlander A, 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).

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.

Schauffler, 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.

Scott, W. B., and M. G. Scott. 1988. Atlantic fishes of Canada. Can Bull Fish Aquat Sci. 219: 731p.

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, C. L. 1997. National Audobon Society field guide to tropical marine fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda. Knopf, Inc. New York. Pp. 720.

Smith, S. W., D. W. Au and C. Show. 1998. Intrinsic rebound potential of 26 species of Pacific sharks. Mar Freshwat Res. 49:663-678.

Soderlund, E., Dykstra, C., Geernaert, T., Anderson-Chao, E., Ranta, A. 2009. 2008 Standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2008: 469-496.

Stevens, J. D. 1975. Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.). J Mar Biol Assoc UK. 55:657-665.

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. 1986. Sharks. Iden (Heredity). 40:19-22.

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., 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. 2012. 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. 1771-1848.

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. Fishery Bulletin. 102:119-135.

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., C. Rodgveller, K. Echave, P.J. Hulson. 2015. 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 2015. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. Pgs. 1569-1642.

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.

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.

White W.T., P.R. Last, J.D. Stevens, G.K. Yearsley, Fahmi and Dharmadi. 2006 Economically important sharks and rays of Indonesia Australian Centre for International Agricultural Research, Canberra, Australia.

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.

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.

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

# Tables

Table 20.1. Biological characteristics and depth ranges for shark species in the eastern Bering Sea and Aleutian Islands (BSAI). Missing information is denoted by "?".

| Scientific Name | Common Name | Max. Obs. Length (TL, cm) | Max. Obs. Age | Age, Length, 50% Maturity | Feeding Mode | Fecundity | Depth Range (m) |
|---|---|---|---|---|---|---|---|
| *Apristurus brunneus* | brown cat shark | 68[1] | ? | ? | Benthic[3] | ? | 1,306[2] |
| *Carcharodon carcharias* | white shark | 792[4] | 36[7] | 15 yrs, 5 m[7] | Predator[6] | 7-14[5] | 1,280[3] |
| *Cetorhinus maximus* | basking shark | 1,520[1] | ? | 5 yrs, 5m[8] | Plankton[6] | ? | ? |
| *Hexanchus griseus* | sixgill shark | 482[9] | ? | 4m[1] | Predator[6] | 22-108[1] | 2,500[10] |
| *Lamna ditropis* | salmon shark | 305[1] | 20[11] | 6-9 yrs, 165 cm PCL[11] | Predator[6] | 3-5[7] | 668[12] |
| *Prionace glauca* | blue shark | 400[16] | 15[13] | 5 yrs[5], 221 cm[14] | Predator[6] | 15-30 (up to 130)[15] | 150[16] |
| *Somniosus pacificus* | Pacific sleeper shark | 700[1] | ? | ? | Benth/Scav[17] | Up to 300[1] | 2,700[18] |
| *Squalus suckleyi* | spiny dogfish | 125[19] | 80-100[19] | 34 yrs, 80 cm[19] | Pred/Scav/Bent[19] | 7-14[19] | 300[3] |

[1]Compagno 1984; [2]Eschmeyer et al. 1983; [3]Mecklenburg et al. 2002; [4]Scott and Scott 1988; [5]Smith et al. 1998; [6]Cortes 1999; [7]Gilmore 1993; [8]Mooney-Seus and Stone 1997; [9]Castro 1983; [10]Last and Stevens 1994; [11]Goldman and Musick 2006, [12]Hulbert et al. 2005; [13]Stevens 1975; [14] ICES 1997; [15] White et al. 2006; [16]Smith 1997; [17]Yang and Page 1999; [18]www.nurp.noaa.gov; [19]Tribuzio and Kruse 2012.

Table 20.2. Time series of Other Species TAC, Other Species and shark catch, and ABC for sharks and the shark species complex (management method) for 1997–2018.

| 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 Complex TAC |
| 2012 | 50 | | 96 | 1,020 | Shark Complex TAC |
| 2013 | 100 | | 116 | 1,020 | Shark Complex TAC |
| 2014 | 125 | | 136 | 1,022* | Shark Complex TAC |
| 2015 | 125 | | 107 | 1,022 | Shark Complex TAC |
| 2016 | 125 | | 132 | 1,022 | Shark Complex TAC |
| 2017 | 125 | | 142 | 517 | Shark Complex TAC |
| 2018 | 180 | | 94 | 517 | Shark 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.

Data Sources: TAC, ABC and management category came from AKRO catch statistics website. Catch data was queried from AKFIN on Oct 9, 2018.

Table 20.3. Estimated discard rates of sharks (by species) in the BSAI. Source: AKFIN database, Oct 9, 2018. Blanks are where there was no catch reported.

| Year | Spiny dogfish | Pacific sleeper shark | Salmon shark | Other/Unidentified shark |
|---|---|---|---|---|
| | **Aleutian Islands** | | | |
| 1999 | | | | |
| 2000 | | 100% | 100% | |
| 2001 | | | | |
| 2002 | 100% | 100% | | |
| 2003 | 100% | 99% | 40% | 0% |
| 2004 | 100% | 100% | | 100% |
| 2005 | 100% | 100% | 100% | |
| 2006 | 100% | 100% | 100% | |
| 2007 | 99% | 100% | 100% | |
| 2008 | 100% | 100% | | |
| 2009 | 100% | 100% | 100% | 100% |
| 2010 | 100% | 100% | 100% | |
| 2011 | 100% | 100% | 100% | |
| 2012 | 100% | 100% | 100% | |
| 2013 | 100% | 100% | 100% | |
| 2014 | 100% | 100% | 100% | |
| 2015 | 100% | 100% | 100% | |
| 2016 | 100% | 100% | 100% | |
| 2017 | 100% | 100% | 100% | |
| 2018 | 100% | 100% | 100% | 100% |
| Average | 100% | 100% | 100% | 100% |
| | **Bering Sea** | | | |
| 1999 | 60% | 98% | 99% | 100% |
| 2000 | 96% | 95% | 97% | 100% |
| 2001 | 100% | 96% | 84% | 100% |
| 2002 | 96% | 86% | 91% | 97% |
| 2003 | 100% | 100% | 100% | |
| 2004 | 100% | 100% | 100% | |
| 2005 | 83% | 78% | 98% | 87% |
| 2006 | 98% | 98% | 94% | 97% |
| 2007 | 99% | 96% | 97% | 74% |
| 2008 | 98% | 95% | 98% | 97% |
| 2009 | 98% | 93% | 99% | 47% |
| 2010 | 100% | 94% | 97% | 47% |
| 2011 | 99% | 96% | 100% | 63% |
| 2012 | 100% | 95% | 99% | 60% |
| 2013 | 100% | 92% | 96% | 76% |
| 2014 | 100% | 95% | 97% | 90% |
| 2015 | 100% | 96% | 100% | 86% |
| 2016 | 100% | 97% | 96% | 96% |
| 2017 | 97% | 97% | 99% | 98% |
| 2018 | 89% | 94% | 99% | 87% |
| Average | 99% | 95% | 98% | 74% |

Table 20.4. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species as of October 9, 2018. 1997–2002 from the NMFS pseudo-blend catch estimation procedure (Gaichas 2001, 2002), 2003–2018 from NMFS AKRO blend-estimated annual catches. Note that the restructured observer program went into effect in 2013.

| Year | Spiny dogfish | Pacific sleeper shark | Salmon shark | Other/ Unidentified shark | Total sharks |
|---|---|---|---|---|---|
| 1997 | 4 | 304 | 7 | 53 | 368 |
| 1998 | 6 | 336 | 18 | 136 | 496 |
| 1999 | 5 | 319 | 30 | 176 | 530 |
| 2000 | 9 | 490 | 23 | 68 | 590 |
| 2001 | 17 | 687 | 24 | 35 | 763 |
| 2002 | 9 | 839 | 47 | 468 | 1,363 |
| 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 | 60 |
| 2011 | 8 | 48 | 47 | 5 | 107 |
| 2012 | 20 | 47 | 26 | 3 | 96 |
| 2013 | 24 | 65 | 23 | 1 | 114 |
| 2014 | 20 | 63 | 52 | 2 | 138 |
| 2015 | 8 | 63 | 33 | 3 | 107 |
| 2016 | 3 | 71 | 37 | 0 | 112 |
| 2017 | 10 | 59 | 71 | 1 | 142 |
| 2018 | 4 | 38 | 51 | 1 | 94 |

Table 20.5. Estimated catches (t) of Pacific sleeper sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997–2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2004–2018 are from NMFS AKRO blend-estimated annual catches, as of Oct 9, 2018. Estimated catch of Pacific sleeper shark by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003. Note that the restructured observer program went into effect in 2013. “NR” denotes target categories not reported. The total of the catch by target fisheries for the 1997–2001 time series may not equal that in Table 20.4 due to the estimation procedure used in the early years.

| Year | Atka Mackerel | Flatfish | Halibut | Other Species | Pacific Cod | Pollock | Rockfish | Sablefish | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1997 | 0.1 | 0.9 | NR | NR | 74.8 | 105.2 | 0.9 | 45.3 | 227.2 |
| 1998 | 0 | 0.9 | NR | NR | 146.7 | 74.4 | 0 | 0 | 222.0 |
| 1999 | 2.4 | 39.4 | NR | NR | 103.3 | 76.8 | 3.0 | 15.1 | 240 |
| 2000 | 0.3 | 42 | NR | NR | 114.7 | 103.8 | 2.7 | 143.7 | 407.2 |
| 2001 | 27.8 | 179.6 | NR | NR | 252.7 | 205.7 | 0 | 1.8 | 667.6 |
| 2002 | | | | | | | | | |
| 2003 | 0.7 | 45.4 | 18.6 | 0.1 | 172.6 | 85.0 | 0.5 | 19.7 | 342.5 |
| 2004 | 2.0 | 40.0 | 1.1 | 0.2 | 230.1 | 144.0 | 0.7 | 2.3 | 420.5 |
| 2005 | 0 | 10.4 | 0.1 | 0 | 191.2 | 127.6 | 0.1 | 3.8 | 333.2 |
| 2006 | 0 | 10.8 | 0.1 | 0 | 123.2 | 178.1 | 0.1 | 1.0 | 313.4 |
| 2007 | 1.1 | 9.6 | <0.1 | 3.7 | 44.3 | 181.6 | 14.5 | 2.5 | 257.3 |
| 2008 | 0.1 | 6.7 | 0 | 0 | 20.0 | 97.9 | 1.2 | 1.3 | 127.2 |
| 2009 | 0.6 | 8.3 | 0 | 0 | 14.4 | 24.6 | 0.6 | 2.1 | 50.6 |
| 2010 | 0 | 1.3 | 0 | 0 | 15.1 | 10.5 | 0.1 | 1.4 | 28.4 |
| 2011 | 0 | 2.3 | 0.7 | 0.1 | 20.2 | 18.2 | 4.8 | 1.5 | 47.9 |
| 2012 | 0.9 | 8.3 | 0 | 0 | 9.8 | 27.6 | 0.6 | 0.2 | 47.4 |
| 2013 | 0 | 1.2 | 24.1 | 0 | 19.8 | 20.7 | 1.6 | 0.8 | 68.1 |
| 2014 | 0 | 1.1 | 0.5 | <0.1 | 36.9 | 23.7 | 0.8 | 0.2 | 63.2 |
| 2015 | 0 | 2.3 | 1.9 | 0.1 | 35.9 | 20.2 | 1.7 | 0.3 | 62.2 |
| 2016 | 0.9 | 7.4 | 15.9 | 0 | 37.7 | 20.1 | 1.5 | 0 | 83.4 |
| 2017 | 0.9 | 4.6 | 0 | 0 | 29.0 | 23.5 | 0.6 | <0.1 | 58.6 |
| 2018 | 1.2 | 6.9 | 0 | 0 | 13.2 | 14.4 | 2.1 | 0.2 | 38.1 |

Table 20.6. Estimated catches (t) of salmon sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997–2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2003–2018 are from NMFS AKRO blend-estimated annual catches, as of Oct 9, 2018. Estimated catch of salmon sharks by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003. Note that the restructured observer program went into effect in 2013. "NR" denotes target categories not reported. The total of the catch by target fisheries for the 1997–2001 time series may not equal that in Table 20.4 due to the estimation procedure used in the early years.

