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

Cindy A. Tribuzio, Mary Elizabeth Matta, Katy Echave, and Cara Rodgveller
November 2020

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.

Summary of Changes in Assessment Inputs

Changes to the input data

1. Total catch for BSAI sharks is updated for 2003–2020 (as of Oct 13, 2020)
2. International Pacific Halibut Commission (IPHC) longline survey relative population numbers (RPNs) are updated through 2019
3. Biomass estimates have been updated for the Bering Sea shelf trawl survey through 2019 (no surveys were conducted in 2020).

Changes in assessment methodology

None

Summary of Results

There is no evidence to suggest that overfishing is occurring for any shark species in the BSAI because the OFL has not been exceeded. Total shark catch in 2019 was 150 t, and catch in 2020 was 198 t, as of October 13, 2020. On average, 15% of the total annual catch occurs after October 1st each year.

For 2021–2022 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.

ABC and OFL calculations and Tier 6 recommendations for 2021–2022. OFL = maximum shark catch from 2003–2015. ABC = OFL*0.75.

Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021	2022
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: 2018	2019	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Shark Complex	2019	NA	689	517	180	150
	2020	NA	689	517	150	198
	2021	NA	689	517		
	2022	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 13, 2020

Responses to SSC and Plan Team Comments on Assessments in General

Risk Tables

"The SSC requests that all authors fill out the risk table in 2019…" (SSC December 2018)
"…risk tables only need to be produced for groundfish assessments that are in 'full' year in the cycle." (SSC, June 2019)

"The Teams recommended that authors continue to fill out the risk tables for full assessments. The Teams recommended that adjustment of ABC in response to levels of concern should be left to the discretion of the author, the Team(s), and/or the SSC, but should not be mandated by the inclusion of a >1 level in any particular category. The Teams request clarification and guidance from the SSC regarding the previously noted issues associated with completing the risk table, along with any issues noted by the assessment authors. The Teams plan to discuss the risk table process at the September meeting." (Plan Team Nov 2019).

"*The SSC requests the GPTs, as time allows, update the risk tables for the 2020 full assessments."* (Dec 2019)

"*The SSC provided direct responses to 10 specific requests raised by the Teams:*

1. *Whether an overall elevated risk level (>1) mandates a reduction in ABC, and, more generally, the relationship of the risk level to the amount of reduction (if any);*

No. The intention was to organize, report and clarify risks that are not addressed in the assessment or the Tier system to promote transparency and consistency among assessments. The GPT minutes and the risk tables in this year's SAFE report suggest this is happening. As the SSC outlined in the December 2018 report, the risk tables are intended to be informative rather than prescriptive regarding potential reductions from maximum ABC.

2. *How to document changes that may not warrant higher levels of precaution, specifically when an overall elevated level of risk (>1) does not lead to a reduction in ABC (e.g., BSAI northern rockfish, GOA POP, GOA arrowtooth flounder);*

Notation in the table along with associated explanation of the rationale in the SAFE reports is sufficient.

3. *The appropriateness of the overall level of risk being based on the maximum value across the categories, such that scores of 4, 4, 4, and 4 would be the same as a score of 1, 1, 1 and 4;*

This approach is consistent with between-category variability in risk meaning and serves to elevate stocks with any risk concerns for further review (but see comments below regarding the overall rating).

4. *Whether to state a default level of no risk (=1) or an unknown level of risk when there is no information to evaluate the risk level for a given category (this was of particular concern for Tier 5 and 6 stocks);*

"No risk" versus "no information" determinations are different and should be specified (GOA Atka mackerel and BSAI Alaska plaice provide good examples). Further, a rating of 1 does not necessarily mean no risk, but instead may reflect that the risks are dealt with in the assessment directly or via the Tier system and that no additional, unaccounted for risk was identified.

5. *How to determine the relative influence of stock-specific versus indirect ecosystem indicators for setting the risk level (e.g., EBS Pacific cod, BSAI northern rockfish);*

This is at the discretion of the author/team. No between-category "influence" is likely to be consistent between assessments and attempts to establish category weights is likely to cause as many issues as it might address.

6. *How many direct or indirect ecosystem indicators would constitute an elevated concern;*

This is left to the judgement of the assessment author and the team on a case-by-case basis.

7. *How evaluations of fishery performance indicators determine risk to stock productivity;*

As indicated in the SSC's December 2018 report, this additional column should include indications of fishery concern, such as inability to catch the TAC, large changes in CPUE (when not accounted for in the model), or dramatic changes in spatial or temporal distribution that could indicate anomalous biological conditions. If, and how, these indicators are developed is left up to the assessment author and GPT on a case-by-case basis.

8. *Delineating issues that fall under more than one category;*

This is at the discretion of the author and GPT. Categories are not mutually exclusive, and risks can be attributed as deemed most appropriate by the author/GPT.

9. *Whether every item, positive or negative, listed in the context of the risk table necessarily constitutes a "concern" (e.g., for Alaska sablefish, is an unusually large year class necessarily a "concern" simply because it is unusual?);*

No. The tables are intended to promote transparency and prompt further discussion as appropriate. Whether or not an unusual event (e.g. large year class) merits notation in the table is at the discretion of the assessment author and the GPT.

10. *The Teams noted that risk table discussions were time consuming and could be simplified if the process to determine levels of risk was decoupled from the decision to propose a reduction and the associated amount.*

As stated in our December 2018 report, it is the intention of the SSC that these be decoupled but developed in concert: The SSC endorsed the Teams' request that the authors continue to fill out the risk tables for full assessments and affirmed the Teams' recommendation that adjustment from maxABC in response to levels of concern should be left to the discretion of the author, the Team(s), and/or the SSC, but should not be mandated by the inclusion of a >1 level in any particular category. The SSC encourages authors or Teams to provide recommendations on reductions and rationale for those reductions when appropriate. The SSC also requests authors to note changes in risk scoring from one assessment to the next, along with the rationale. The SSC reminds the authors that the tables are intended to capture risks and uncertainties that are NOT addressed in assessment and/or the application of the Tier system. In cases where these concerns are partially addressed, the SSC requests that the authors clearly articulate the extent to which the listed items are not already addressed by the assessment and/or the Tier system.

…..The SSC recommends dropping the overall risk scores in the tables.

.....The SSC requests that the table explanations be included in all the assessments which include a risk table for completeness.

....The SSC notes that the risk tables provide important information beyond ABC-setting which may be useful for both the AP and the Council and welcomes feedback to improve this tool going forward." (SSC December 2019)
The authors appreciate the clarifications to the above questions and the flexibility to fill in the risk table as most appropriate for the assessment. The process of developing the risk tables, as expected, requires some feedback as questions continue to arise. As requested, the overall risk score has been removed from the risk table summary and the table explanations have been added to the stock assessment guidelines. The 2020 BSAI shark full assessment includes an updated risk table in the *Harvest Recommendations* section. After completing this exercise, we do not recommend any changes to the ABC.

Completing the risk table for complexes raises questions. In the case when one or more of the species in a complex have different risk scores from the bulk of the complex, should the complex risk score be based on the bulk of the complex, or highest level of concern? For example, in the GOA shark complex, three of the four species would be level 1 in all categories, but one species has level 2 risk in at least one category.

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); "*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)
We have coordinated with the AKRO Catch Accounting System staff and have received catch estimates in numbers updated through 2019. It is unlikely that this time series will be able to go back prior to 2011. While technically possible, it would be a substantial investment of time and a low priority for AKRO staff. We would like to commend the AKRO CAS staff for the quick turnaround and rapid responses to questions about this topic. Analysis is ongoing. We also have data collections ongoing to investigate the potential bias in catch estimates in fisheries where Pacific sleeper sharks can not be brought onboard to be measured.

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

"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)
The authors have initiated a pilot study to estimate ages of Pacific sleeper sharks by measuring the levels of radiocarbon (^{14}C) in their eye lens cores. While the pilot study has been delayed due to the pandemic, early results have shown that ^{14}C is detectable in the eye lens core. Further, the growth rate is likely faster than that published using the same methods for the closely related Greenland shark. A proposal has been submitted to fully fund the complete study.

"The Teams encourage continued exploration of utilizing data limited methods for this assessment." (JGPT September 2018), *"The SSC agrees with the JGPT for continued exploration of utilizing data limited methods for this assessment. The SSC further recommends in addition to sharks, it would be helpful for the Plan Teams and other authors of Tiers 5 and 6 stocks to explore the increasing number of methods available for data limited situations."* (SSC October 2018), *"The Team accepted the author's choice of OFL and ABC (the same as 2017 and 2018) and looks forward to the author's new analysis*

with a greatly expanded set of data-limited methods for 2020" (PT November 2018), *"For the next full assessment in 2020, the SSC looks forward to the authors' new analysis with a greatly expanded set of data-limited methods."* (SSC December 2018)
Both the GOA and BSAI shark assessments would benefit from explorations of data-limited assessment methods. We continue to explore these methods including improved estimates of natural mortality and hope to bring forth improved methods in the future."

"Also for the next assessment, the SSC suggests using the 5th and 95th percentile of catches as an alternative for confidence intervals to avoid the issue that catches are not normally distributed." (SSC December 2018).
These are presented in the results section of this assessment.

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 19.1). In total, eight shark species have been reported in the BSAI (Table 19.1). 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 Pacific spiny dogfish (*Squalus suckleyi)*. These three species are the main focus of this assessment, as catches of the remaining five species (bluntnose sixgill shark *Hexanchus griseus*, basking shark *Cetorhinus maximus*, brown cat shark *Apristurus brunneus*, blue shark *Prionace glauca*, and Pacific sharpnose shark *Rhizoprionodon longurio*) are rare in BSAI groundfish fisheries or surveys. There are also unverified reports of great white sharks, *Carcharodon carcharias*, preying upon marine mammals in the BSAI.

General Distribution

Pacific Sleeper Shark

The Pacific sleeper shark is the most commonly encountered shark in the BSAI, ranging as far north as the Chukchi Sea (Benz et al. 2004), off the Asian coast from the western Bering Sea (Orlov and Moiseev 1999) to at least as far south as Taiwan (Wang and Yang 2004), and along the North American Pacific coast from Alaska to Baja California (Ebert et al. 2009). It has also been reported off the coast of South America (de Astarloa et al. 1999). However, Yano et al. (2004) reviewed the systematics of *Somniosus* species and suggested that records in the southern hemisphere were misidentified as Pacific sleeper sharks and are actually *Somniosus antarcticus*, a species of the same subgenus.