| Year | Atka Mackerel | Flatfish | Halibut | Other Species | Pacific Cod | Pollock | Rockfish | Sablefish | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1997 | 0.1 | 0 | NR | NR | 0.0 | 6.7 | 0 | 0 | 6.8 |
| 1998 | 0 | 0.1 | NR | NR | 0.8 | 16.2 | 0 | 0 | 17.1 |
| 1999 | 0.2 | 2.5 | NR | NR | 1.2 | 24.7 | 0 | 0 | 28.6 |
| 2000 | 0 | 0 | NR | NR | 3.8 | 19.5 | 0 | 0 | 23.3 |
| 2001 | 0.4 | 0.4 | NR | NR | 1.2 | 22.5 | 0 | 0 | 24.5 |
| 2002 | | | | | | | | | |
| 2003 | 0.2 | 0.5 | 0 | 0 | 1.2 | 197.4 | 0 | 0 | 199.3 |
| 2004 | 0 | 0.1 | 0 | 0 | 0.1 | 25.5 | 0 | 0 | 25.6 |
| 2005 | 18.2 | 0.7 | 0 | 0 | 2.0 | 25.7 | 0 | 0 | 46.7 |
| 2006 | 0.2 | 25.9 | 0 | 0 | 1.2 | 36.2 | 0 | 0 | 63.4 |
| 2007 | 0.1 | 0 | 0 | 0 | 0 | 44.1 | 0 | 0 | 44.2 |
| 2008 | 0 | 0.8 | 0 | 0 | 0 | 40.7 | 0 | 0 | 41.4 |
| 2009 | 0.3 | 0.4 | 0 | 0 | 0.1 | 70.0 | 0 | 0 | 70.8 |
| 2010 | 0.1 | 0.4 | 0 | 0 | 0 | 11.0 | 0 | 0 | 11.6 |
| 2011 | 0.2 | 1.5 | 0 | 0 | 0.1 | 45.3 | 0 | 0 | 47.1 |
| 2012 | 0.3 | 0 | 0 | 0 | 0 | 25.4 | 0 | 0 | 25.7 |
| 2013 | 0.3 | 0.8 | 0 | 0 | 0.2 | 22.1 | 0.1 | 0 | 23.5 |
| 2014 | 0.6 | 0.7 | 0 | 0 | 0 | 51.0 | 0 | 0 | 52.4 |
| 2015 | 0.1 | 1.4 | 0 | 0 | 1.1 | 30.7 | 0 | 0 | 33.3 |
| 2016 | 0.7 | 2.5 | 0 | 0 | 1.2 | 37.4 | 0.4 | 0 | 42.2 |
| 2017 | 1.4 | 1.2 | 0 | 0 | <0.1 | 68.7 | 0 | 1.0 | 71.3 |
| 2018 | 0.9 | 1.8 | 0 | 0 | 0.4 | 47.3 | 0.2 | 2.0 | 50.6 |

Table 20.7. Estimated catches (t) of spiny dogfish in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997–2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2003–2018 are from NMFS AKRO blend-estimated annual catches, as of Oct 9, 2018. Estimated catch of spiny dogfish by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003. Note that the restructured observer program went into effect in 2013. "NR" denotes target categories not reported. The total of the catch by target fisheries for the 1997–2001 time series may not equal that in Table 20.4 due to the estimation procedure used in the early years.

| Year | Atka Mackerel | Flatfish | Halibut | Other species | Pacific Cod | Pollock | Rockfish | Sablefish | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1997 | 0 | 0 | NR | NR | 4.1 | 0 | 0 | 0 | 4.1 |
| 1998 | 0.2 | 0.4 | NR | NR | 5.6 | 0.1 | 0 | 0 | 6.3 |
| 1999 | 0 | 0 | NR | NR | 4.9 | 0 | 0 | 0 | 4.9 |
| 2000 | 0 | 0.2 | NR | NR | 8.6 | 0 | 0 | 0 | 8.8 |
| 2001 | 2.8 | 1.6 | NR | NR | 12.7 | 0.1 | 0 | 0.1 | 17.3 |
| 2002 | | | | | | | | | |
| 2003 | 0.1 | <0.1 | <0.1 | <0.1 | 13.1 | <0.1 | 0 | 0 | 13.3 |
| 2004 | 0 | 0.2 | <0.1 | <0.1 | 8.3 | <0.1 | 0 | 0 | 8.6 |
| 2005 | <0.1 | 0.1 | 0 | <0.1 | 11.2 | <0.1 | 0 | 0 | 11.4 |
| 2006 | <0.1 | 0.1 | <0.1 | 0 | 6.6 | 0.2 | 0 | 0 | 7.1 |
| 2007 | 0 | 0.3 | 0 | 0 | 2.5 | 0.2 | 0 | 0 | 3.0 |
| 2008 | 0.1 | 0.2 | 6.2 | 0 | 10.2 | 0.2 | 0.1 | <0.1 | 17.1 |
| 2009 | <0.1 | 0.6 | 0 | 0 | 18.4 | 0.4 | 0 | 0.2 | 19.7 |
| 2010 | <0.1 | 0.7 | 0 | 0 | 13.8 | 0.3 | 0 | <0.1 | 14.9 |
| 2011 | 0 | 0.4 | 0 | <0.1 | 7.3 | 0.2 | 0 | 0 | 7.8 |
| 2012 | 0.1 | 0 | 0 | 0 | 19.6 | 0.1 | 0.3 | 0 | 20.1 |
| 2013 | 0.4 | 0.2 | 4.6 | 0 | 18.3 | 0.1 | 0 | <0.1 | 23.6 |
| 2014 | 0 | 1.0 | 1.9 | 0 | 15.8 | 0.1 | 0 | 0 | 18.7 |
| 2015 | 0 | 0.5 | 0.3 | 0 | 7.1 | 0.3 | 0 | 0 | 8.3 |
| 2016 | 0.2 | 0.5 | 0.1 | 0.1 | 4.3 | 0.6 | 0 | 0 | 5.8 |
| 2017 | 0 | 0.2 | 1.3 | <0.1 | 8.9 | 0.1 | 0 | 0 | 10.4 |
| 2018 | 0 | 0 | 0.3 | 0.3 | 3.3 | 0.1 | 0 | 0 | 4.0 |

Table 20.8. Estimated catches (t) of other and unidentified sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by target fishery. Years 1997–2002 from the pseudo-blend catch estimation procedure (Gaichas 2002), 2003–2018 are from NMFS AKRO blend-estimated annual catches, as of Oct 3, 2016. Estimated catch of other and unidentified sharks by target fishery are not available for 2002 because the Gaichas (2002) catch estimates ended in 2001 and CAS did not begin until 2003. Note that the restructured observer program went into effect in 2013. “NR” denotes target categories not reported. The total of the catch by target fisheries for the 1997–2001 time series may not equal that in Table 20.4 due to the estimation procedure used in the early years.

| Year | Atka Mackerel | Flatfish | Halibut | Other Species | Pacific Cod | Pollock | Rockfish | Sablefish | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1997 | 0 | 0.4 | NR | NR | 26.8 | 15.6 | 2.5 | 1.2 | 46.5 |
| 1998 | 13.1 | 0 | NR | NR | 48.4 | 45.4 | 0 | 2.1 | 109.0 |
| 1999 | 0 | 0.2 | NR | NR | 18.8 | 10.3 | 0 | 1.8 | 31.1 |
| 2000 | 0 | 1.2 | NR | NR | 56.1 | 0.1 | 0 | 7.2 | 64.6 |
| 2001 | 0 | 0 | NR | NR | 19.6 | 2.3 | 0 | 10.4 | 32.3 |
| 2002 | | | | | | | | | |
| 2003 | 0 | 1.3 | 0 | 0 | 20.8 | 11.9 | 0 | 0.1 | 34.1 |
| 2004 | 0 | 22.2 | 0 | 0 | 20.2 | 20.2 | 17.6 | 0 | 60.1 |
| 2005 | 0 | 0 | 0 | 0 | 10.1 | 10.1 | 16.0 | 0 | 26.2 |
| 2006 | 0 | 3.7 | 0 | 0 | 3.6 | 3.6 | 298.0 | 0 | 305.5 |
| 2007 | 0 | 5.9 | 0 | 0 | 2.1 | 2.1 | 19.8 | 0 | 27.8 |
| 2008 | 0 | 0.5 | 0 | 0 | 1.6 | 1.6 | 5.9 | 0 | 8.0 |
| 2009 | 0 | 0 | 0 | 0 | 4.5 | 4.5 | 5.5 | 0.2 | 10.2 |
| 2010 | 0 | 0 | 0 | 0 | 1.6 | 1.6 | 4.1 | 0 | 5.7 |
| 2011 | 0 | 0 | 0 | 0 | 2.6 | 2.6 | 2.0 | 0 | 4.6 |
| 2012 | 0 | 0 | 0 | 0 | 1.0 | 1.0 | 1.7 | 0 | 2.7 |
| 2013 | 0 | 0 | 0 | 0 | 0.8 | 0.8 | 0.4 | 0 | 1.1 |
| 2014 | 0 | 0 | 0 | 0 | 1.3 | 1.3 | 0.5 | 0 | 1.9 |
| 2015 | 0 | 0 | 0 | 0 | 1.8 | 1.8 | 1.2 | 0 | 3.0 |
| 2016 | 0 | 0 | 0 | 0 | 0.3 | 0.3 | 0.4 | 0 | 0.6 |
| 2017 | 0 | 0 | 0 | 0 | 0.9 | 0.9 | 0.5 | 0 | 1.4 |
| 2018 | 0 | 0 | <0.1 | 0 | 0.3 | 0.3 | 1.1 | 0 | 1.5 |

Table 20.9. Eastern Bering Sea slope AFSC trawl survey estimates of individual shark species total biomass (metric tons) with CV, and number of hauls. There was no survey in 2018 (AKFIN, queried October 9, 2018).

| | | Spiny Dogfish | | | Pacific sleeper Shark | | | Salmon Shark | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Survey Hauls | Hauls w/catch | Biomass Est. | CV | Hauls w/catch | Biomass Est. | CV | Hauls w/catch | Biomass Est. | CV |
| 1979 | 105 | 0 | | | 0 | | | 0 | | |
| 1981 | 205 | 1 | 1 | 0.83 | 0 | | | 0 | | |
| 1982 | 299 | 3 | 8 | 0.73 | 1 | 12 | 1.02 | 0 | | |
| 1985 | 325 | 3 | 2 | 0.66 | 19 | 543 | 0.1 | 0 | | |
| 1988 | 131 | 0 | | | 10 | 1,993 | 0.39 | 0 | | |
| 1991 | 85 | 0 | | | 6 | 1,235 | 0.44 | 0 | | |
| Change in slope survey design | | | | | | | | | | |
| 2002 | 141 | 0 | | | 15 | 25,445 | 0.87 | 0 | | |
| 2004 | 231 | 0 | | | 24 | 2,282 | 0.34 | 0 | | |
| 2008 | 207 | 1 | 13 | 1 | 28 | 1,968 | 0.27 | 0 | | |
| 2010 | 200 | 0 | | | 19 | 833 | 0.27 | 0 | | |
| 2012 | 189 | 0 | | | 16 | 1,337 | 0.28 | 0 | | |
| 2016 | 175 | 0 | | | 5 | 251 | 0.49 | 0 | | |

Table 20.10. Aleutian Islands AFSC trawl survey estimates of individual shark species total biomass (metric tons) with CV, and number of hauls (AKFIN, queried October 9, 2018).

| | | Spiny Dogfish | | | Pacific sleeper Shark | | | Salmon Shark | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Survey Hauls | Hauls w/catch | Biomass Est. | CV | Hauls w/catch | Biomass Est. | CV | Hauls w/catch | Biomass Est. | CV |
| 1980 | 129 | 0 | | | 0 | | | 0 | | |
| 1983 | 372 | 3 | 2 | 0.61 | 3 | 249 | 0.66 | 0 | | |
| 1986 | 443 | 6 | 14 | 0.51 | 12 | 1,995 | 0.36 | 0 | | |
| 1991 | 331 | 0 | | | 3 | 2,927 | 0.69 | 0 | | |
| 1994 | 381 | 9 | 47 | 0.37 | 3 | 374 | 0.64 | 0 | | |
| 1997 | 397 | 2 | 11 | 0.71 | 10 | 2,486 | 0.29 | 0 | | |
| 2000 | 419 | 3 | 25 | 0.62 | 3 | 2,638 | 0.57 | 0 | | |
| 2002 | 417 | 0 | | | 4 | 536 | 0.55 | 1 | 1,021 | 1.00 |
| 2004 | 420 | 0 | | | 2 | 1,017 | 0.96 | 0 | | |
| 2006 | 358 | 6 | 62 | 0.49 | 1 | 76 | 1.00 | 0 | | |
| 2010 | 418 | 0 | | | 1 | 74 | 1.00 | 0 | | |
| 2012 | 420 | 0 | | | 1 | 22 | 1.00 | 0 | | |
| 2014 | 410 | 2 | 23 | 0.72 | 0 | | | 0 | | |
| 2016 | 419 | 1 | 7 | 1.00 | 0 | | | 0 | | |
| 2018 | 420 | 0 | 0 | 0 | 2 | 100 | 0.65 | 0 | 0 | 0 |