Pacific sleeper sharks have been documented at a wide range of depths, from surface waters to depths of 2,000 m or more (Compagno 1984, Hulbert et al. 2006). This species appears to have a latitudinal relationship with depth, occurring in relatively shallow waters at higher latitudes and in deeper habitats in temperate waters (Ebert et al. 2009).

Salmon Shark

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

Spiny Dogfish

The Pacific spiny dogfish (hereafter, "spiny dogfish") occupies shelf and upper slope waters from the Bering Sea to the southern Baja Peninsula in the eastern North Pacific (ENP) and south through the

Japanese archipelago in the western North Pacific (WNP, Ebert et al. 2010). Spiny dogfish are considered more common off the U.S. West Coast and British Columbia (BC) than in the GOA or BSAI (Hart 1973, Ketchen 1986, Mecklenburg et al. 2002). In Alaska, they are more common in the GOA than in the BSAI (Gasper and Kruse 2013). Spiny dogfish inhabit both benthic and pelagic environments. They are commonly found in surface waters and throughout the water column, with a maximum recorded depth of 677 m in Alaska waters (Tribuzio, unpublished data).

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 (Ebert et al. 2010). The variant in the North Pacific was reclassified by Girard as *S. suckleyi* in 1854. However, Girard's original description was vague and no type specimens were preserved. Therefore, the scientific name *S. acanthias* was retained for spiny dogfish from the North Pacific until 2010, when *S. suckleyi* was resurrected based on morphological, meristic, and molecular data (Ebert et al. 2010, Verissimo et al. 2010). This scientific name has subsequently been accepted by the American Fisheries Society naming committee. Accordingly, the North Pacific spiny dogfish has been classified as *S. suckleyi* in the SAFE since 2010, though some data sources and older citations refer to the previous name, *S. acanthias*.

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 are little data available to confirm whether different stocks exist among regions within the GOA or BSAI for any of the three major species of the shark complex. However, 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 geographically interspersed across the range of the species (S. Wildes, NMFS, AFSC pers. comm.). Staff at the AFSC are continuing examination of the genetic stock structure using genomics and next generation DNA sequencing. Upon completion of genetic results, we will reexamine stock structure of PSS in the BSAI region and address any management concerns.

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

Life History Information

There are little life history data specific to the BSAI region for any of the three primary shark species, thus GOA information is used as a proxy. Sharks are generally long-lived with slow growth to maturity, a large maximum size, and low fecundity (Musick et al. 2000). 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 the salmon shark, spiny dogfish, and Pacific sleeper shark were among the most vulnerable species in the BSAI fishery management plan.

Pacific Sleeper Shark

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

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

The reproductive mode of sleeper sharks is likely aplacental viviparity, with embryos thought to be nourished by yolk in utero (Carter and Soma 2020), and, as in all elasmobranchs, fertilization is internal. Size at maturity is estimated based on limited reports of mature animals. Published observations suggest that mature female Pacific sleeper sharks are in excess of 365-cm *TL* and mature male Pacific sleeper sharks are in excess of 397-cm *TL* (Gotshall and Jow 1965, Yano et al. 2007). Three mature females 370–430 cm *TL* were opportunistically sampled off the coast of California. One of these sharks had 372 large vascularized eggs (24–50 mm) present in the ovaries (Ebert et al. 1987). Another mature Pacific sleeper shark 370-cm *TL* long was caught off Trinidad, California (Gotshall and Jow 1965) with ovaries containing 300 large ova. Despite these ovarian reserves of large ova, litter sizes of *Somniosus* species are thought to be small due to oxygenation limitations in the uterus (Carter and Soma 2020). To date, no pregnant females of *S. pacificus* have ever been landed; however, there is one record of a pregnant 5-meter female *S. microcephalus* caught south of the Faroe Islands in 1954, containing 10 embryos of about the same size, 37 cm (Koefoed 1957). These embryos appeared to be near-term, and size at birth of *Somniosus* species is thought to be approximately 40-cm TL (Yano et al. 2007). Very small Pacific sleeper sharks are not frequently encountered. Of two 74-cm TL *S. pacificus* that were caught off the coast of California (at depths of 1300 and 390 m), one still had an umbilical scar (Ebert et al. 1987);

unfortunately, the date of capture was not reported. A newly-born shark of 41.8 cm was also caught at a depth of 35 m off Hiraiso, Ibaraki, Japan (Yano et al. 2007). Additionally, three small sharks, 65–75 cm *TL*, have been sampled in the Northwest Pacific, but the date of sampling was not reported (Orlov and Moiseev 1999). Sharks under 80-cm *TL* have only been captured in AFSC surveys a handful of times, mostly in the summer bottom trawl survey in the Bering Sea. Because of a lack of observations of mature and newly-born sharks, and the absence of capture dates in literature, the mating and pupping seasons are unknown for sleeper sharks. One study has examined the lengths of Pacific sleeper shark caught in the GOA, eastern Bering Sea (EBS, AFSC trawl survey data for both regions), western Bering Sea, along the Kamchatka Peninsula and in the Sea of Okhotsk (Russian survey and fishery data), and found that there were very few fish greater than 200 cm (Orlov and Baitalyuk 2014). These data indicate that the animals caught in the BSAI are small, some possibly even being neonates, and are all likely immature. In all of the other regions, the animals being caught are also primarily small, but occasionally larger, possibly mature animals are captured.

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

<u>Salmon Shark</u>

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

Salmon sharks show a high degree of size and sex segregation within the North Pacific Ocean. Larger sharks are found further north, with males dominant in the WNP and females dominant in the eastern North Pacific , particularly at high latitudes (Nagasawa 1998, Goldman and Musick 2008). Adult salmon sharks typically range in size from 180–210 cm pre-caudal length *PCL* (Goldman and Musick 2006) in the ENP and can weigh upwards of 220 kg. Length-at-maturity in the WNP is approximately 140-cm *PCL* for males and 170–180 cm *PCL* for females (Tanaka 1980), and these lengths correspond to approximate ages of 5 years and 8–10 years, respectively. Length-at-maturity in the ENP is 125–145 cm *PCL* (3–5 years) for males and from 160–180 cm *PCL* (6–9 years) for females (Goldman and Musick 2006). Salmon sharks in the ENP and WNP attain the same maximum length (approximately 215-cm *PCL* for females and about 190-cm *PCL* for males). However, males larger than approximately 140-cm *PCL* and females larger than approximately 110-cm *PCL* in the ENP attain a greater weight-at-length than their same-sex counterparts in the WNP (Goldman and Musick 2006).Tanaka (1980) (see also Nagasawa 1998) determined that maximum age from vertebral analysis of WNP salmon sharks is at least 25 years for males and 17 years for females, and von Bertalanffy growth coefficients are 0.17 and 0.14 for males and females, respectively. Goldman and Musick (2006) gave maximum ages for ENP salmon sharks (also from vertebral analysis) of 17 years for males and 30 years for females, with growth coefficients of 0.23 and 0.17 for males and females, respectively. It should be noted that salmon shark ages estimated from growth-zone counts in vertebral centra have yet to be independently validated, and as such all reported ages should be regarded as unconfirmed.

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

Spiny Dogfish

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

Spiny dogfish grow to a maximum size of 160 cm in the ENP (Compagno 1984). The estimated age-at-50% maturity of spiny dogfish in the GOA is 36 years for females and 21 years for males (Tribuzio and Kruse 2012), similar to estimates from 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, $\kappa = 0.03$ for females and 0.06 for males (Tribuzio et al. 2010b). Spiny dogfish is the only species within the shark stock complex that has been age-validated (Campana et al. 2006).

The mode of reproduction for spiny dogfish is 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 occurs between February and April (Kaganovskaia 1937, Yamamoto and Kibezaki 1950). Off of Washington State, spiny dogfish have a long pupping season, which peaks from October to November (Tribuzio et al. 2009). Pupping is believed to occur in estuaries and bays or in mid-water over depths of approximately 165–370 m (Ketchen 1986). Small juveniles and young-of-the-year tend to inhabit the water column near the surface or areas not fished commercially and are therefore not available to commercial fisheries until they grow or migrate to fished areas (Beamish et al. 1982, Tribuzio and Kruse 2012). The average litter size is 8.5 pups for spiny dogfish in the GOA (Tribuzio and Kruse 2012), 6.9 in Puget Sound, WA (Tribuzio et al. 2009), and 6.2 in BC (Ketchen 1972). The number of pups per female also increases with the size of the adult female, with estimates ranging from 0.20–0.25 more pups for every additional centimeter in length (Ketchen 1972, Tribuzio et al. 2009, Tribuzio and Kruse 2012).

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 96 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 19.2).

Directed Fishery, Effort and CPUE

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

Current Incidental Fishery

Historical catches of sharks in the BSAI are composed entirely of incidental catch. Pacific sleeper shark have been the primary species of shark incidentally caught in the BSAI by weight; although, in recent years, salmon shark have made up a greater proportion of the total shark catch, particularly in 2020 (Table 19.3, Figure 19.2). This trend is mirrored in the GOA. At this point, it is unclear what is driving the increased salmon shark catch. A potential cause is that catch from catcher-vessels in the walleye pollock trawl fishery that are participating in the Electronic Monitoring Exempted Fishing Permit program are reporting higher catches than in the past. Through the development of the program, gaps in observer coverage were identified where large sharks may not have been counted previously.
Nearly all of the shark catch within the BSAI occurs in the Bering Sea (Figure 19.3). Pacific sleeper shark and spiny dogfish are caught primarily in the Pacific cod longline and the walleye pollock (*Gadus chalcogrammus*) trawl fisheries (Figure 19.4). Salmon shark are almost entirely caught in the walleye pollock fishery (Figure 19.4).

The other/unidentified shark category is difficult to assess. Most of the "other" shark species are rare and likely anomalous. Since 2003, there has been one basking shark (*Cetorhinus maximus*), one brown cat shark (*Apristurus brunneus*) and six bluntnose six-gill sharks (*Hexanchus griseus*) observed in the BSAI. Catch estimated 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. With the exception of 2006, incidental catch of "other" sharks is relatively split between the walleye pollock trawl fishery and Pacific cod longline fishery (Figure 19.4).