Table 20.11. Eastern Bering Sea shelf AFSC trawl survey estimates of Pacific sleeper shark total biomass (metric tons) with CV and number of hauls (Dan Nichol, pers. comm., October, 2018).

| Year | Total Hauls | Hauls w/catch | Biomass Est. | CV |
|---|---|---|---|---|
| 1979 | 452 | 0 | | |
| 1980 | 342 | 0 | | |
| 1981 | 290 | 0 | | |
| 1982 | 329 | 0 | | |
| 1983 | 354 | 0 | | |
| 1984 | 355 | 0 | | |
| 1985 | 353 | 0 | | |
| 1986 | 354 | 0 | | |
| 1987 | 342 | 0 | | |
| 1988 | 353 | 0 | | |
| 1989 | 353 | 0 | | |
| 1990 | 352 | 0 | | |
| 1991 | 351 | 0 | | |
| 1992 | 336 | 2 | 2,564 | 0.72 |
| 1993 | 355 | 0 | | |
| 1994 | 355 | 2 | 5,012 | 0.82 |
| 1995 | 356 | 1 | 1,005 | 1.00 |
| 1996 | 355 | 2 | 2,804 | 0.82 |
| 1997 | 356 | 0 | | |
| 1998 | 355 | 1 | 2,124 | 1.00 |
| 1999 | 353 | 2 | 2,079 | 0.71 |
| 2000 | 352 | 1 | 1,463 | 1.00 |
| 2001 | 355 | 0 | | |
| 2002 | 355 | 3 | 5,602 | 0.65 |
| 2003 | 356 | 1 | 2,104 | 0.74 |
| 2004 | 355 | 2 | 3,093 | 0.71 |
| 2005 | 353 | 2 | 1,679 | 0.76 |
| 2006 | 356 | 2 | 2,944 | 0.78 |

| Year | Total Hauls | Hauls w/catch | Biomass Est. | CV |
|---|---|---|---|---|
| 2007 | 356 | 0 | | |
| 2008 | 375 | 0 | | |
| 2009 | 376 | 0 | | |
| 2010 | 376 | 4 | 5,300 | 0.53 |
| 2011 | 376 | 1 | 760 | 1.00 |
| 2012 | 376 | 1 | 267 | 1.00 |
| 2013 | 376 | 0 | | |
| 2014 | 376 | 0 | | |
| 2015 | 376 | 2 | 2,581 | 0.85 |
| 2016 | 376 | 3 | 3,057 | 0.84 |
| 2017 | 376 | 1 | 1,327 | 1.00 |
| 2018 | 376 | 1 | 756 | 1.00 |

Table 20.12. Eastern Bering Sea shelf AFSC trawl survey estimates of spiny dogfish total biomass (metric tons) with CV and number of hauls (Dan Nichol, pers. comm., October, 2018).

| Year | Total Hauls | Hauls w/catch | Biomass Est. | CV |
|---|---|---|---|---|
| 1979 | 452 | 4 | 389 | 0.56 |
| 1980 | 342 | 0 | | |
| 1981 | 290 | 0 | | |
| 1982 | 329 | 0 | | |
| 1983 | 354 | 2 | 403 | 0.78 |
| 1984 | 355 | 0 | | |
| 1985 | 353 | 1 | 47 | 1.00 |
| 1986 | 354 | 0 | | |
| 1987 | 342 | 3 | 216 | 0.60 |
| 1988 | 353 | 1 | 246 | 1.00 |
| 1989 | 353 | 0 | | |
| 1990 | 352 | 0 | | |
| 1991 | 351 | 0 | | |
| 1992 | 336 | 0 | | |
| 1993 | 355 | 0 | | |
| 1994 | 355 | 0 | | |
| 1995 | 356 | 0 | | |
| 1996 | 355 | 0 | | |
| 1997 | 356 | 1 | 37 | 1.00 |
| 1998 | 355 | 1 | 254 | 1.00 |
| 1999 | 353 | 0 | | |
| 2000 | 352 | 0 | | |
| 2001 | 355 | 0 | | |
| 2002 | 355 | 0 | | |
| 2003 | 356 | 0 | | |
| 2004 | 355 | 1 | 28 | 1.00 |
| 2005 | 353 | 0 | | |
| 2006 | 356 | 0 | | |
| 2007 | 356 | 0 | | |
| 2008 | 375 | 0 | | |
| 2009 | 376 | 1 | 72 | 1.00 |
| 2010 | 376 | 1 | 89 | 1.00 |
| 2011 | 376 | 0 | | |
| 2012 | 376 | 0 | | |
| 2013 | 376 | 0 | | |
| 2014 | 376 | 0 | | |
| 2015 | 376 | 1 | 91 | 1.00 |
| 2016 | 376 | 0 | | |
| 2017 | 376 | 0 | | |
| 2018 | 376 | 0 | | |

Table 20.13. Research survey catch of sharks 1977–2015 in the Bering Sea/Aleutian Islands (BSAI). The AFSC LL and IPHC LL survey catches are provided in numbers prior to 2010. The total catch numbers from the IPHC survey are estimated based on the subsample of observed hooks, the estimated catch (t) is directly from the survey. Beginning in 2010 all research and other non-commercial catch is provided by the AKRO (AKFIN, queried October 9, 2018). Data is lagged by one year.

| Year | Source | AFSC Trawl Surveys (t) | AFSC LL Survey (#s) | AFSC LL Survey (t) | IPHC LL Survey (#s) | IPHC LL Survey (t) | ADF&G (t) (includes sport and research) |
|---|---|---|---|---|---|---|---|
| 1977 | Assessment of the sharks in the Bering Sea and Aleutian Islands (Tribuzio et al. 2010a) | 0 | | | | | |
| 1978 | | | | | | | |
| 1979 | | 0.03 | 4 | NA | | | |
| 1980 | | 0 | 4 | NA | | | |
| 1981 | | 0.07 | 5 | NA | | | |
| 1982 | | 0.16 | 15 | NA | | | |
| 1983 | | 0.01 | 33 | NA | | | |
| 1984 | | | 40 | NA | | | |
| 1985 | | 0.59 | 53 | NA | | | |
| 1986 | | | 52 | NA | | | |
| 1987 | | 0.01 | 61 | NA | | | |
| 1988 | | 1.06 | 30 | NA | | | |
| 1989 | | 0.07 | 27 | NA | | | |
| 1990 | | 0 | 4 | NA | | | |
| 1991 | | 0.56 | 18 | NA | | | |
| 1992 | | 0.09 | 55 | NA | | | |
| 1993 | | | 75 | NA | | | |
| 1994 | | 0.17 | 111 | NA | | | |
| 1995 | | 0.04 | 0 | NA | | | |
| 1996 | | 0.1 | 3 | NA | | | |
| 1997 | | 0.11 | 59 | NA | | | |
| 1998 | | 0.09 | 1 | NA | 207 | NA | |
| 1999 | | 0.08 | 20 | NA | 152 | NA | |
| 2000 | | 8.5 | 2 | NA | 723 | NA | |
| 2001 | | | 12 | NA | 164 | NA | |
| 2002 | | 5.74 | 1 | NA | 169 | NA | |
| 2003 | | 0.03 | 22 | NA | 368 | NA | |
| 2004 | | 0.76 | 3 | NA | 251 | NA | |
| 2005 | | 0 | 6 | NA | 237 | NA | |
| 2006 | | 0 | 3 | NA | 241 | NA | |
| 2007 | | 0 | 34 | NA | 170 | NA | |
| 2008 | | 0.47 | 8 | NA | 208 | NA | |
| 2009 | | 2.02 | 2 | NA | 234 | NA | |
| 2010 | AKRO | 0.43 | 0 | 0 | NA | 8.38 | <0.01 |
| 2011 | | 0.05 | 5 | 0.29 | NA | 1.5 | 0.03 |
| 2012 | | 3.01 | 0 | 0 | NA | 1.62 | 0.12 |
| 2013 | | <0.01 | 5 | 0.18 | NA | 4.96 | <0.01 |
| 2014 | | 0.01 | 1 | <0.01 | NA | 5.93 | <0.01 |
| 2015 | | 0.09 | 2 | 0.12 | NA | 2.55 | <0.01 |
| 2016 | | 0.17 | 0 | 0 | NA | 6 | 0 |
| 2017 | | 0.04 | 2 | 0.12 | NA | 4.56 | 0 |

Table 20.14. 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 $L_\infty$ 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 | Sample size |
|---|---|---|---|---|---|---|---|---|
| **Spiny dogfish** | GOA | NMFS bottom trawl surveys | M | 63.4 | 2 | 1.40E-05 | 2.86 | 92 |
| **Spiny dogfish** | GOA | NMFS bottom trawl surveys | F | 63.8 | 2.29 | 8.03E-06 | 3.02 | 140 |
| **Spiny dogfish** | GOA | Longline surveys | M | 64.6 | 1.99 | 9.85E-06 | 2.93 | 156 |
| **Spiny dogfish** | GOA | Longline surveys | F | 64.7 | 2.2 | 3.52E-06 | 3.2 | 188 |
| **Pacific sleeper shark** | Central GOA | Longline surveys | M | 166 | 69.7 | 2.18E-05 | 2.93 | NA |
| **Pacific sleeper shark** | Central GOA | Longline surveys | 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 | a184.7 | 146.9 | 8.20E-05 | 2.759 | NA |

| Species | Sex | $L_\infty$ (cm) | κ | $t_0$ (years) | M | Max Age | Age at first Recruit |
|---|---|---|---|---|---|---|---|
| **Spiny Dogfish** | M | 93.7 ($TL_{ext}$) | 0.06 | -5.1 | 0.097 | 80-100 | NA |
| **Spiny Dogfish** | F | 132.0 ($TL_{ext}$) | 0.03 | -6.4 | | | |
| **Pacific Sleeper Shark** | M | NA | NA | NA | NA | NA | NA |
| **Pacific Sleeper Shark** | F | NA | NA | NA | | | |
| **Salmon Shark** | M | 182.8 (PCL) | 0.23 | -2.3 | 0.18 | 30 | 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).

Table 20.15. Analysis of ecosystem considerations for the shark complex.

| **Ecosystem effects on *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 1980's, 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 GOA | Habitat changes may shift distribution | No concern |

| ***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

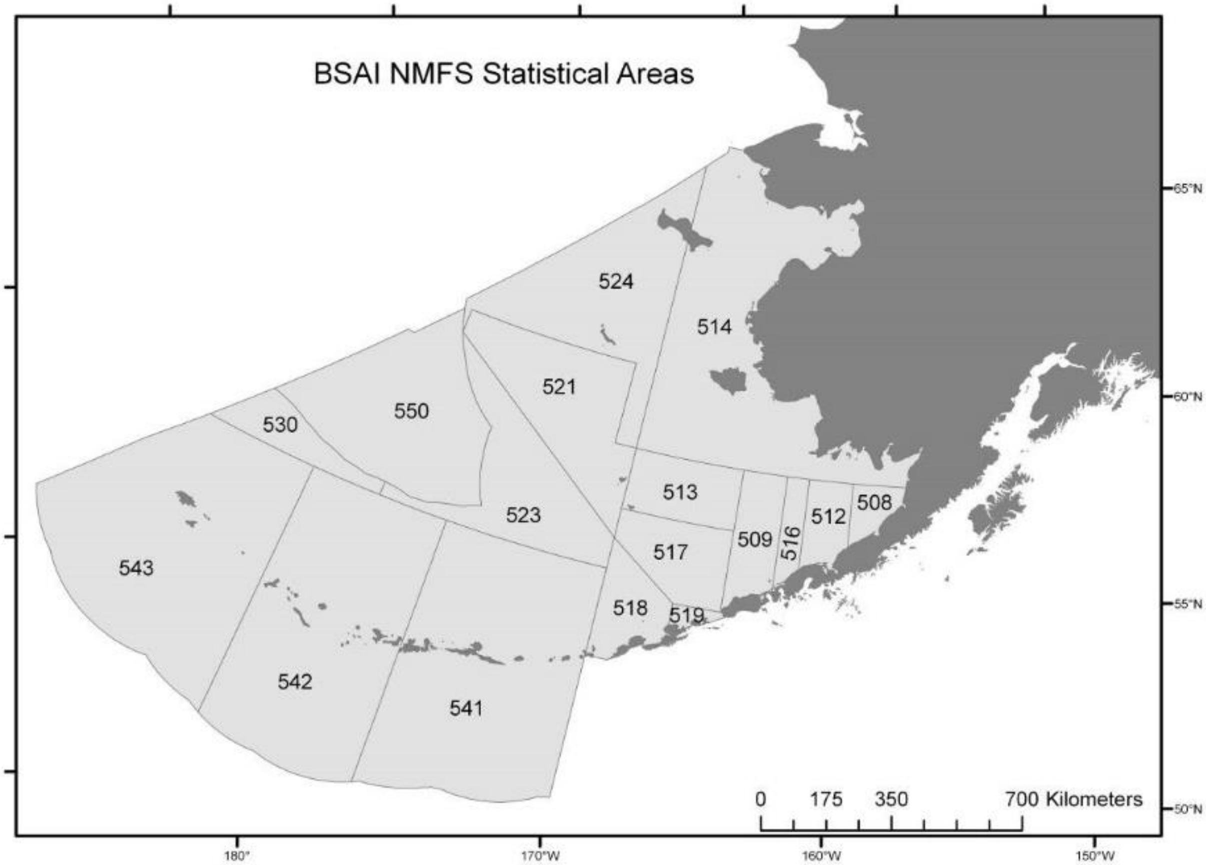


Figure 20.1. NMFS statistical areas in the Bering Sea (NMFS Areas 508-530) and Aleutian Islands (NMFS Areas 541-542).