Sharks are not targeted and therefore catch is driven by other fisheries that incidentally capture the species. As such, shark catch generally occurs in two main pulses coinciding with late winter and late summer/early autumn walleye Pollock fisheries (Figure 19.5). However, in the last two years, the late winter catch has been minimal and most catch has occurred later in the year. Over the last 10 years, about 15% of the catch occurs after data are queried for use in the assessment (approximately October 1st of each year).

Distribution of Catch in Fisheries

Observer data were mapped to analyze spatial distribution of shark 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 2016 – 2019 (data can be found here: https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map).

Incidental catch of Pacific sleeper sharks within observed BSAI commercial fisheries primarily occurs in NMFS areas 517 and 531, along the western edge of the EBS shelf (Figure 19.6). The largest incidental catches of Pacific sleeper shark tended to occur in hauls on the southern shelf as well as a few scattered hauls in the AI. However, the observed catches in NMFS areas 541–543, while rare, tended to be larger animals.

Salmon shark incidental catch rate in the Bering Sea is generally low. Salmon shark occur in a small number of hauls, with 94% of hauls in which salmon shark are observed reporting only one shark (Figure 19.7). Most of the catch occurs in NMFS areas 517 and 521 along the EBS shelf break and the shelf waters in the EBS outside of Bristol Bay in NMFS area 509. Each year since 2014 there have been a small number of hauls with large catches of salmon sharks in the southern Bering Sea, occurring near Unimak Pass or along the Alaska Peninsula.

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 19.8). Spiny dogfish bycatch occurs throughout the EBS shelf, generally along the shelf break and northwest from Unimak Pass; however, the majority of observed catch is farther south, near Unimak Pass and along the Alaska Peninsula.

Observed bycatch of other/unidentified sharks within commercial fisheries in the EBS is generally patchy and rare and has declined in recent years (Figure 19.9), owing to improved species identification. Hauls reporting catch of other/unidentified sharks are generally near the EBS shelf edge, with some larger hauls occurring near the southern end of the shelf. During the years 2016–2019 only one “other” shark, a brown cat shark, was observed and identified to species.

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 (rates in Table 19.4). Over the last 10 years, 100% of the catch has been discarded in the Aleutian Islands (AI), and >90% in the Bering Sea, with the exception of other/unidentified sharks, which are discarded at a lower rate (62% on average, <2 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 10 t of sharks have been retained annually on average over the last 10 years about 6 t of which is Pacific sleeper shark, and nearly all is used for fishmeal (C. Tide, AKRO, pers. comm.). Mortality rates of discarded sharks are unknown but are conservatively estimated in this report as 100%. This assumption is supported by tag releases of Pacific sleeper shark captured on catcher-vessels in the pollock fishery. A total of 10 fish were tagged; all appeared dead at time of release or died shortly after (Tribuzio, unpublished data). The lower discard rate for spiny dogfish in 2020 is likely due to the extrapolation, as opposed to increased retention. Only two observed hauls reported retention of a single spiny dogfish each in 2020.

Data

Data for sharks were obtained from the following sources:

Source	Data	Years
AKRO Catch Accounting System	Nontarget Catch	2003 – 2020
NMFS Bottom Trawl Surveys –Eastern Bering Sea Shelf (Annual)	Biomass Index	1979 – 2019
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 – 2020
IPHC Longline Surveys	Abundance Index	1997 – 2019

Fishery

Incidental shark catches by species are reported in two distinct time series: 1997–2002, estimated by staff at the AFSC using the "improved pseudo-blend" approach (Gaichas 2001, 2002), and 2003–present, estimated by the NMFS AKRO Catch Accounting System (CAS). The "improved pseudo-blend" time series is no longer used in this assessment, but are available in previous assessments (Tribuzio et al. 2018). Estimates generated by CAS are updated retroactively, as input data are error-checked and as improvements to CAS are made. The catch estimates used in this assessment are presented in Table 19.3. Further, sharks were not always identified to species; 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 (< 1%) (Table 19.3).

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 19.2 and Table 19.3). The restructured observer program went into effect in 2013. This restructuring increased observer coverage on vessels < 60 ft in length as well as incorporated those participating in the Pacific halibut IFQ fishery into the program. Because a large portion of shark catch originates from the vessels now included in the observer program, the catch time series beginning in 2013 may not be comparable to prior catch time series for sharks. While vessels participating in the Pacific halibut IFQ fishery in the BSAI are now included, the majority of the change in the composition of catch after observer restructuring went into effect was due to increased coverage in small vessels targeting Pacific cod (*Gadus macrocephalus*).

Catch by area and target fishery are shown in Figure 19.3 and Figure 19.4, respectively.

Survey

Catch at Length

The shark stock complex is in Tier 6, and so 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 specification procedures. Length data for spiny dogfish and salmon shark are rare in the BSAI, and thus are not presented in this assessment.

The authors have compiled length data for Pacific sleeper sharks from standard and non-standard AFSC trawl surveys in the GOA and BSAI, the Northwest Fisheries Science Center (NWFSC) groundfish trawl survey off the U.S. West Coast, and International Pacific Halibut Commission (IPHC) longline surveys. 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, likely immature, animals (50 – 200 cm *TL*) are caught coast-wide; larger fish, those >250-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 19.10).

Similarly, the average weight per animal captured in the AFSC trawl surveys is consistent from 1980–2018, with most animals being <100 kg (Figure 19.11). 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.

AFSC Trawl Survey Biomass Estimates

Biomass estimates are available for shark species from NMFS AFSC bottom trawl surveys conducted in the BSAI on the EBS slope (2002–2016; Table 19.5 and Figure 19.12), the AI (1980-2018, Table 19.6 and Figure 19.12) and the EBS shelf (1979–2019, Table 19.7 and Figure 19.12). We are not including the earlier time series of the EBS slope survey (1979–1991) because the earlier time series used a different gear type, survey strata, and survey design; thus, the estimates are not comparable to the modern time series. The EBS shelf survey is annual, but the EBS slope and AI surveys take place as funding allows.

Sharks in the BSAI may not be sampled well by bottom trawl surveys. In many years, surveys fail to capture a single specimen of some shark species. As a result, the estimation procedure often produces a biomass of zero or biomass estimates with high levels of uncertainty, and trends in biomass estimates from trawl surveys are not informative. Spiny dogfish, for example, occurred in < 1% of 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 or they may occupy depths outside those surveyed. As a result, biomass estimates are uncertain because the gear may not efficiently capture this species. These surveys are not informative for spiny dogfish because they are rarely caught in the trawl surveys. However, catches are reported in the observer data and in other surveys sampling the same area; differences in catch rates are likely due to gear differences, as spiny dogfish may be more susceptible to longline gear.

Pacific sleeper sharks are the most commonly caught shark species within BSAI surveys. They are most consistently caught on the EBS slope survey; however, the number of hauls with Pacific sleeper sharks has declined since 2008, with the lowest biomass estimate of the time series in 2016 (Table 19.5and Figure 19.12). Pacific sleeper sharks are also captured consistently in NMFS bottom trawl surveys in the AI (Table 19.6), 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 19.5 and Figure 19.12). Pacific sleeper sharks are not often caught during the annual EBS shelf survey (Table 19.7 and Figure 19.12).

Spiny dogfish 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 19.5 and Figure 19.12). Spiny dogfish are caught sporadically in the AI (Table 19.6 and Figure 19.12) and EBS shelf surveys (Table 19.7 and Figure 19.12).

Longline Surveys

The IPHC conducts a longline survey each year to assess Pacific halibut (*Hippoglossus stenolepis*). This is a fixed-station survey that samples depths 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 Goen et al. (2018). The IPHC survey is likely the most informative survey for the shark species in the BSAI because it reliably catches Pacific sleeper shark and spiny dogfish. There was no survey conducted in the BSAI in 2020 due to COVID-19; data are updated through the 2019 survey (Table 19.8).

Relative population numbers (RPNs) for spiny dogfish and Pacific sleeper shark were calculated using the same methods 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., EBS and AI separately). The CPUE was then multiplied by the area size of that stratum, obtained from the AFSC trawl survey program. A FMP-wide RPN was calculated by summing the RPNs for all strata in the area, and confidence limits were estimated by bootstrap resampling the stations within each region.

For Pacific sleeper sharks, which are the primary shark species caught in the BSAI, EBS RPNs from the IPHC survey declined steeply from the late 1990s through 2004 and then remained at low levels since 2005 (Figure 19.13). Almost all of the IPHC survey catch of sharks occurs in the Bering Sea and only limited catch occurs in the AI. The 2017 RPN was much greater than in recent years, but large confidence intervals in that year indicate a high degree of uncertainty in the estimate. Spiny dogfish are not commonly caught in the IPHC survey in the BSAI, with no catch in the AI since the 2014 survey. Salmon sharks are extremely rare in the IPHC survey, thus the RPNs do not provide useful information.

The AFSC longline survey samples fixed stations in the EBS in odd years and the AI in even years (survey protocol can be found here: https://www.fisheries.noaa.gov/resource/document/survey-protocol-alaska-sablefish-longline-survey). 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.

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 during the IPHC longline survey (Figure 19.14) and NMFS trawl surveys (Figure 19.15) 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 AI (Figure 19.16). The IPHC survey catches spiny dogfish regularly along the AI, but in small numbers. Spiny dogfish are rarely caught in the AFSC trawl or longline surveys in the BSAI and 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 OFL for the BSAI is based on the maximum of the aggregate shark complex catch, as determined by the Plan Team (November 2010) and supported by the SSC (December 2010). As per Amendment 56, the harvest control rule dictates that the ABC is 75% of the OFL. The assessment began using the maximum of the catch history from 1997 – 2007 to determine OFLs for the 2011 fishery (Tribuzio et al. 2010a). The model currently in use was accepted for the 2016 stock assessment (Tribuzio et al. 2016), and following the model-naming convention, it is henceforth termed Model 16.0. Model 16.0 uses the maximum of the catch history from 2003 – 2015 to determine the OFL. The more recent and abbreviated time series is due to substantial concerns regarding the accuracy of catch estimates prior to 2003.

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

Description of Alternative Models

We are including three alternative models in the 2020 assessment. In the 2018 assessment, alternative models using the mean historical catch (Model 18.0), the 95% and 99% confidence intervals (Models 18.1 and 18.2, respectively) were presented. There were concerns over the non-normality of the data and those models were not selected in the 2018 assessment. As a result, the SSC requested that the 2020 assessment include harvest specification options using the 5th and 95th percentile of the catch history data from 2003–2015. We present the median historical catch as a model alternative as well. Models 20.0, 20.1 and 20.2 are calculated at the complex level.