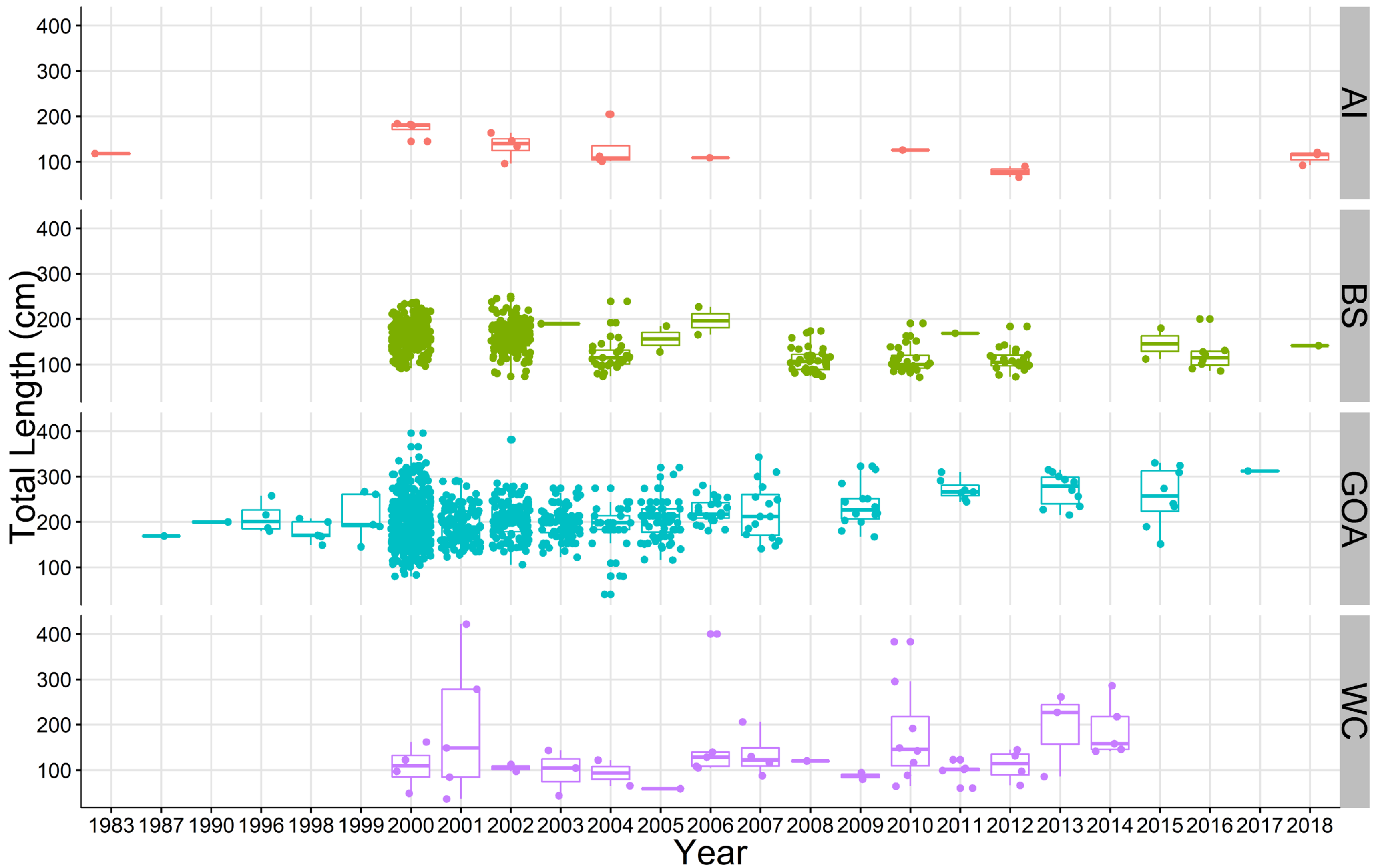


Figure 20.2. Size distribution of Pacific sleeper shark collected in the Aleutian Islands (AI), Bering Sea (BS), Gulf of Alaska (GOA) and the U.S. West Coast (WC). Data is compiled from standard NMFS groundfish trawl surveys, non-standard NMFS surveys (i.e., opportunistic sample collection), directed research surveys, and special projects on IPHC surveys.

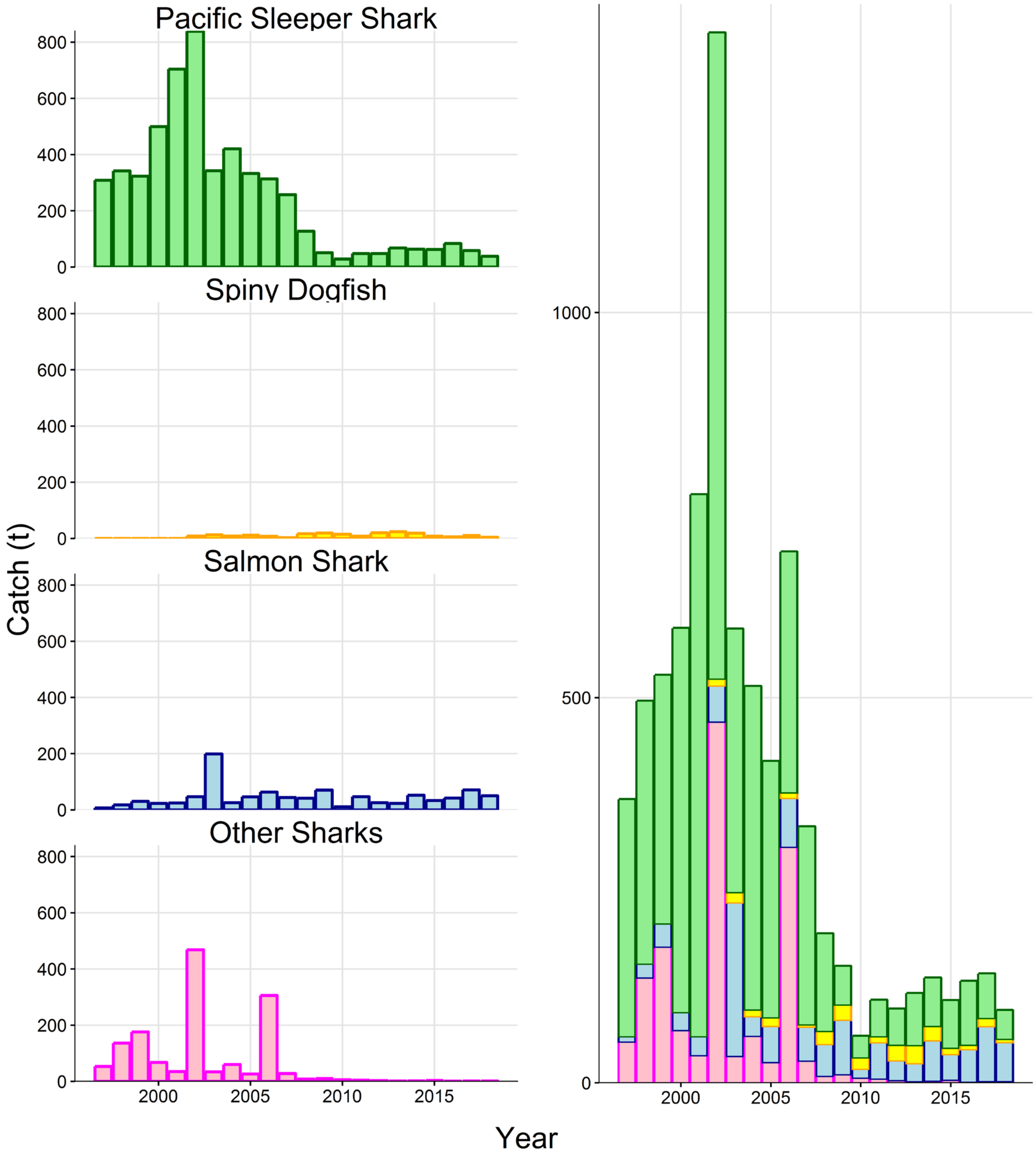


Figure 20.3. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species as of October 9, 2018. 1997–2002 from the NMFS pseudo-blend catch estimation procedure (Gaichas 2001, 2002), 2003–2016 from NMFS AKRO blend-estimated annual catches.

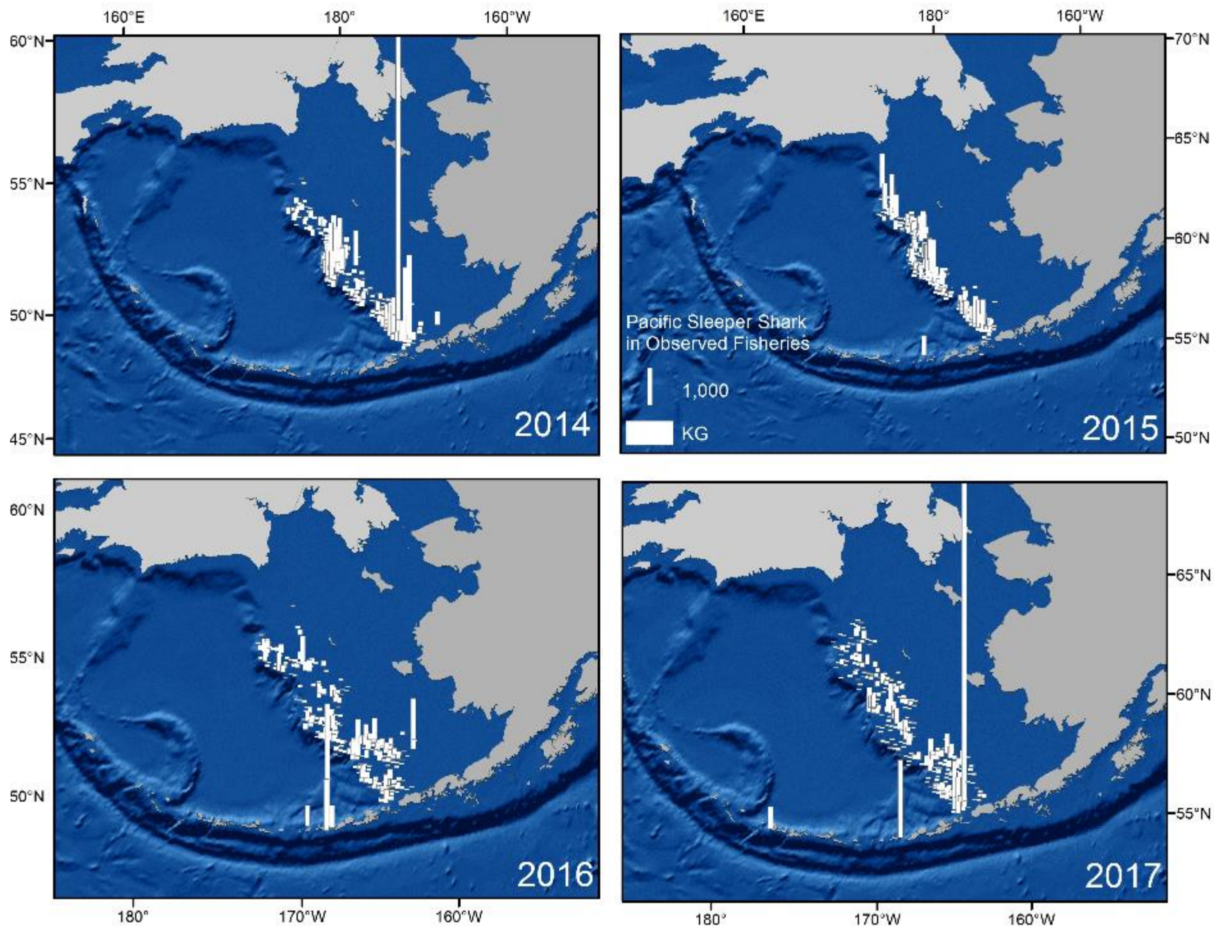


Figure 20.4. Spatial distribution of observed Pacific sleeper shark catch in the BSAI from 2014–2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km$^2$ grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 23, 2018 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