Alternative Models	OFL	Equation
20.0	Median complex catch 2003–2015	$OFL = med(C_{2003-2015})$
20.1	5th percentile of the complex catch 2003–2015	$OFL = P_5(C_{2003-2015})$
20.2	99th percentile of the complex catch 2003–2015	$OFL = P_{99}(C_{2003-2015})$

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 19.9). Estimates are not available for BSAI stocks, and thus, GOA or North Pacific values are used as proxies. Parameters include weight-at-length, length-at-age, natural mortality (*M*), maximum age, and age at first recruitment. Weight at length and average length model 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 applicable for 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. To mitigate this risk, Model 16.0 was adopted as the maximum of the full complex catch, as opposed to the sum of the individual species maximum catches, resulting in a more conservative OFL.

Models 20.0 and 20.1 are substantially more conservative than Model 16.0 (table below) and there are a number of reasons to consider a more conservative model. Given the life-history and declining survey indices, there are indications of a potential conservation concern for Pacific sleeper shark. Also, for Pacific sleeper shark, ongoing research suggests that, at least in one fishery, catch estimates may be biased low. Preliminary data analysis of the actual size of Pacific sleeper sharks caught, but not brought onboard and made available to observer to weigh, in longline fisheries is larger than the mean size used for those sharks. Data are still being collected to address this question. Another consideration in the accuracy of the catch is that catch is estimated in metric tons, but, especially in the longline fisheries as described before, catches in numbers may be more accurate. Preliminary comparisons of catch estimates in numbers and weight suggest that in some cases, as numbers of sharks increase, the total catch weight does not increase. One interpretation of this is that a large number of very small Pacific sleeper sharks are being caught, while another is that the catch estimates in weight may be biased. The author is conducting detailed analyses of catch in numbers compared to catch in weight.

However, there are reasons to retain Model 16.0. No conservation concern has been established, and it is unclear if current catch rates are sustainable. A number of research projects are ongoing to examine the accuracy of catch estimates but are not yet complete. Models 20.0 and 20.1 would result in an OFL that could restrict other fisheries, and the lack of data at this time does not indicate the need to do that. The species in the shark complex are "undesirable," and there is no directed fishing because there is little to no value to promote retention.

Model 20.2 can be considered as a slightly more conservative alternative to Model 16.0 and less conservative than Model 20.0. While catch history scalars are a high risk for data-limited species, choosing a different catch scalar method, such as Model 20.2, will have minimal impact on catch rates because current catches are well below current ABC, as well as the calculated ABC from Model 20.2.

The below table summarizes the OFLs and ABCs from the four models presented here. The individual species values are shown here for information purposes only and are not used in the harvest recommendations.

Species	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/Unidentified shark	Total shark Complex*
Maximum Catch (t)	24	421	199	305	689
Model 16.0 OFL	24	421	199	305	689
Model 16.0 ABC	18	315	149	229	517
Median Catch (t)	8	68	44	13	151
Model 20.0 OFL	8	68	44	13	151
Model 20.0 ABC	6	51	33	10	113
5th Percentile	5	38	19	2	82
Model 20.1 OFL	5	38	19	2	82
Model 20.1 ABC	4	30	14	1	61
99th Percentile	276	411	184	23	677
Model 20.2 OFL	276	411	184	23	677
Model 20.2 ABC	207	308	138	17	508

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

Harvest Recommendations

We recommend Model 16.0 for the 2021–2022 harvest specifications. 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.

Amendment 56 Reference Points

The BSAI sharks is a Tier 6 complex, thus the only reference point is that which is used to set the Tier 6 OFL, the maximum catch from 2003–2015 of 689 t.

Specification of OFL and Maximum Permissible ABC

Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021	2022
Tier	6	6	6	6
OFL (t)	689	689	**689**	689
maxABC (t)	517	517	517	517
ABC (t)	517	517	**517**	517

Risk Table and ABC Recommendation

Overview

The following template is used to complete the risk table:

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

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

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

Assessment Considerations

All of the species in the shark complex are Tier 6. This complex is severely data-limited, and the assessment does not incorporate life history or any other biological information in the OFL/ABC calculations. For non-targeted, low value (i.e., discarded) species, a catch-scalar approach may suffice if the species is sufficiently productive to be sustainably harvested at that rate. For Pacific sleeper sharks, it is unclear how productive the species is, and indications are that it is highly vulnerable to overfishing. There are concerns over the accuracy of the catch estimates due to the difficulty in sampling such large species. Because the assessment for the sharks in the BSAI do not incorporate any biological or trend information, we consider this a level 2 concern.

Population Dynamics Considerations

The only informative indicator of stock trends is the IPHC longline survey RPNs. The index is not included in considerations of OFL within this assessment. The Pacific sleeper shark RPNs declined from their peak at the beginning of the time series and have remained low since 2004. This trend is mirrored in other regions (e.g., GOA, Canada and U.S. West Coast) of the IPHC survey and in other surveys, such as the ADF&G Southeast Alaska longline survey (see GOA shark SAFE). It is unclear if the peak at the beginning of the time series was unusual, or if the current low state reflects low population sizes. We consider this a level 2 concern for Pacific sleeper shark because of the potential vulnerability of the species and low productivity; however, we acknowledge that stock status is unknown. We consider the rest of the species in the complex to be level 1. The population dynamics risk level for the full complex is rated a Level 2, representing the most concerning value for the species.

Environmental/Ecosystem Considerations (contributions from Bridget Ferris, Ivonne Ortiz, and Ellen Yasumiishi)

The BSAI shark complex consists mostly of Pacific sleeper shark and salmon shark. Smaller Pacific sleeper sharks (<1m) are found in the Bering Sea along the slope, suggesting a possible important rearing habitat for younger sharks. However, tagging studies suggest that these sharks are highly mobile.

Water temperatures may impact shark abundances, linked through prey abundances, as opposed to direct impacts on growth or survival. Sharks are either highly mobile and able to shift distributions with temperatures, or in the case of salmon shark, endothermic such that they can tolerate a wide range of temperatures. Foraging conditions for sharks during 2020 are considered average due to limited temperature and prey information. Sea surface temperatures were about 1°C above normal in the central and eastern Bering Sea and 3°C above average in nearshore waters of Norton Sound and Bristol Bay during the 2020 summer (Alaska Center for Climate Assessment & Policy ACCAP, Thoman personal communication). In the BSAI, the AFSC Longline Survey Subsurface Temperature Index indicates above average temperatures at the surface and at depth (250 m) in 2020 relative to the 2005–2019 time series, and cooler temperatures in 2020 relative to 2019 (Siwicke, personal communication). This survey samples stations in the AI in odd years and the Bering Sea slope in even years.

Sharks are opportunistic feeders. Preferred prey items vary by species and size. Pacific sleeper sharks feed on fish, squid, and carrion, while salmon sharks feed on Pacific salmon and walleye pollock. Sharks are able to prey-switch depending on what species of prey are most abundant at the time. They are more likely to act as a "boom" buffer, by feeding on highly abundant species, than they are to cause substantial impacts on low abundant species. Thus, zooplankton indicators, while informative for lower trophic level species, are less meaningful for sharks.

The 2020 foraging conditions for sharks were likely average, although data are limited, for the predominately fish eating sharks in the BSAI. We scored this category as Level 1, as normal concern.

Fishery Performance

Defining fishery performance indicators is difficult for non-targeted, low retention species, especially when confounded with concerns over accuracy of catch estimates. We examined the mean catch of sharks per trip (or more accurately landings event) by species as a possible index of fishery performance through time, with one caveat being that fish size may fluctuate through time. Within the BSAI, Pacific sleeper sharks mean catch per trip has been flat or variable with no apparent trend since 2010, however, current levels (~0.05 t per trip) are substantially lower than those in the earlier part of the time series (~0.17 t per trip). This tracks the total catch per year in Figure 19.2 and the IPHC survey in Figure 19.13. When examining mean catch per trip of Pacific sleeper sharks by gear and target fishery, there are some trends. Initially, the greatest mean catches were from longline fisheries (primarily Pacific cod), but over the last ten years the greatest mean catch has been in the non-pelagic trawl fisheries (primarily Atka mackerel *Pleurogrammus monopterygius* and flatfish). The non-pelagic trawl walleye pollock fishery mean catch per trip has declined steeply since 2016. The mean catch per trip of salmon shark has been increasing within the walleye pollock fisheries (pelagic trawl gear in particular) since 2010. Spiny dogfish are sparse in the BSAI and were not evaluated. In summary, if the mean catch of sharks per trip is considered an indicator of fishery performance, then Pacific sleeper shark is currently stable and salmon shark is increasing.

The ABCs for the shark complex have not been exceeded and have not limited other fisheries. Because of the Tier 6 methods used, they are unlikely to be exceeded. The fishery performance indicators are a risk level 1.

Summary and ABC recommendation

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

The above levels of concern do not warrant an ABC reduction at this time. There are a number of ongoing projects aimed at informing and improving this stock assessment, for Pacific sleeper shark in particular. We do not recommend any reductions in the ABC until alternative assessment methods have been proposed and discussed.

Status Determination

Overfishing is not occurring because catch has not exceeded the OFL for this Tier 6 complex.

Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

Ecosystem Considerations

The ecosystem considerations for the BSAI shark stock complex are summarized in Table 19.10.

Ecosystem Effects on Stock

Pacific sleeper shark

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

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

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

Salmon Shark

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

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

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

Spiny dogfish

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

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

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

Fishery Effects on Ecosystem

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

Data Gaps and Research Priorities

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

1. Catch estimation for large, hard to measure species.
    a. Actions: Investigating catch in numbers for Pacific sleeper sharks and exploring management options.
    b. Actions: Funded study to examine using EM to improve catch estimates in numbers of large sharks.
    c. Actions: Ongoing project to examine how frequent “other” sharks are caught, and if species IDs can be improved.
2. Define the stock structure and migration patterns (i.e., tagging and genetic studies)
    a. Actions: Analyses of a tagging and migration study of spiny dogfish.
    b. Actions: Genetic stock structure study of Pacific sleeper shark using genomics and next generation DNA sequencing.
    c. Actions: Collaborating with ADF&G on salmon shark tagging and migration studies.
3. Explore ageing methods for difficult to age species
    a. Actions: Pilot study underway to examine using 14C (bomb-radiocarbon) in the eye lens core of Pacific sleeper shark as an indicator of age. Proposals have been submitted to fully fund the study.