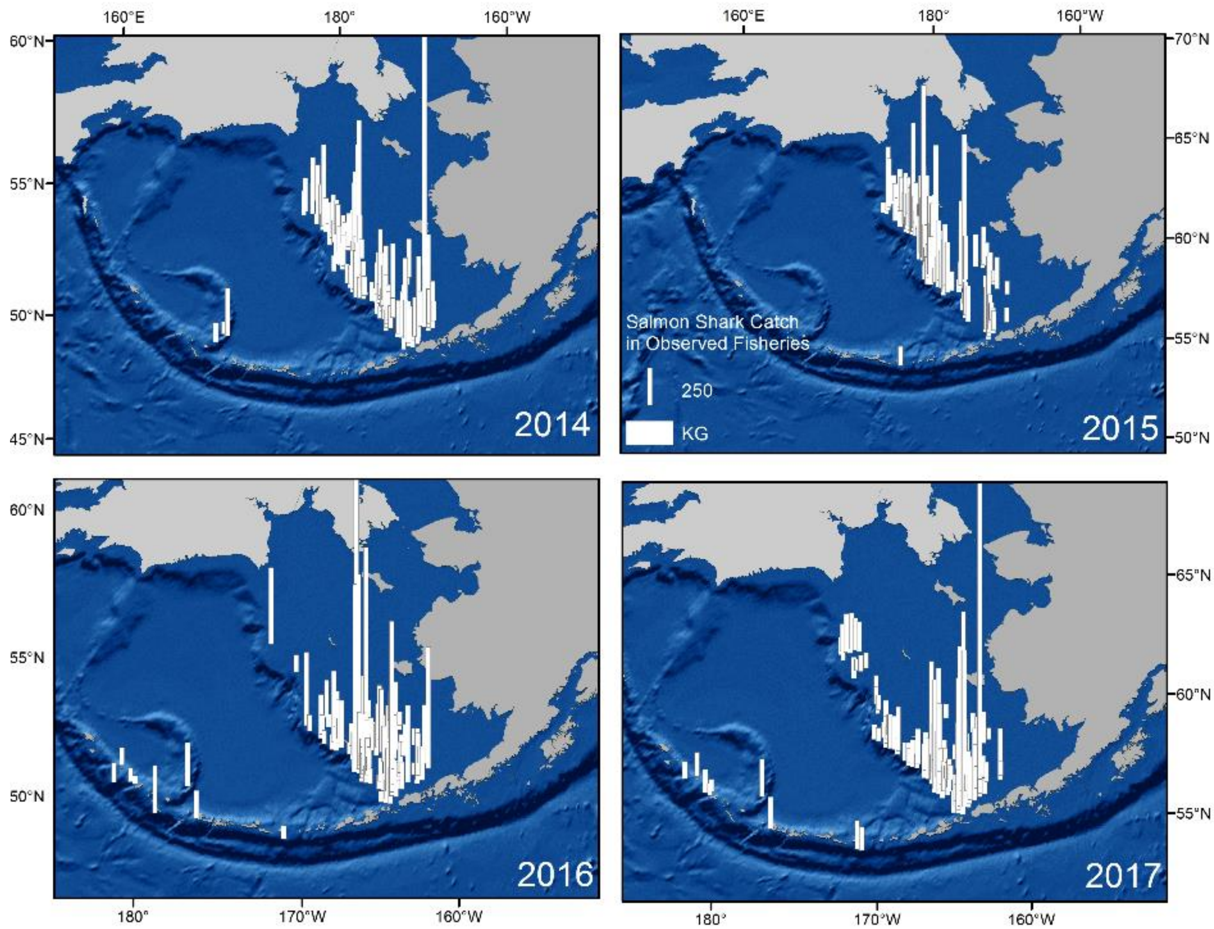


Figure 20.5. Spatial distribution of salmon shark catch in the BSAI from 2014–2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km$^2$ grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 23, 2018 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

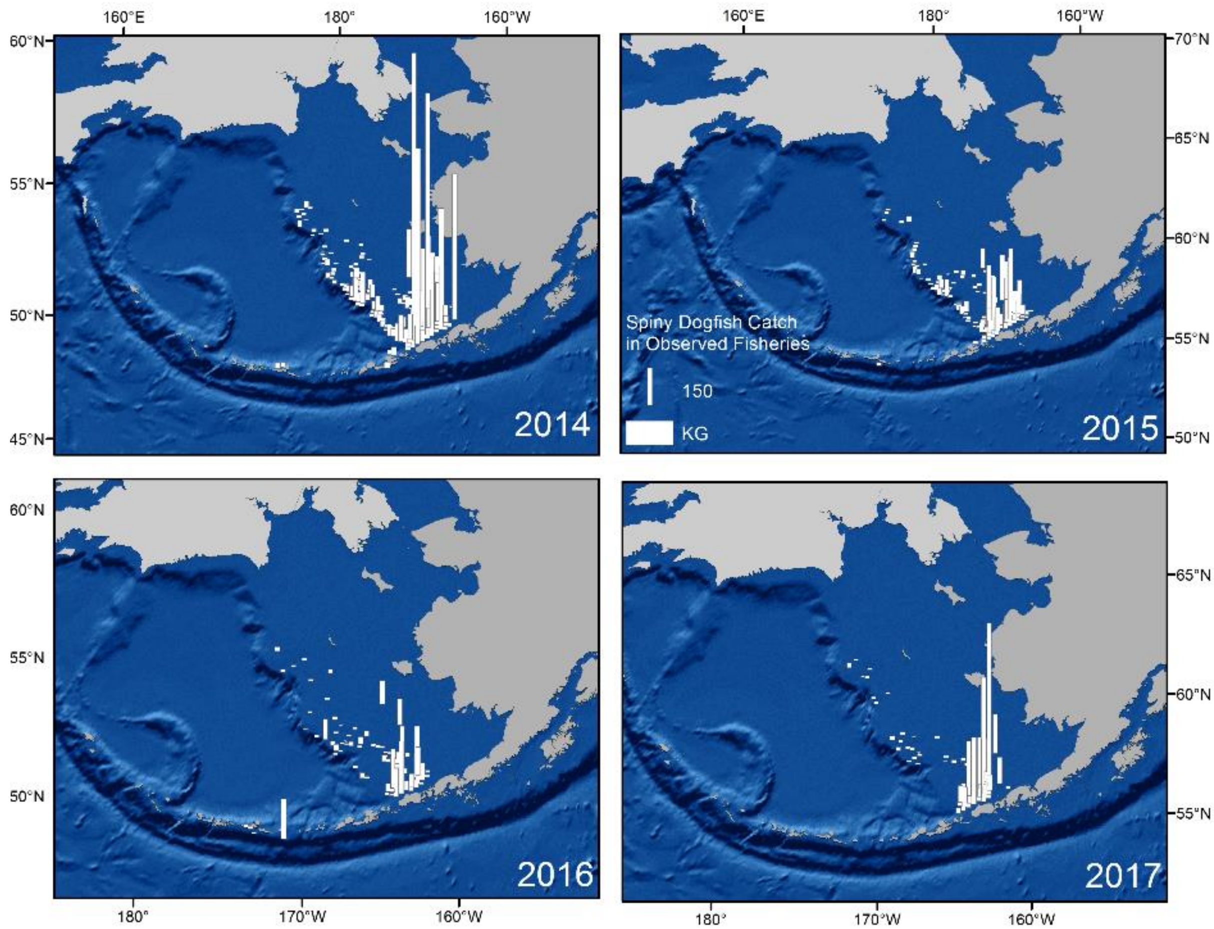


Figure 20.6. Spatial distribution of observed spiny dogfish catch in the BSAI from 2014–2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km$^2$ grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 23, 2018 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

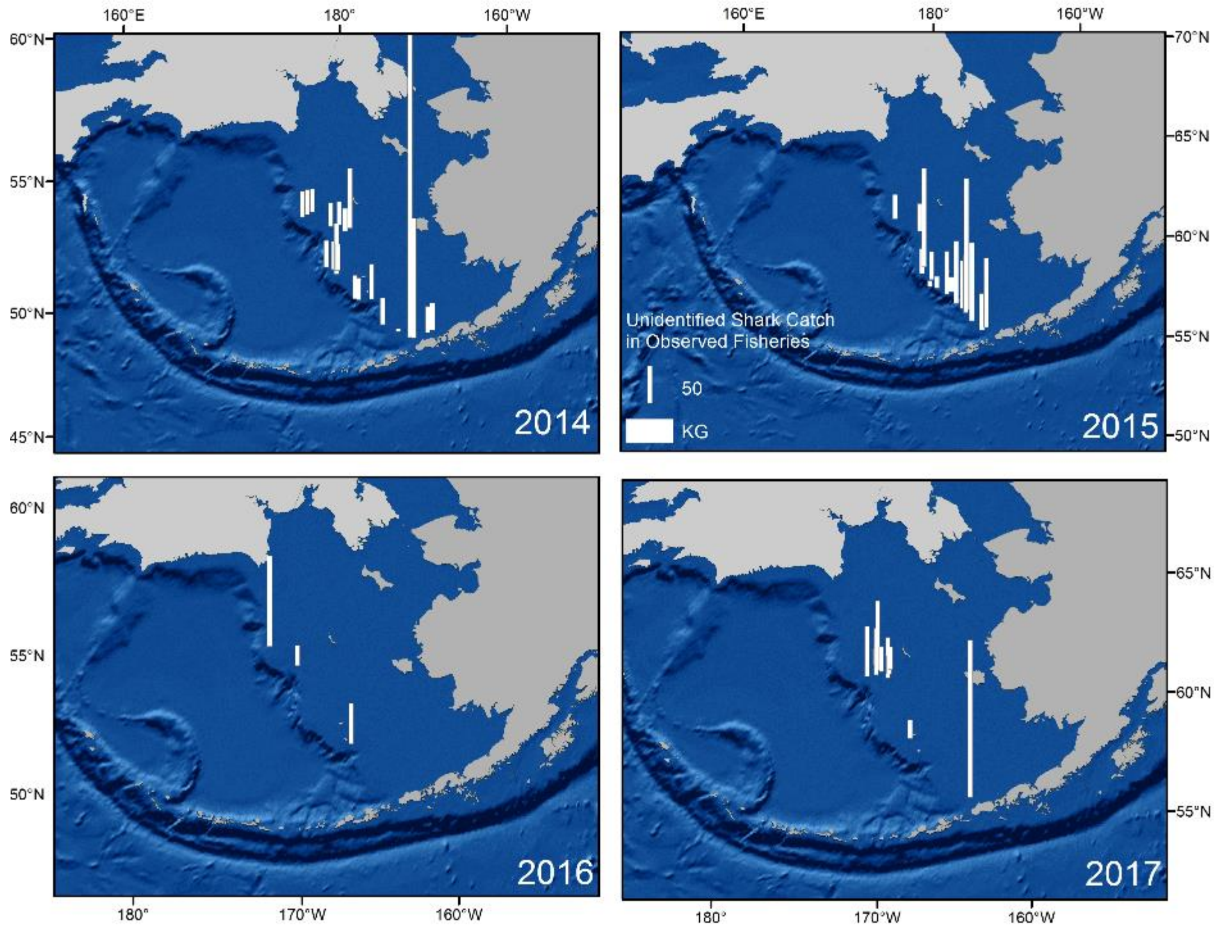


Figure 20.7. Spatial distribution of observed unidentified shark catch in the BSAI from 2014–2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km$^2$ grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 23, 2018 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

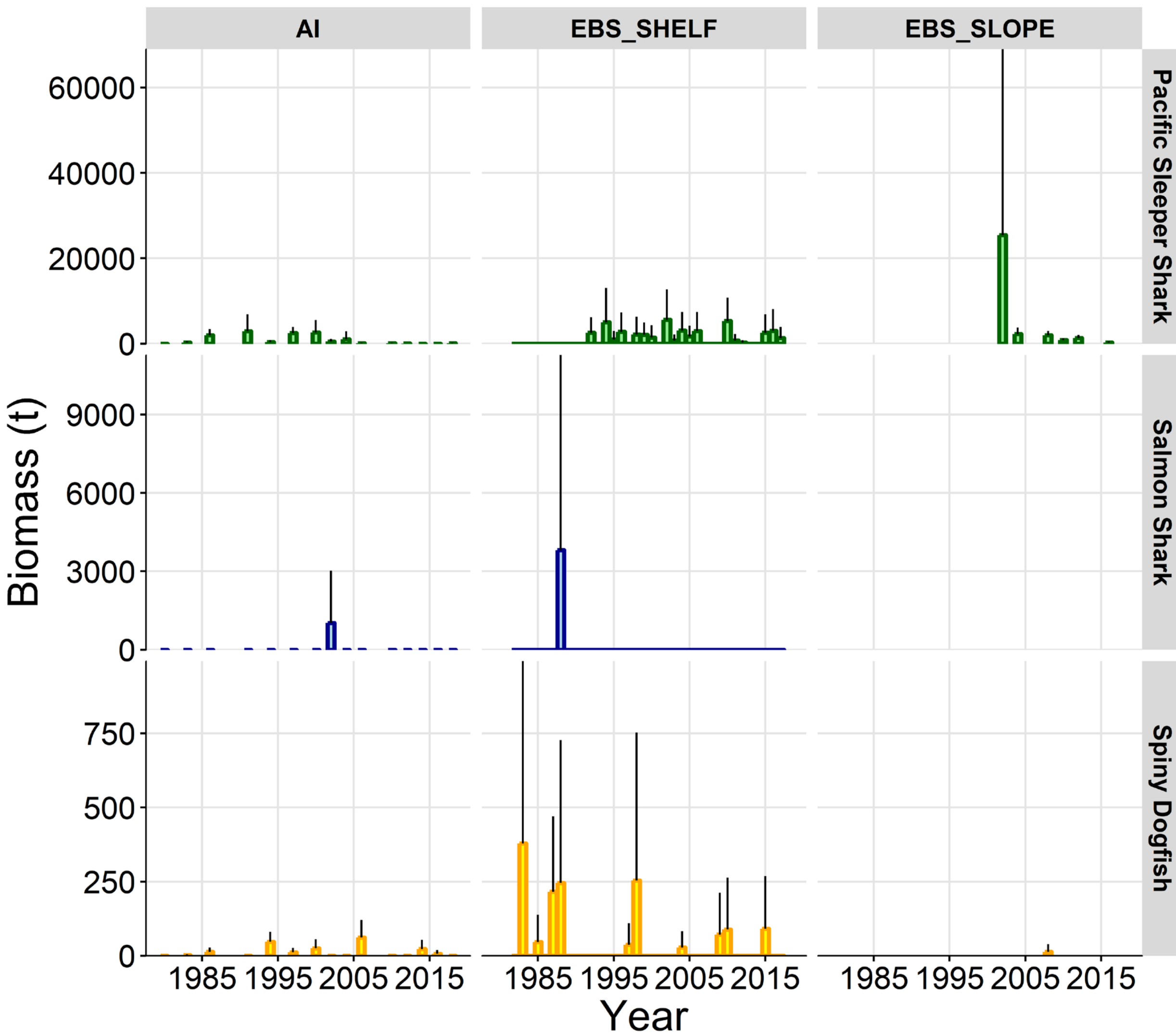


Figure 20.8. Time series of biomass estimates (t) of sharks in the AFSC eastern Bering Sea (EBS) slope, shelf, and Aleutian Islands (AI) bottom trawl surveys. Biomass values are reported here as an index of relative abundance. Error bars are 95% confidence intervals. Analysis of EBS slope survey biomass trends is subject the following time series caveats: the slope survey was standardized in 2002 to its current gear type, survey strata, and survey design; biomass estimates are not comparable between the historical EBS slope survey (1979–1991) and the new slope survey biomass (2002–present) due to differences in stratification; and prior to 2002, the survey utilized a mix of commercial and research vessels with various gear configurations.

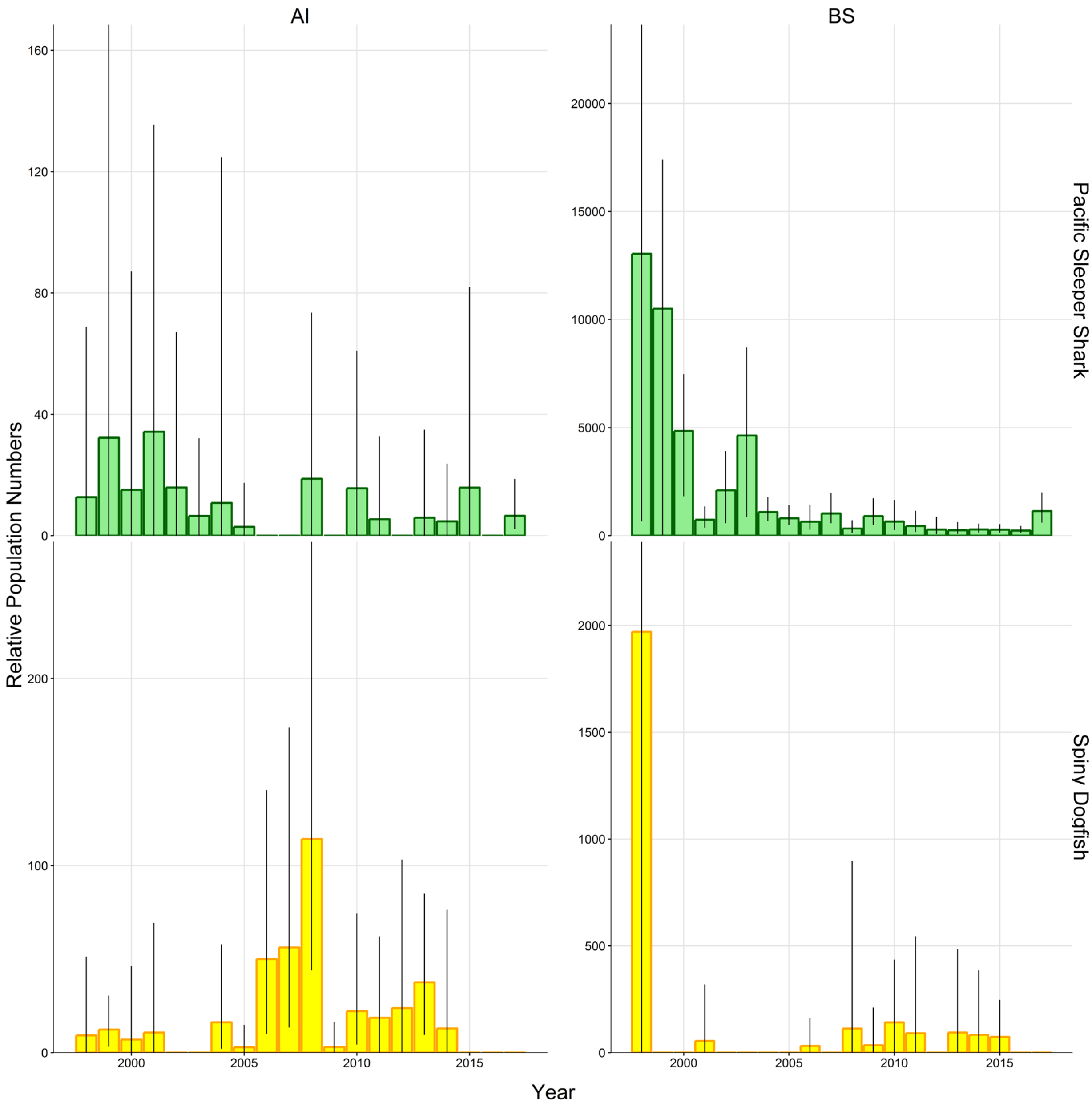


Figure 20.9. Estimated relative population numbers with bootstrapped 95% confidence interval from the IPHC annual longline survey in the BSAI for Pacific sleeper sharks (top) and spiny dogfish (bottom).

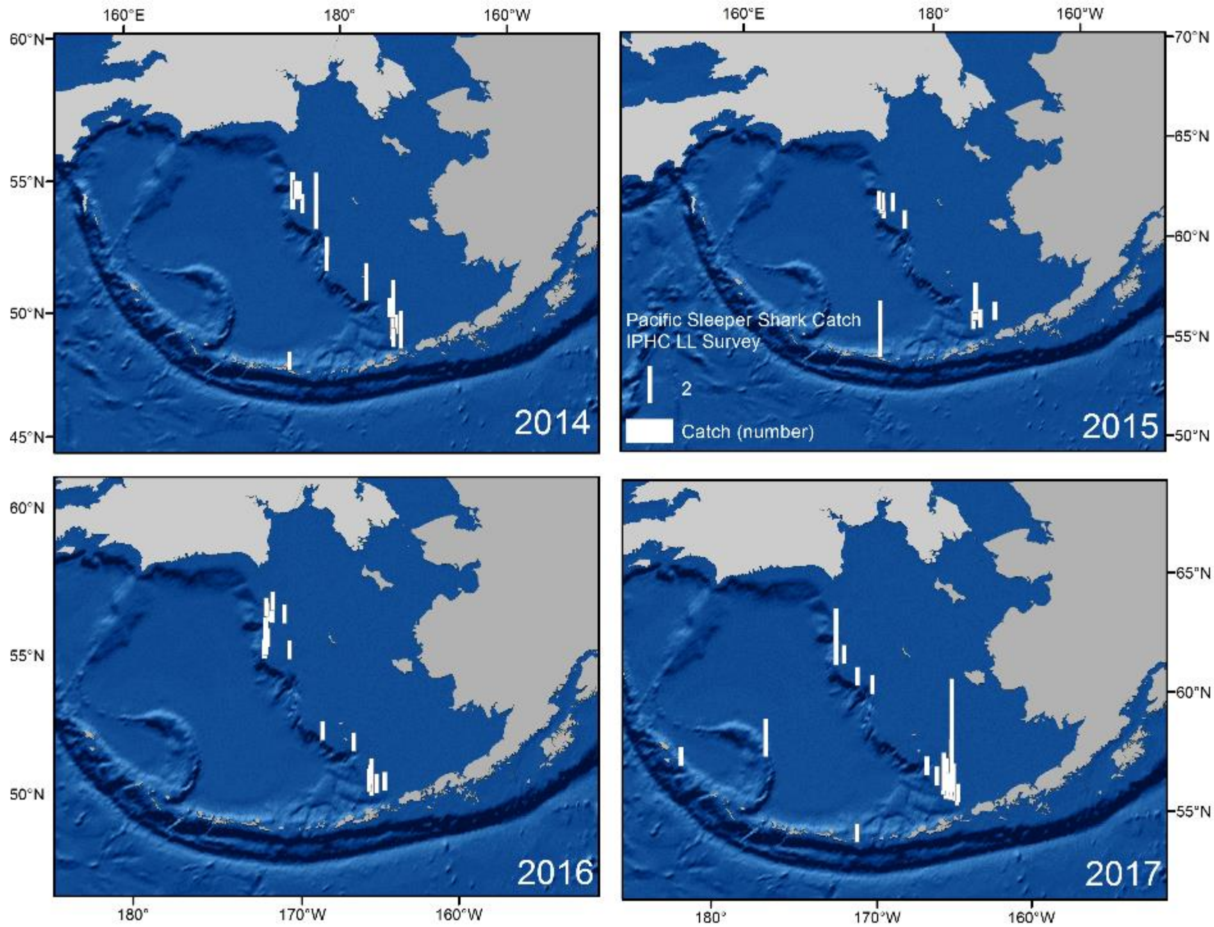


Figure 20.10. Spatial distribution of the catch of Pacific sleeper shark during the 2014–2017 IPHC longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