Acknowledgments

We gratefully acknowledge the following individuals for their timely and efficient work in providing data and input for shark species: Bridget Ferris, Ivonne Ortiz and Ellen Yasumiishi (AFSC) for their contributions to the Ecosystem Considerations sections; Sarah Webster (ADF&G) for the shark state-wide harvest survey/sport catch estimates; staff at the IPHC for providing longline survey data; Bob Ryzner, Rob Ames, Niels Leuthold and Jean Lee (AKFIN, Pacific States Marine Fisheries Commission) provided a user friendly portal to access Catch Accounting System data and multiple AFSC survey data sources; Jason Gasper and Jacob Van Baalen (AKRO) for rapid responses to catch data needs and the Catch Accounting System for all things catch estimates.

Literature Cited

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

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

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

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

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

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.

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

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

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

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

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.

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

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

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

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

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

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

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

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.

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

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

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.

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

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.

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

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

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

Ebert, D. A. 2002. Some observations on the reproductive biology of the sixgill shark *Hexanchus griseus* (Bonnaterre, 1788) from southern African waters. South African Journal of Marine Science 24:359-363.

Ebert, D.A., Goldman, K.J. & Orlov, A.M. 2009. *Somniosus pacificus*. The IUCN Red List of Threatened Species 2009: e.T161403A5416294. http://dx.doi.org/10.2305/IUCN.UK.2009-2.RLTS.T161403A5416294.en

Ebert, D.A., T.W. White, K.J. Goldman, L.J.V. Compagno, T.S. Daly-Engel and R.D. Ward. 2010. Resurrection and redescriptions of *Squalus suckleyi* (Girard, 1854) from the North Pacific, with comments on the *Squalus acanthias* subgroup (Squaliformes: Squalidae). Zootaxa. 2612:22-40.

Erikson, L., and R. Webster. 2019. IPHC fishery-independent setline survey (FISS) design and implementation in 2019. IPHC-2019-IM095-06. 8pgs.

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.

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

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.

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

Gasper, J.R. and G.H. Kruse. 2013. Modelling the spatial distribution of Pacific spiny dogfish (*Squalus suckleyi*) in the Gulf of Alaska using generalized additive and generalized linear models. Can. J. Fish. Aquat. Sci. 70:1372-1385.

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

Goen, J., T. Geernaert, E. Henry, E. Soderlund, A.M. Ranta, T.M. Kong, and J. Forsberg. 2018. Fishery-independent setline survey (FISS) design and implementation in 2017, including current and future expansions. IPHC-2018-AM094-06

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.

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

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

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

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

Hazen, E. L., S. Jorgensen, R. R. Rykaczewski, S. J. Bograd, D. G. Foley, I. D. Jonsen, S. A. Shaffer, J. P. Dunne, D. P. Costa, L. B. Crowder, and B. A. Block. 2012. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change 3:234-238.

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.
Horning, M., and J. A. E. Mellish. 2014. In cold blood: evidence of Pacific sleeper shark (*Somniosus pacificus*) predation on Steller sea lions (*Eumetopias jubatus*) in the Gulf of Alaska. Fishery Bulletin 112:297-310.
Hulbert, L., 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.
Indian Ocean Tuna Commission. 2016. Blue shark supporting information. Available at http://www.iotc.org/sites/default/files/documents/science/species_summaries/english/Blue%20shark%20Supporting%20Information.pdf
Kaganovskaia, S. M. 1937. On the commercial biology of *Squalus acanthias*. Izv. Tikhookean. Nauch. Issled. Inst. Ryb. Khoz. Okeanogr. 10:105-115.
Ketchen, K. S. 1972. Size at maturity, fecundity, and embryonic growth of the spiny dogfish (*Squalus acanthias*) in British Columbia waters. J Fish Res Bd 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.
Koefoed, E. 1957. A uterine foetus and the uterus from a Greenland shark. Notes on the Greenland shark *Acanthorhinus carcharias* (Gunn). Report on Norwegian Fishery and Marine Investigations 11:8-12.
Loughlin, T. R., and A. E. York. 2000. An accounting of the sources of Steller sea lion, *Eumetopias jubatus*, mortality. Marine Fisheries Review 62:40-45.
Love, M. S., C. W. Mecklenburg, T. A. Mecklenburg, and L. K. Thorsteinson. 2005. Resource inventory of marine and estuarine fishes of the West Coast and Alaska: A checklist of North Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon border. US Department of the Interior, US Geological Survey, Biological Resources Division, Seattle, WA.
Máquez-Farias, J. F., D. Corro-Espinosa, and J. L. Castillo-Géniz. 2005. Observations on the Biology of the Pacific Sharpnose Shark (*Rhizoprionodon longurio*, Jordan and Gilbert, 1882), Captured in Southern Sinaloa, México. Journal of Northwest Atlantic Fishery Science 35:107-114.
Matta, M. E., C. A. Tribuzio, D. A. Ebert, K. J. Goldman, and C. M. Gburski. 2017. Age and growth of elasmobranchs and applications to fisheries management and conservation in the northeast Pacific Ocean. Pages 179-220 in S. Larson and D. Lowry, editors. Northeast Pacific Shark Biology, Research and Conservation Part A. Academic Press.
McClain, C. R., M. A. Balk, M. C. Benfield, T. A. Branch, C. Chen, J. Cosgrove, A. D. Dove, L. C. Gaskins, R. R. Helm, F. G. Hochberg, F. B. Lee, A. Marshall, S. E. McMurray, C. Schanche, S. N. Stone, and A. D. Thaler. 2015. Sizing ocean giants: patterns of intraspecific size variation in marine megafauna. PeerJ 3:e715.
McFarlane, G. A., and J. R. King. 2003. Migration patterns of spiny dogfish (*Squalus acanthias*) in the North Pacific Ocean. Fishery Bulletin 101:358-367.
Mecklenburg, C.W., T.A. Anthony, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda Maryland 1037 pp.
Musick, J. A., G. Burgess, G. Cailliet, M. Camhi, and S. Fordham. 2000. Management of sharks and their relatives (Elasmobranchii). Fisheries 25:9-13.Nagasawa, K. 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean. Bulletin of the North Pacific Anadromous Fish Commission, No. 1:419-433.
Nakano, H., and K. Nagasawa. 1996. Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. Fisheries Science 62:860-865.

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

Natanson, L. J., A. H. Andrews, M. S. Passerotti, and S. P. Wintner. 2019. History and mystery of age and growth studies in elasmobranchs: Common methods and room for improvement. Pages 177-199 in J. C. Carrier, M. R. Heithaus, and C. A. Simpfendorfer, editors. Shark research: emerging technologies and applications for the field and laboratory. CRC Press, New York, NY.

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

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

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

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

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

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

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

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.

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

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

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

Smith, C. R., A. R. Baco, and A. G. Glover. 2002. Faunal succession on replicate deep-sea whale falls: time scales and vent-seep affinities. Cahiers De Biologie Marine 43:293-297.

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

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

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

Tanaka, S. 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., K. Echave, C. Rodgveller, P.J. Hulson. 2016. Assessment of the shark stock complex in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands for 2012. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. Pgs. 1915-1962.

Tribuzio, C. A., 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.

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

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

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

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

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

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

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

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

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

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

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

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. 2004. A review of the systematics of the sleeper shark genus *Somniosus* with redescriptions of *Somniosus (Somniosus) antarcticus* and *Somniosus (Rhinoscymnus) longus* (Squaliformes: Somniosidae). Ichthyological Research 51:360-373.

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

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

Tables

Table 19.1. Biological characteristics and depth ranges for shark species in the eastern Bering Sea and Aleutian Islands (BSAI). The life history data reported in this table are specific to the Northeastern Pacific Ocean when available; however, some data sources are from other regions (e.g., North Atlantic) for poorly studied species. TL is total length with the tail in a natural position, TLext is total length with the tail extended, and PCL is pre-caudal length. Missing information is denoted by "?".

Scientific Name	Common Name	Maximum Length (TL, cm)	Maximum Age (yr)	Age, Length at 50% Maturity	Feeding Mode	Fecundity	Depth Range (m)
Lamna ditropis	Salmon shark	310[1]	20[2]	♀6-9 yr, 165 cm PCL ♂3-5 yr, 124 cm PCL[2]	Predator[3]	4-5[4]	0-1864[1]
Somniosus pacificus	Pacific sleeper shark	700[5]	?	♀370 cm TL[6]	Predator/Benthic/Scavenger[7]	?	0-≥2,000[5]
Squalus suckleyi	Pacific spiny dogfish	160[5]	80-107[8]	♀36 yr, 97.3 cm TLext ♂21 yr, 74.5 cm TLext[8]	Predator/Benthic/Scavenger[9]	7-14[8]	0-1,244[1]
Apristurus brunneus	Brown cat shark	71[1]	?	♀50.1 cm TL, ♂51.4 cm TL[10]	Benthic[11]	?	33-1,306[1]
Cetorhinus maximus	Basking shark	1,227[12]	?	♀8.1-9.8 m TL, ♂4.0-5.0 m TL[5]	Plankton[3]	34[13]	0-1,500[14]
Hexanchus griseus	Bluntnose sixgill shark	550[12]	?	♀421 cm TL[15]	Predator[3]	22-108[15]	0-2,500[1]
Prionace glauca	Blue shark	380[1]	25[16]	♀5-7 yr, 194 cm TL, ♂4-7 yr, 201 cm TL[16]	Predator[3]	4-135[16]	0-350[1]
Rhizoprionodon longurio	Pacific sharpnose shark	154[5]	?	♀92.9 cm TL, ♂100.6 cm TL[17]	Predator/Benthic[18]	1-12[18]	0-100[19]

[1] Stevenson et al. (2007)
[2] Goldman & Musick (2006)
[3] Cortes (1999)
[4] Gallucci et al. (2008)
[5] Compagno (1984)
[6] Ebert et al. (1987)
[7] Sigler et al. (2006)
[8] Tribuzio & Kruse (2012)
[9] Tribuzio et al. (2017)
[10] Flammang et al. (2008)
[11] Mecklenburg et al. (2002)
[12] McClain et al. (2015)
[13] Ali et al. (2012)
[14] Doherty et al. (2019)
[15] Ebert (2002)
[16] Indian Ocean Tuna Commission (2016)
[17] Corro-Espinosa et al. (2011)
[18] Máquez-Farias et al. (2005)
[19] Love et al. (2005)

Table 19.2. Time series of Other Species Total Allowable Catch (TAC), Other Species and shark catch, and Acceptable Biological Catch (ABC) for sharks and the shark species complex (management method) for 1997–2020. All data queried through AKFIN Oct 13, 2020.

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	588	N/A	Other Species TAC
2004	27,205	29,455	516	N/A	Other Species TAC
2005	29,000	29,483	417	N/A	Other Species TAC
2006	29,000	27,018	688	N/A	Other Species TAC
2007	37,355	26,800	332	463	Other Species TAC
2008	50,000	29,474	193	463	Other Species TAC
2009	50,000	27,883	152	447	Other Species TAC
2010	50,000	23,374	61	449	Other Species TAC
2011	50		108	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		106	1,022	Shark Complex TAC
2016	125		132	1,022	Shark Complex TAC
2017	125		140	517	Shark Complex TAC
2018	180		102	517	Shark Complex TAC
2019	180		150	517	Shark Complex TAC
2020	150		198	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.

Table 19.3. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species as of October 13, 2020. Estimates are provided by NMFS AKRO blend-estimated annual catches, queried through AKFIN.

Year	Pacific Sleeper Shark	Salmon Shark	Spiny Dogfish	Other Sharks	Total
2003	342	199	13	34	588
2004	421	26	9	60	516
2005	333	47	11	26	417
2006	313	63	7	305	688
2007	257	44	3	28	332
2008	127	41	17	8	193
2009	51	71	20	10	152
2010	28	12	15	6	61
2011	48	47	8	5	108
2012	47	26	20	3	96
2013	68	23	24	1	116
2014	63	52	19	2	136
2015	62	33	8	3	106
2016	80	48	6	1	135
2017	56	73	10	1	140
2018	40	51	10	1	102
2019	53	92	4	1	150
2020	65	129	2	2	198

Table 19.4. Estimated discard rates of sharks (by species) in the BSAI. The mean is calculated for the last 10 years (2011-2020). Source: AKFIN database, Oct 13, 2020. Blanks are where there was no catch reported.

FMP Subarea	Year	Pacific Sleeper Shark	Salmon Shark	Spiny Dogfish	Other Sharks	All Sharks
Aleutian Islands	2003	99%	40%	100%	0%	99%
	2004	100%		100%	100%	100%
	2005	100%	100%	100%		100%
	2006	100%	100%	100%		100%
	2007	100%	100%	99%		100%
	2008	100%		100%		100%
	2009	100%	100%	100%	100%	100%
	2010	100%	100%	100%		100%
	2011	100%	100%	100%		100%
	2012	100%	100%	100%		100%
	2013	100%	100%	100%		100%
	2014	100%	100%	100%		100%
	2015	100%	100%	100%		100%
	2016	100%	100%	100%		100%
	2017	100%	100%	100%		100%
	2018	100%	100%	100%	100%	100%
	2019	100%	100%	100%		100%
	2020	100%	100%	100%		100%
	Mean	100%	96%	100%	100%	100%
Bering Sea	2003	78%	98%	83%	87%	86%
	2004	98%	94%	98%	97%	97%
	2005	96%	97%	99%	74%	95%
	2006	95%	98%	98%	97%	96%
	2007	93%	99%	98%	47%	90%
	2008	94%	97%	100%	47%	93%
	2009	96%	100%	99%	63%	96%
	2010	92%	96%	100%	31%	89%
	2011	85%	93%	99%	57%	89%
	2012	81%	91%	99%	60%	87%
	2013	91%	96%	100%	66%	94%
	2014	91%	95%	100%	71%	93%
	2015	93%	97%	97%	78%	94%
	2016	91%	97%	89%	42%	93%
	2017	86%	98%	100%	66%	93%
	2018	78%	92%	100%	22%	87%
	2019	91%	97%	100%	44%	95%
	2020	87%	96%	43%	72%	92%
	Mean	90%	96%	95%	62%	92%

Table 19.5. AFSC Eastern Bering Sea slope trawl survey estimates of individual shark species total biomass (metric tons) with coefficient of variation (CV), and number of hauls. There was no survey in 2018 or 2020 (AKFIN, queried October 13, 2020).

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

Table 19.6. AFSC Aleutian Islands trawl survey estimates of individual shark species total biomass (metric tons) with coefficient of variation (CV), and number of hauls (AKFIN, queried October 13, 2020). There was no survey in 2020.

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

Table 19.7. AFSC Eastern Bering Sea shelf trawl survey estimates of individual shark species total biomass (metric tons) with coefficient of variation (CV) and number of hauls (AKFIN, queried October 13, 2020). There was no survey in 2020.

		Spiny Dogfish			Pacific Sleeper Shark		
Year	Survey Hauls	Hauls w/Catch	Biomass	CV	Hauls w/Catch	Biomass	CV
1982	329	0	0	0.00	0	0	0.00
1983	353	2	379	0.83	0	0	0.00
1984	355	0	0	0.00	0	0	0.00
1985	353	1	47	1.00	0	0	0.00
1986	354	0	0	0.00	0	0	0.00
1987	343	3	216	0.60	0	0	0.00
1988	353	1	246	1.00	0	0	0.00
1989	354	0	0	0.00	0	0	0.00
1990	351	0	0	0.00	0	0	0.00
1991	352	0	0	0.00	0	0	0.00
1992	336	0	0	0.00	2	2,564	0.72
1993	355	0	0	0.00	0	0	0.00
1994	355	0	0	0.00	2	5,012	0.82
1995	356	0	0	0.00	1	1,005	1.00
1996	355	0	0	0.00	2	2,804	0.82
1997	356	1	37	1.00	0	0	0.00
1998	355	1	254	1.00	1	2,124	1.00
1999	353	0	0	0.00	2	2,079	0.71
2000	352	0	0	0.00	1	1,463	1.00
2001	355	0	0	0.00	0	0	0.00
2002	355	0	0	0.00	3	5,602	0.65
2003	356	0	0	0.00	1	723	1.00
2004	355	1	28	1.00	2	3,093	0.71
2005	353	0	0	0.00	2	1,679	0.76
2006	356	0	0	0.00	2	2,944	0.78
2007	356	0	0	0.00	0	0	0.00
2008	355	0	0	0.00	0	0	0.00
2009	356	1	72	1.00	0	0	0.00
2010	356	1	89	1.00	4	5,300	0.53
2011	356	0	0	0.00	1	760	1.00
2012	356	0	0	0.00	1	267	1.00
2013	356	0	0	0.00	0	0	0.00
2014	356	0	0	0.00	0	0	0.00
2015	356	1	91	1.00	2	2,581	0.85
2016	356	0	0	0.00	3	3,057	0.84
2017	356	0	0	0.00	1	1,327	1.00
2018	356	0	0	0.00	1	839	1.00
2019	356	0	0	0.00	0	0	0.00

Table 19.8. Research survey catch of sharks 1977–2019 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. Prior to 2010, all data are from the 2010 SAFE (Tribuzio et al. 2010a). Beginning in 2010 all research and other non-commercial catch is provided by the AKRO (AKFIN, queried October 13, 2020). Data are lagged by one year.

Year	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	0					
1979	0.03	4				
1980	0	4				
1981	0.07	5				
1982	0.16	15				
1983	0.01	33				
1984		40				
1985	0.59	53				
1986		52				
1987	0.01	61				
1988	1.06	30				
1989	0.07	27				
1990	0	4				
1991	0.56	18				
1992	0.09	55				
1993		75				
1994	0.17	111				
1995	0.04	0				
1996	0.1	3				
1997	0.11	59				
1998	0.09	1		207		
1999	0.08	20		152		
2000	8.50	2		723		
2001		12		164		
2002	5.74	1		169		
2003	0.03	22		368		
2004	0.76	3		251		
2005	0	6		237		
2006	0	3		241		
2007	0	34		170		
2008	0.47	8		208		
2009	2.02	2		234		
2010	0.43	0	0		8.38	<0.01
2011	0.05	5	0.29		1.50	0.03
2012	3.01	0	0		1.62	0.12
2013	0	5	0.18		4.96	<0.01
2014	0.01	1	<0.01		5.93	<0.01
2015	0.09	2	0.12		2.55	<0.01
2016	0.17	0	0		6	0
2017	0.04	2	0.12		4.56	0
2018	0.06	1	<0.01		0.55	0
2019	<0.01	5	0.29		0.91	0

Table 19.9. Life history parameters for spiny dogfish, Pacific sleeper sharks, and salmon sharks. Top: Length-weight coefficients and average lengths and weights are provided for the formula $W=aL^b$, where W = weight in kilograms and L = PCL (precaudal length in cm). Bottom: Length-at-age coefficients from the von Bertalanffy growth model, where L_∞ is PCL or the TL_{ext} (total length with the upper lobe of the caudal fin depressed to align with the horizontal axis of the body).

Species	Area	Gear type	Sex	Average size PCL (cm)	Average weight (kg)	A	b	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	184.7	146.9	8.20E-05	2.759	NA

Species	Sex	L_∞ (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 19.10. Analysis of ecosystem considerations for the shark complex.