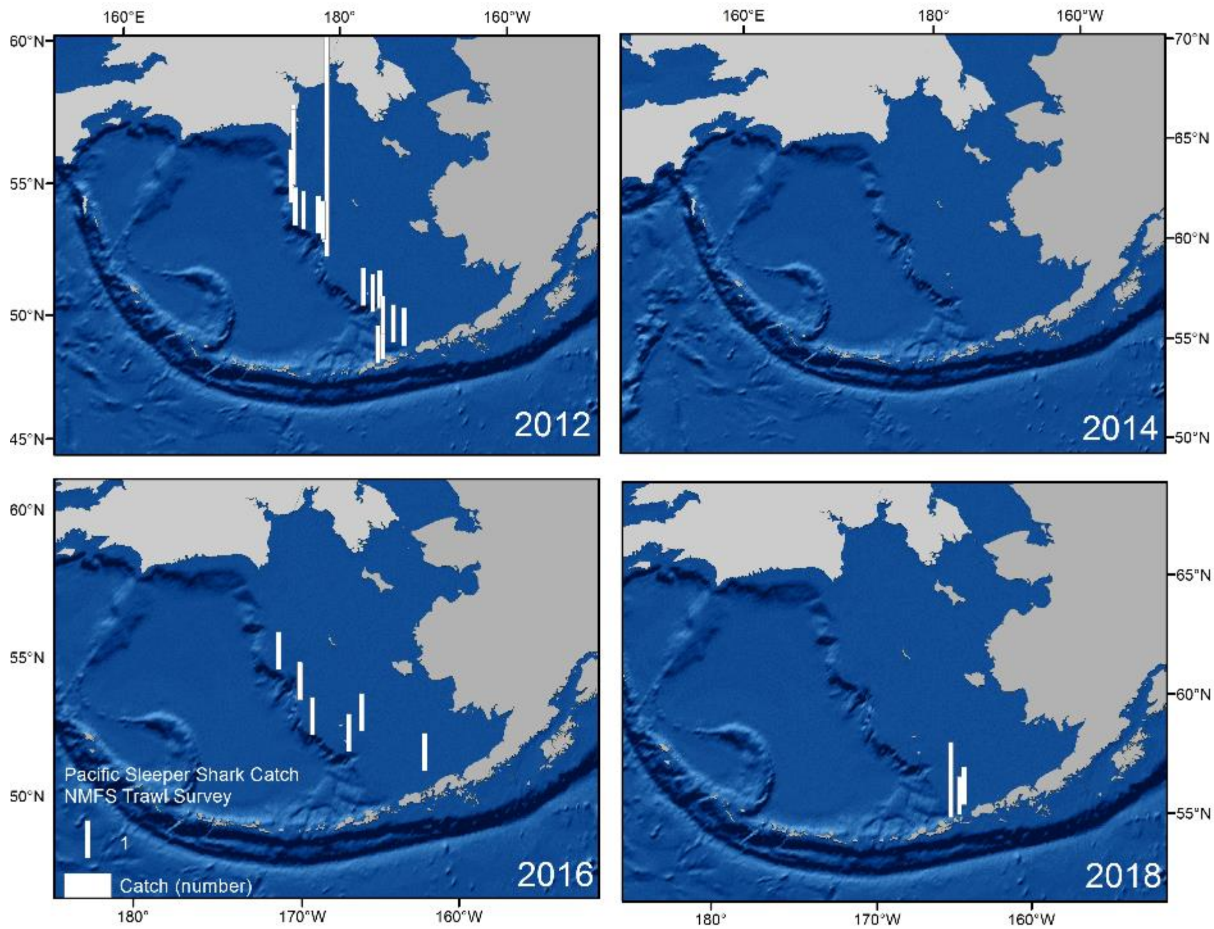


Figure 20.11. Spatial distribution of the catch of Pacific sleeper shark during the 2012–2018 NMFS Eastern Bering Sea (EBS) and Aleutian Islands trawl surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity. There was no EBS slope survey in 2014 or 2018 and no sharks were caught during the EBS shelf or the Aleutian Islands survey in 2014. Years in which only the EBS shelf survey was conducted (odd years) are not included because that survey has inconsistent catch of sharks.

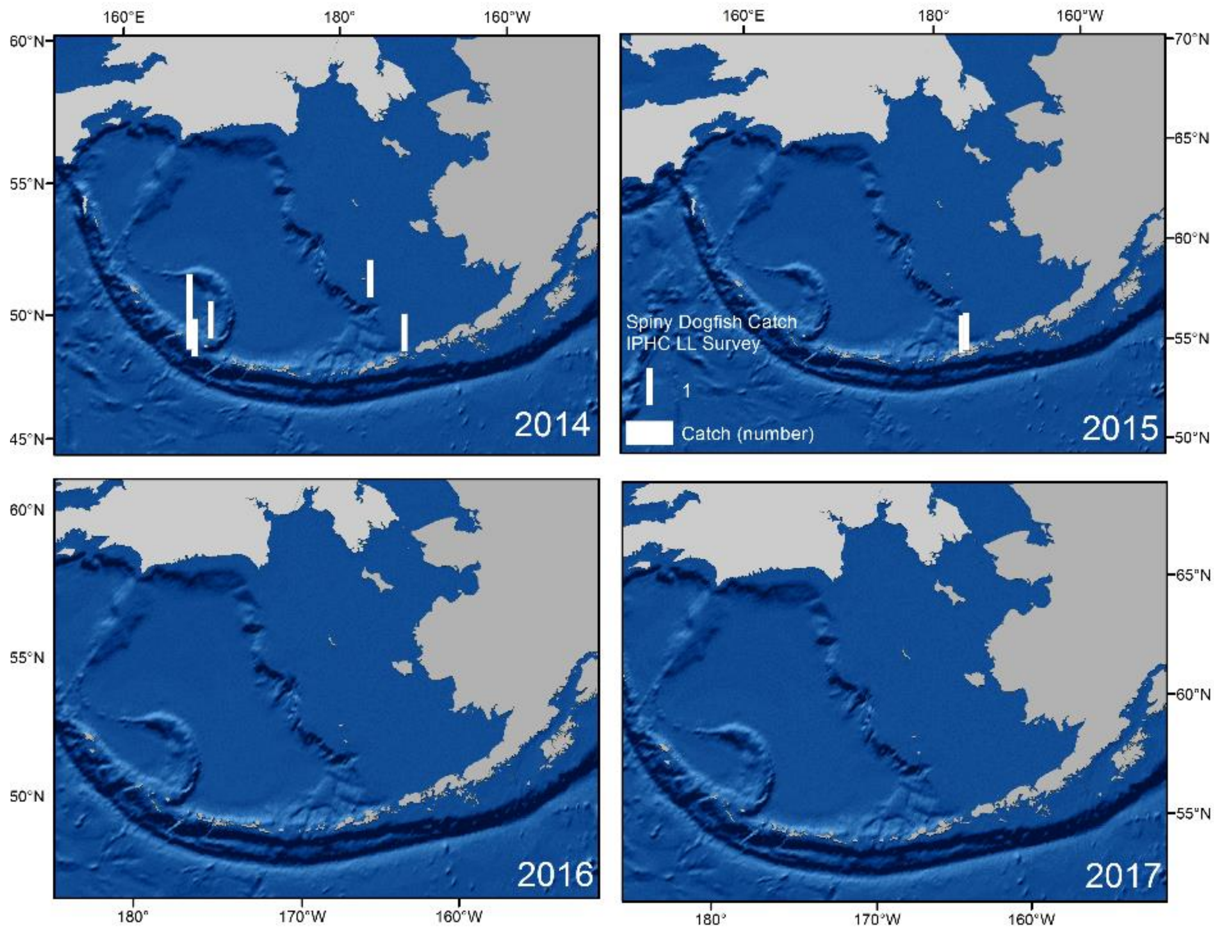


Figure 20.12. Spatial distribution of the catch of spiny dogfish during 2014–2017 IPHC longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity. There were no spiny dogfish caught in the BSAI during the 2016 or 2017 surveys.

# . Improving the Stock Assessments for the Shark Stock Complexes in the BSAI and GOA

September 2018

## Executive Summary

Two main issues are being addressed in this document. The first is the outstanding issue of spiny dogfish catchability in the bottom trawl survey. Catchability has been estimated as a function of vertical availability and applied to the trawl survey biomass estimates. The authors recommend Model 15.3A, which would move the spiny dogfish to Tier 5. The second issue is a discussion of the accuracy of catch estimates of Pacific sleeper shark in longline fisheries. Preliminary results of a special project are presented.

### *SSC and Plan Team Comments Addressed in This Document*

"*The PT also noted that it continues to endorse the FOFL=Fmax rate for the spiny dogfish ABC/OFL calculations as opposed to FOFL=M. The Fmax rate is based on a demographic analysis conducted by the author and published in Tribuzio and Kruse 2011. The author recommended the improved F rate in this assessment, however, the author recommends delaying implementation of using this F rate until trawl survey selectivity can be addressed in the next assessment.*" – GOA PT November 2015

*"The author recommended delaying implementation of the Fmax from the demographic model until concerns over the trawl survey gear efficiency can be addressed in the next assessment. The SSC and PT agreed with this delay and look forward to seeing it again at that time. The SSC requests the author bring the status quo methodology forward, in addition to Fmax from the demographic model, next year and to include the methodology for the demographic model in an appendix. The SSC agrees with the use of M=0.097 for the Tier 5 harvest specifications for the interim."* - SSC December 2015

*"The Team recommended continued work on this alternative approach to developing an F recommendation (demographic model) as well as continued work on improving biomass estimates to be considered during the 2017 cycle (this will be presented at the September 2017 Team meeting)."* – GOA PT September 2016

"*The SSC asks the authors to follow up on the following outstanding issues in future assessments:*

*- Incorporation of a net efficiency study (Hulson et al., in review) that uses tag data to estimate survey catchability*" – SSC Dec 2015 (note: bullets that have either already been addressed or are not part of this document were removed)

**The above comments are addressed in the GOA spiny dogfish trawl survey catchability section.**

*"The Team recommends that the authors continue development of catch of sleeper sharks by numbers, if possible back to 2003, and examine the potential bias in average weight as applied to observed longline caught sleeper sharks."* – BSAI PT November 2016

*"The Team recommends the author continue with efforts to estimate catch by numbers including expanding the time series back to 2003 and pursue investigations into the average weight estimates used for larger sharks as well as instances where no weights are available for observed sharks."* – GOA PT November 2016

*"The SSC supports the Plan Team request to provide catch of sleeper sharks in numbers to better evaluate average weight and catch trends."* – SSC December 2016

**The above comments are discussed in the GOA/BSAI Pacific sleeper shark accuracy of catch estimates section. This work is still ongoing.**

"*In response, the Plan Team recommended:*

1. *Bringing forward a 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*
2. *Coordinating with AKRO catch accounting staff to extend the time series of PSS catch by number of animals back to 2003 (Catch by weight alone may miss high catches of small animals)*
3. *Continuing to work on PSS genetics*
4. *Developing ageing methods for PSS*
5. *Implementing a special project in the observer program to quantify sizes of PSS caught in hook-and-line fisheries*" – GOA PT November 2017

**A research update addressing #'s 1, 3 & 4 is provided in the GOA/BSAI Pacific sleeper shark research update section, and #'s 2 & 4 are discussed in the accuracy of catch estimates section.**

# GOA Spiny Dogfish

### *Trawl Survey Catchability*

Catchability (q) of any gear is a function of the availability of an animal to the survey gear and the selectivity (S) of the gear, or the ability of the gear to catch available animals. Availability can be further broken down into horizontal ($a_h$) and vertical availability ($a_v$). Hulson et al. (2015) examined spiny dogfish satellite tagging data to estimate the vertical availability of the species to the AFSC bottom trawl survey gear using two methods. The first method, developed for Pacific cod, used archival tag depth data, which did not have associated location estimates, and assumed that the deepest depth reading of the tag during a 24 hour period was a proxy for bottom depth (the "depth" method, Nichol et al. 2007). The second method utilized tag geolocation estimates from the satellite tags (including estimated location uncertainty) with associated bathymetry (the "location" method, Hulson et al. 2015). The Hulson et al. (2015) study was presented to the GOA PT in September 2016. The team supported this research effort, and suggested binning tag depth data to match survey strata. Binning the depth data to match the survey depth strata was tested, but there was no change in the resulting estimates of vertical availability.

The vertical availability was estimated to be 3.1% (0-21%, 95% CI, location method) or 60.9% (4.2% - 100%, 95% CI, depth method). The location method is an improvement over the depth method for spiny dogfish for several reasons. The first is that while it may be a reasonable assumption that Pacific cod are on the bottom at some point during the day, this assumption is unlikely for spiny dogfish. Another is that the location method provided more precise estimates of vertical availability compared to the depth method. Thus, we do not recommend using the depth method. However, it is noted in Hulson et al. (2015) that there is substantial uncertainty in the location data. For this reason, we included the point estimate as well as the upper 95% confidence limit of the vertical availability (as a proxy of catchability) to compare with the status quo scenario, where all spiny dogfish are available (i.e., $a_v$ = 0.031, 0.21 or 1).