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

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

Figures

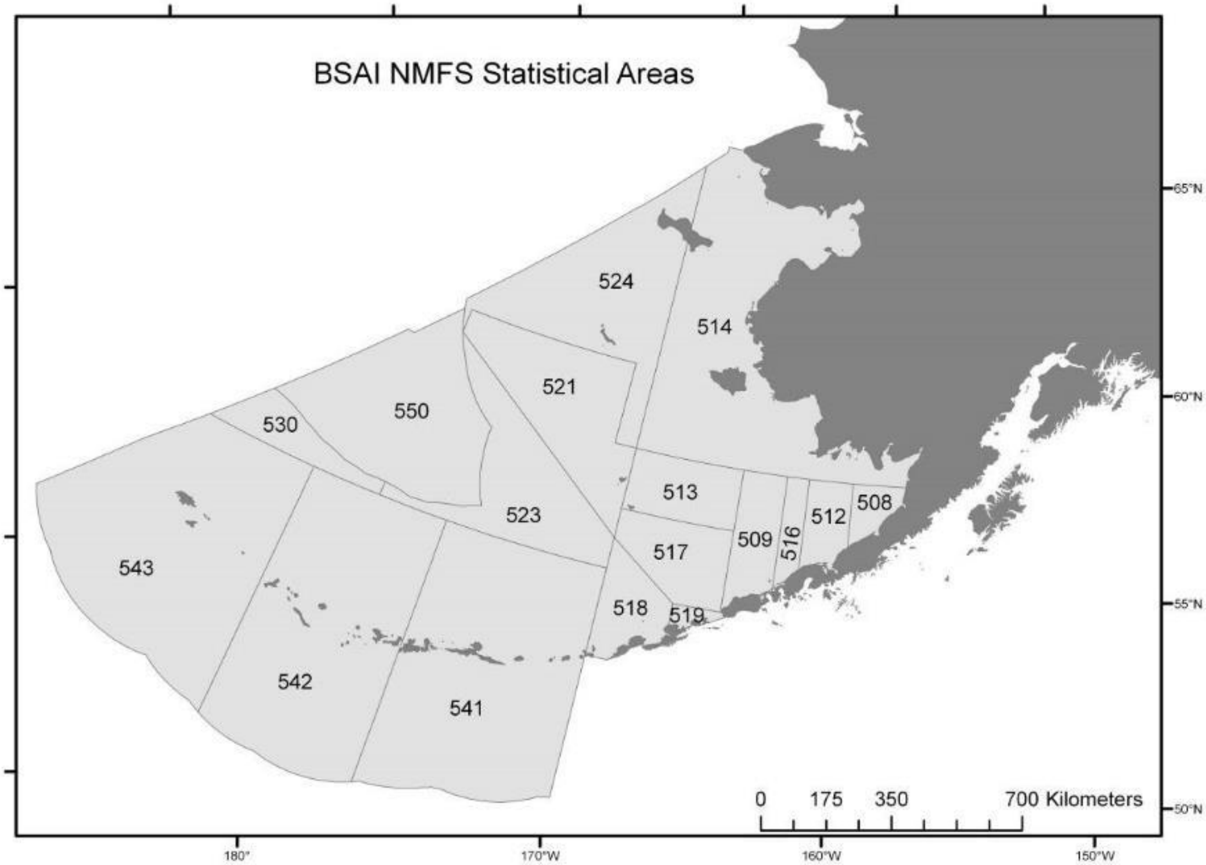

Figure 19.1. NMFS statistical areas in the Bering Sea (NMFS Areas 508–530) and Aleutian Islands (NMFS Areas 541–543).

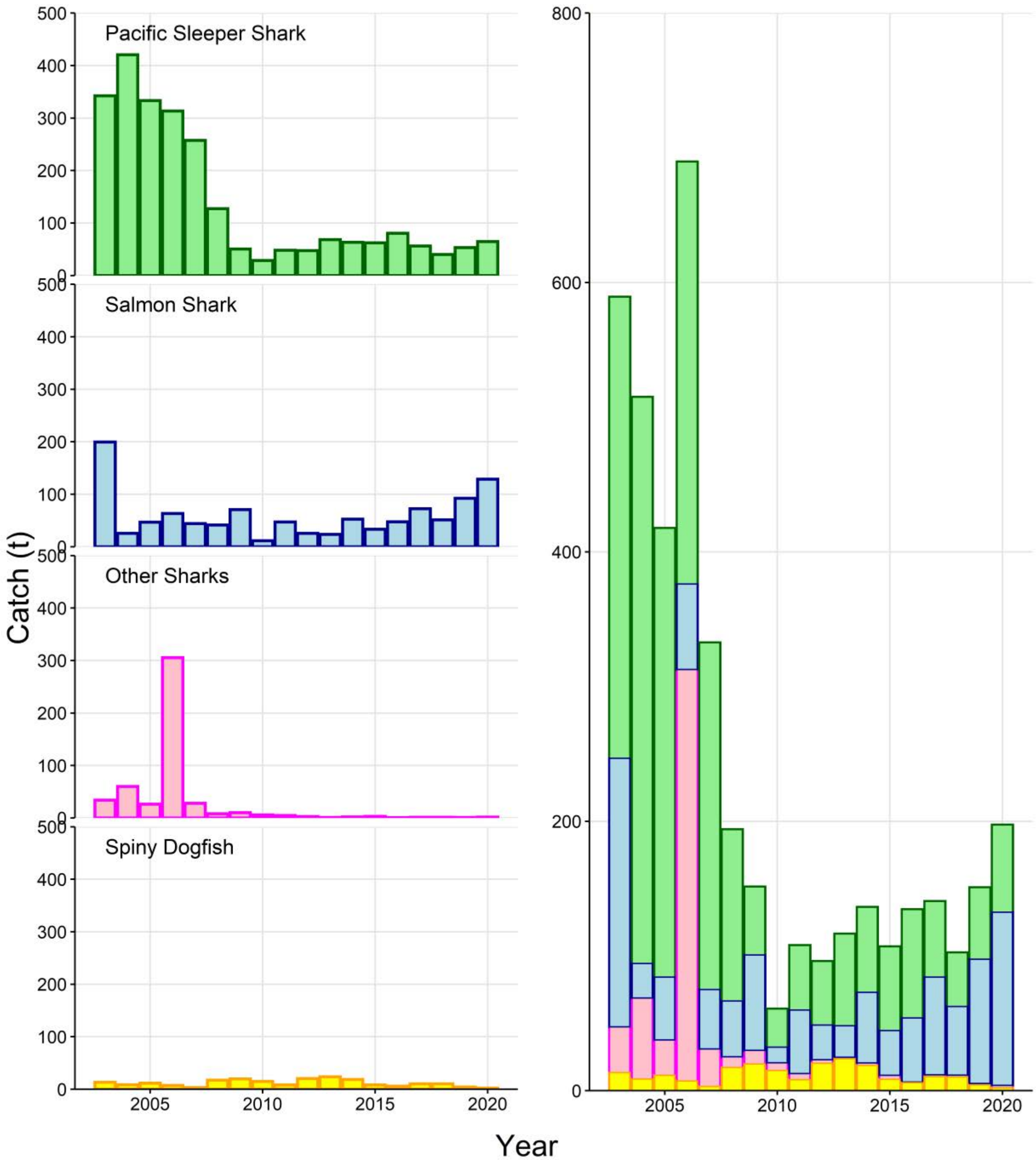

Figure 19.2. Estimated incidental catch (t) of sharks in Bering Sea/Aleutian Islands (BSAI) by species from the Alaska Regional Office Catch Accounting System (queried through AKFIN on October 13, 2020).

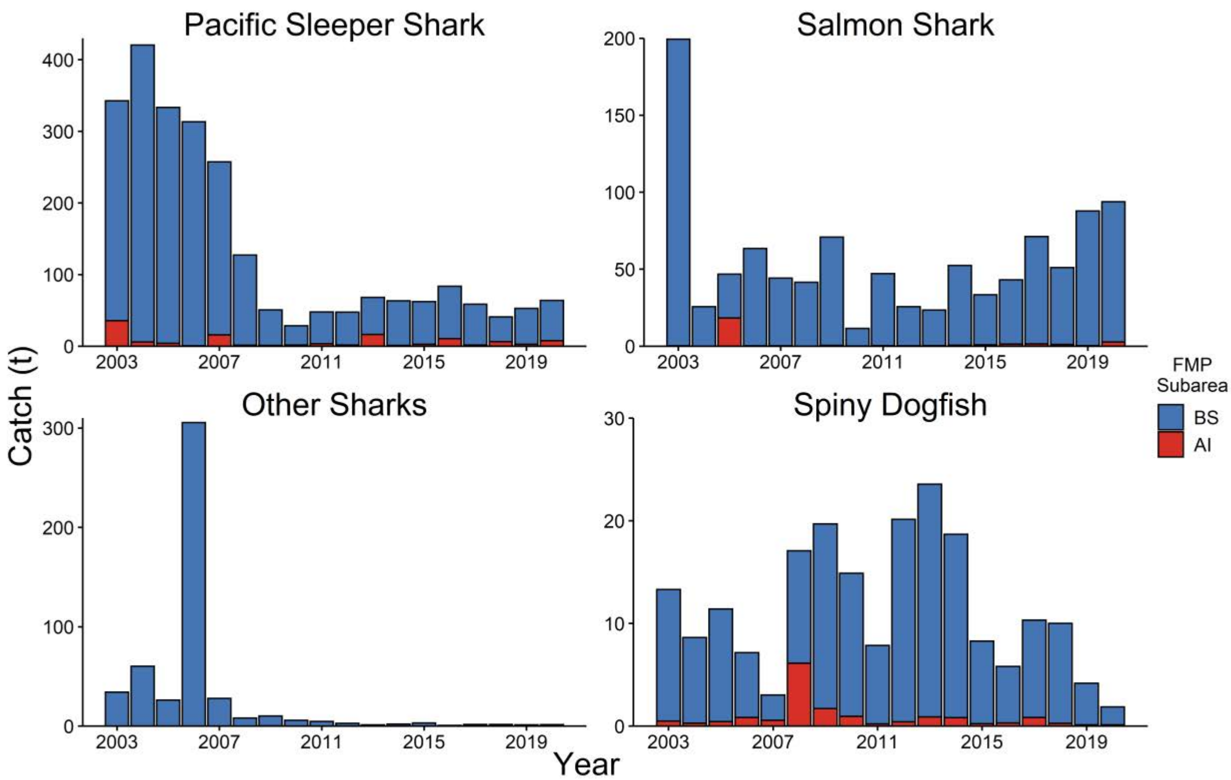

Figure 19.3. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species and FMP Subarea as of October 13, 2020. Note that y-axis scales differ. Data are provided by the AKRO, queried through AKFIN October 13, 2020.