Horizontal availability is based on the proportion of the GOA spiny dogfish population that is present within the survey area. Based on the tags used in the Hulson et al. (2015) study, about 55% of the point estimates of location during the survey time period were outside of the survey area, however, these point estimates were associated with considerable uncertainty, which often overlapped with surveyed areas. While this suggests that more than half of the spiny dogfish that were tagged within the survey area and during the survey months moved outside of the survey area for at least part of the survey months, an unknown number of spiny dogfish likely also move into the survey area. For example, a small number of spiny dogfish were tagged with satellite tags in Canadian waters, of which 11% (2 of 18 tagged fish) moved into the AFSC bottom trawl survey area during the summer months. Due to the limitations of the size of animal that can be tagged, these estimates may not be representative of the movement patterns for the full size range. Archival tag recoveries from fish that would have been too small for satellite tags suggests that smaller dogfish also have high potential for movement (>5,000 km, Voirol et al. in prep). Results of a tagging study conducted in Canadian waters, where a large number of spiny dogfish were tagged with conventional tags, also showed movement from Canadian waters into the GOA (McFarlane and King 2003). For the purposes of this estimation procedure we use $a_h = 1$ because there are data showing movement both into and out of the survey area.

A study of *Squalus acanthias* (a closely related species, previously considered the same species) suggested that trawl net efficiency is a function of how the swept area biomass is estimated (Rago and Sosebee 2009). In short, half of the *S. acanthias* encountered between the trawl doors escape capture, while all of the *S. acanthias* encountered between the trawl wings are captured. Rago and Sosebee (2009) suggest that the net efficiency is 100% when the swept area biomass is estimated using only the area between the wings, but that net efficiency is 50% when the area between the doors is included. The AFSC trawl survey estimates are based on the areas between the wings only, thus for estimating q for spiny dogfish, we are assuming that net efficiency is 100%.

We present the status quo model (15.1) and a series of scenarios based on the assumptions described above for the estimate of catchability (Model 15.2 - 15.3). To incorporate catchability into the biomass estimate of spiny dogfish we use the equation: B = q x Ba, where B is the AFSC trawl survey biomass (as estimated by the random effects model), q is the estimate of catchability, and Ba is the biomass adjusted by catchability that would be used to determine the overfishing limit and acceptable biological catch (OFL and ABC). Thus, Ba = B/q. In Model 15.1 (status quo), q = 1 and so Ba = B/q = B, where B is the random effects estimate of biomass. Models 15.2 - 15.3 are the different scenarios of 15.1, such that Ba = B/q. The biomass estimate, 56,181 t (35,484 – 88,950 t, 95% CI), from the most recent assessment (Tribuzio et al. 2015) is used.

| Model | $q=a_v$ | B (95% CI) | Ba (95% CI) |
|---|---|---|---|
| 15.1 | 1 | 56,181 (35,484 – 88,950) | 56,181 (35,484 – 88,950) |
| 15.2 | 0.031 | 56,181 (35,484 – 88,950) | 1,812,290 (1,144,645 – 2,869,355) |
| 15.3 | 0.21 | 56,181 (35,484 – 88,950) | 267,529 (168,971 – 423,571) |

Due to the large uncertainty associated with the geolocation estimates, Hulson et al. (2015) recommended that using the point estimate of vertical availability may not be appropriate but that the uncertainty in the vertical availability estimate should be used as well, for example, as a prior for catchability estimation. In the current examples, a more conservative approach would be to use the upper confidence limit of vertical availability (0.21). For further examples of applying different fishing mortality rates we use 15.1 and 15.3 and do not present results from 15.2. Using the approach that incorporates q into the biomass estimation allows for the adjustment of biomass, as it is well recognized that the trawl survey biomass estimate of spiny dogfish should be considered as a minimum biomass estimate. For comparison, the NWFSC spiny dogfish assessment uses model estimated q for various trawl surveys ranging from 0.16 – 0.55 (Gertseva and Taylor, 2012).

Spiny dogfish are currently a Tier 6 species, but a Tier 5 approach is used because of the biomass challenges, which preclude it from meeting the requirements for Tier 5. In the 2015 full assessment the authors proposed using a different calculation for F than is standard for Tier 5 methods, where the fishing mortality rate (F) = natural mortality (M). The PT endorsed using F = Fmax from the demographic model, where F = Fmax = 0.04 (0.01-0.08, 95% CI, Tribuzio and Kruse 2011). Based on the authors' recommendation, the GOA PT delayed implementing that change until further investigations of q could be conducted (GOA GF Plan Team Minutes November 2015). Below is a comparison of the ABCs for status quo (15.1) and the alternative q case 15.3, along with using both the F = M and F = Fmax rates. For the sake of brevity, only Fmax = 0.04 is used; the confidence levels are not included. The ABC is calculated using the standard Tier 5 approach, ABC = Ba*F*0.75.

| Model | F | Ba (95% CI) | ABC (95% CI) |
|---|---|---|---|
| 15.1 | 0.097 | 56,181 (35,484 – 88,950) | 4,087 (2,581 – 6,471) |
| 15.1A | 0.04 | 56,181 (35,484 – 88,950) | 1,685 (1,065 – 2,669) |
| 15.3 | 0.097 | 267,529 (168,971 – 423,571) | 19,463 (12,293 – 30,815) |
| 15.3A | 0.04 | 267,529 (168,971 – 423,571) | 8,026 (5,069 – 12,707) |

It should be noted that if Model 15.3A is accepted, which is the model that the author's prefer and would recommend to set ABC/OFL for 2019 in November, spiny dogfish could be moved to Tier 5.

# GOA/BSAI Pacific Sleeper Shark

### *Research Update*

A Pacific sleeper shark (PSS) stock structure document across both FMPs was scheduled for September 2018, but will be delayed pending results of genetic analysis. Microsatellites have been developed and a publication is being prepared on the methods. A more detailed population genetics analysis is underway examining close kin mark recapture to estimate population size and examine relatedness.

A pilot study was begun to investigate the use of C14 in the eye lens as a means of ageing PSS, based on methods used to age Greenland sharks (Nielsen et al. 2016). Results are expected within two months. The investigators plan to apply for grant funding to support a student to take a more detailed look at the biochemistry of the eye and the uptake of C14 to validate the method.

### *Accuracy of Catch Estimates*

A special project is being conducted during the 2018 longline fishery, where observers are classifying PSS into a size class (small, medium or large) based on measurements that they can take at the rail. To date, data from 28 PSS have been returned. Table 20A.1 includes the size class of each specimen, the weight range associated with the size class (determined from length/weight conversion equations), and the mean weight used by CAS to estimate total catch for the haul the specimen was sampled on. The preliminary results suggest that the weight of medium and large sharks is being underestimated in longline fisheries. Further, except for when large animals are able to be brought aboard to be measured, the mean weight used in each of the size classes is similar. In the data available so far, 14 of 28 PSS were classified as either medium or large. These results suggest that the weight is underestimated for half of the PSS observed, and that the magnitude of the underestimation increases with the size of the shark. Therefore, the total catch estimates are likely biased low. The authors plan to request to continue this project for the 2019 fishery and to expand it to all gears. Expanding this project will hopefully provide information on the sizes of fish that the fisheries are encountering.

The AKRO have provided total catch estimates in numbers and in weight for PSS from 2011 – 2017. Preliminary investigations into total catch estimates of PSS by size suggest that much of the catch is composed of small PSS, especially in the BSAI, on both trawl and longline gears (Figure 20A.1). While the reported small weight on longline gear is likely a function of the difficulty of weighing the large animals. It is unlikely that the trawl size estimates are biased because PSS caught on trawl vessels should be able to be measured more easily (either length converted to weight, or weight directly). Because the size of PSS are likely biased in longline gear fisheries, we are examining catch estimates in number. Efforts are underway to extend that time series back to 2003, however the structure of CAS is different prior to 2011 and estimating catch numbers prior to 2011 will require creating a separate estimation program, which is labor/time intensive and a low priority for the AKRO. Therefore, catch estimates in numbers may not be possible prior to 2011. In future work we plan to investigate how mean weight is utilized within NORPAC and CAS, if there are improved options for estimating mean weight on longline vessels (such as utilizing size bins), if utilizing catch by numbers in the assessment would be informative, and the biological impacts of catching large numbers of small animals as opposed to smaller numbers of large animals.

# Acknowledgements

The authors thank staff at the AKRO for providing catch estimates in numbers: Jason Gasper and Brian Lieb; and Jacob Van Baalen of Wostman Associates. The observers and staff at FMA have been extremely helpful in developing and conducting the PSS length special project.

# Literature Cited

Gertseva, V. and I. G. Taylor. 2012. Status of the spiny dogfish shark resource off the continental U.S. Pacific Coast in 2011. https://www.pcouncil.org/wp-content/uploads/Spiny_Dogfish_2011_Assessment.pdf

Hulson, P-J. F., C. A. Tribuzio, K. Coutré. 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 Fiarbanks. 129-149.

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.

Nichol, D. G., T. Honkalehto, and G. G. Thompson. 2007. Proximity of Pacific cod to the sea floor: Using archival tags to estimate fish availability to research bottom trawls. Fish. Res. 86:129-135.

Nielsen, 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.

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. 343-372.

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.

Voirol G. and C. A. Tribuzio. in prep. Seasonal habitat use of Pacific spiny dogfish based on archival tags.

# Tables

Table 20A.1. Summary of PSS observed size data, to date. Each shark_ID is an individual animal. In all but one case, the sampled shark(s) were a complete census of the PSS caught on the haul. The Obs_size is the observer estimated size class, Obs_wt is the weight range associated with that size class and the NORPAC_meanwt is the mean weight of sharks used to estimate total catch.

| Shark_ID | Obs_size | Obs_wt | NORPAC_meanwt |
|---|---|---|---|
| 1 | L | >287 | 101.586667 |
| 2 | L | >287 | 12.52 |
| 3 | L | >287 | 13.35 |
| 4 | L | >287 | 7.7 |
| 5 | M | 50-287 | 12.781429 |
| 6 | M | 50-287 | 12.355 |
| 7 | M | 50-287 | 15.783333 |
| 8 | M | 50-287 | 12.782 |
| 9 | M | 50-287 | 7.21 |
| 10 | M | 50-287 | 15.783333 |
| 11 | M | 50-287 | 6.274 |
| 12 | M | 50-287 | 6.274 |
| 13 | M | 50-287 | 6.274 |
| 14 | M | 50-287 | 7.5 |
| 15 | S | <50 | 15.636667 |
| 16 | S | <50 | 9.776667 |
| 17 | S | <50 | 12.78 |
| 18 | S | <50 | 9.663333 |
| 19 | S | <50 | 15.635556 |
| 20 | S | <50 | 14.1675 |
| 21 | S | <50 | 16.876667 |
| 22 | S | <50 | 15.883333 |
| 23 | S | <50 | 5.95 |
| 24 | S | <50 | 15.635 |
| 25 | S | <50 | 15.783333 |
| 26 | S | <50 | 15.636667 |
| 27 | S | <50 | 16.083333 |
| 28 | S | <50 | 15.635556 |

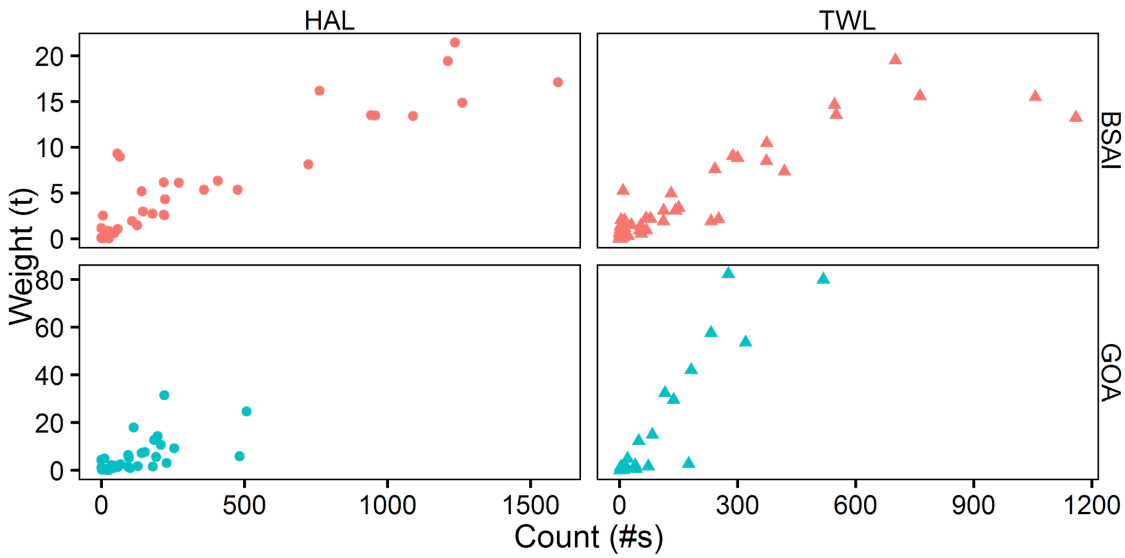


Figure 20A.1. Total estimated catch in tons and numbers. Each dot is a NMFS area and year.