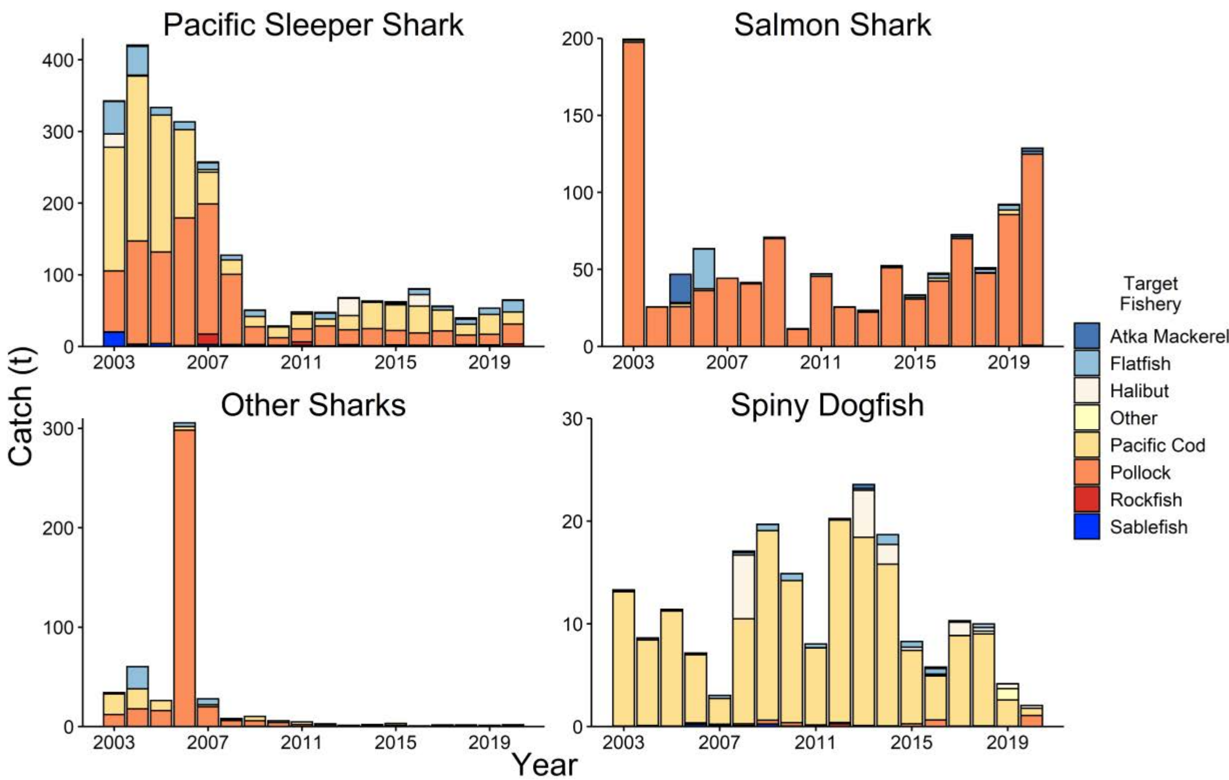

Figure 19.4. Estimated incidental catch (t) of sharks in the eastern Bering Sea and Aleutian Islands (BSAI) by species and target fishery as of October 13, 2020. Data are provided by the AKRO, queried through AKFIN October 13, 2020.

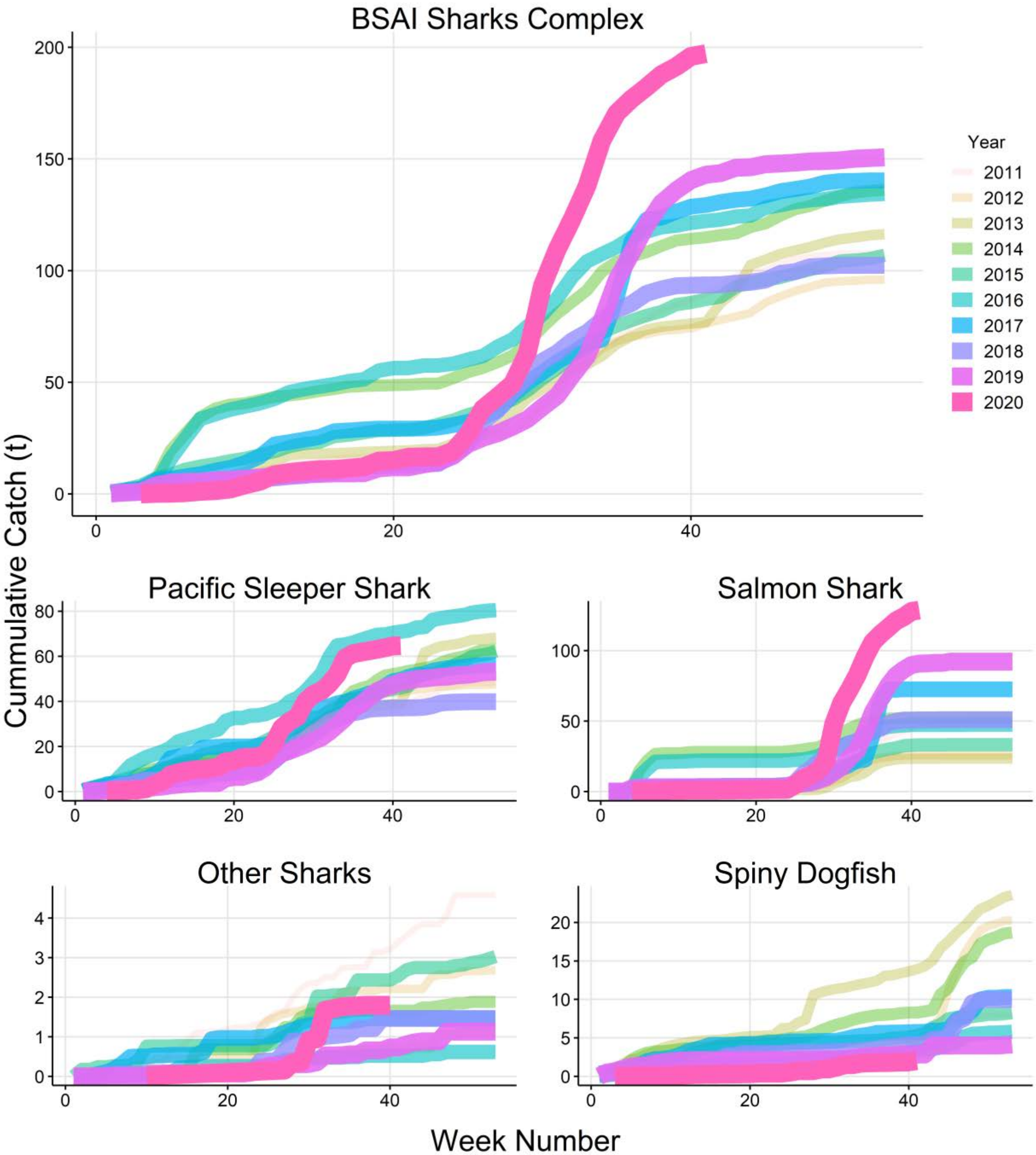

Figure 19.5. Cumulative catch in tons of all sharks in the Bering Sea/Aleutian Islands FMP From 2011-2020. Data are provided by the AKRO, queried through AKFIN October 13, 2020.

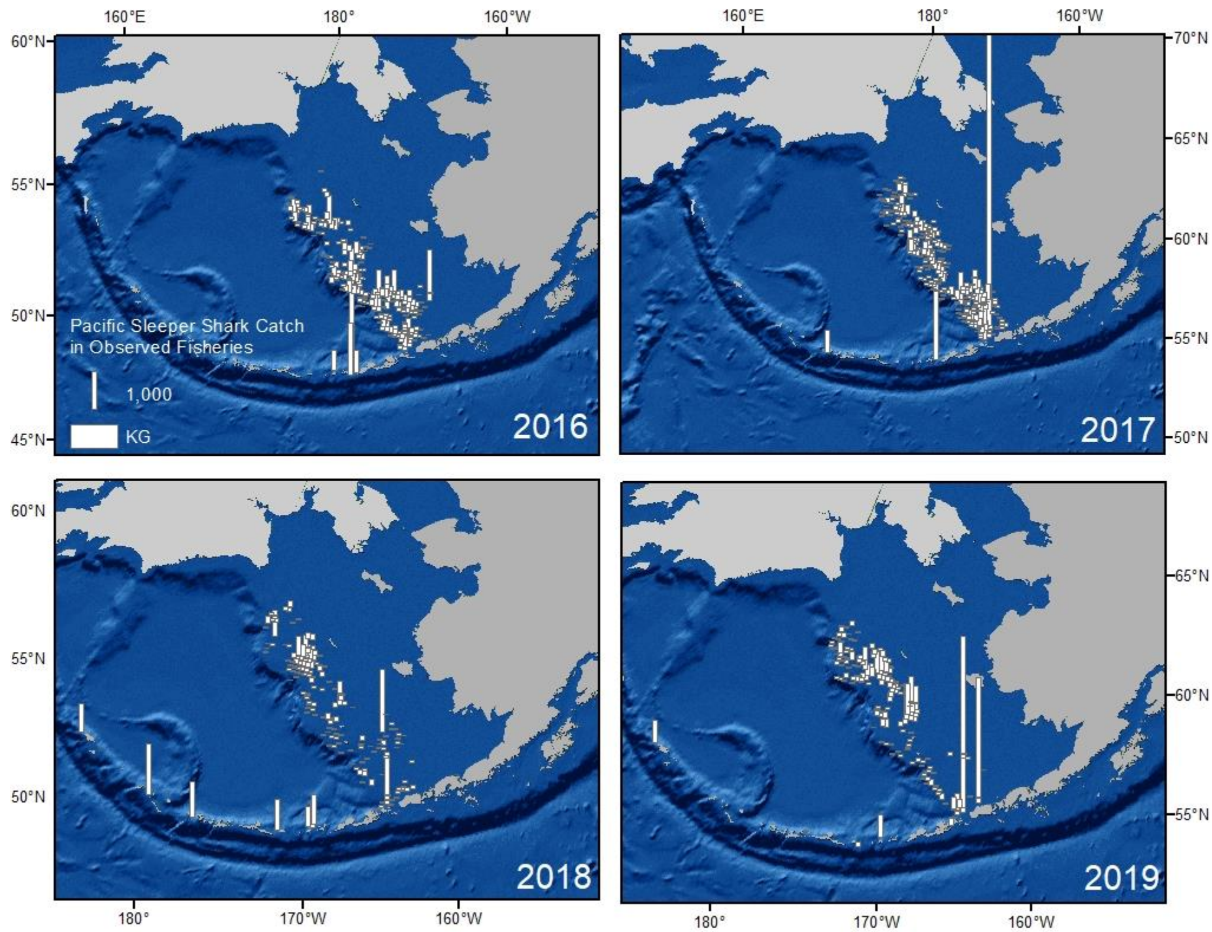

Figure 19.6. Spatial distribution of observed Pacific sleeper shark catch in the BSAI from 2016–2019. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 13, 2020 (https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map).

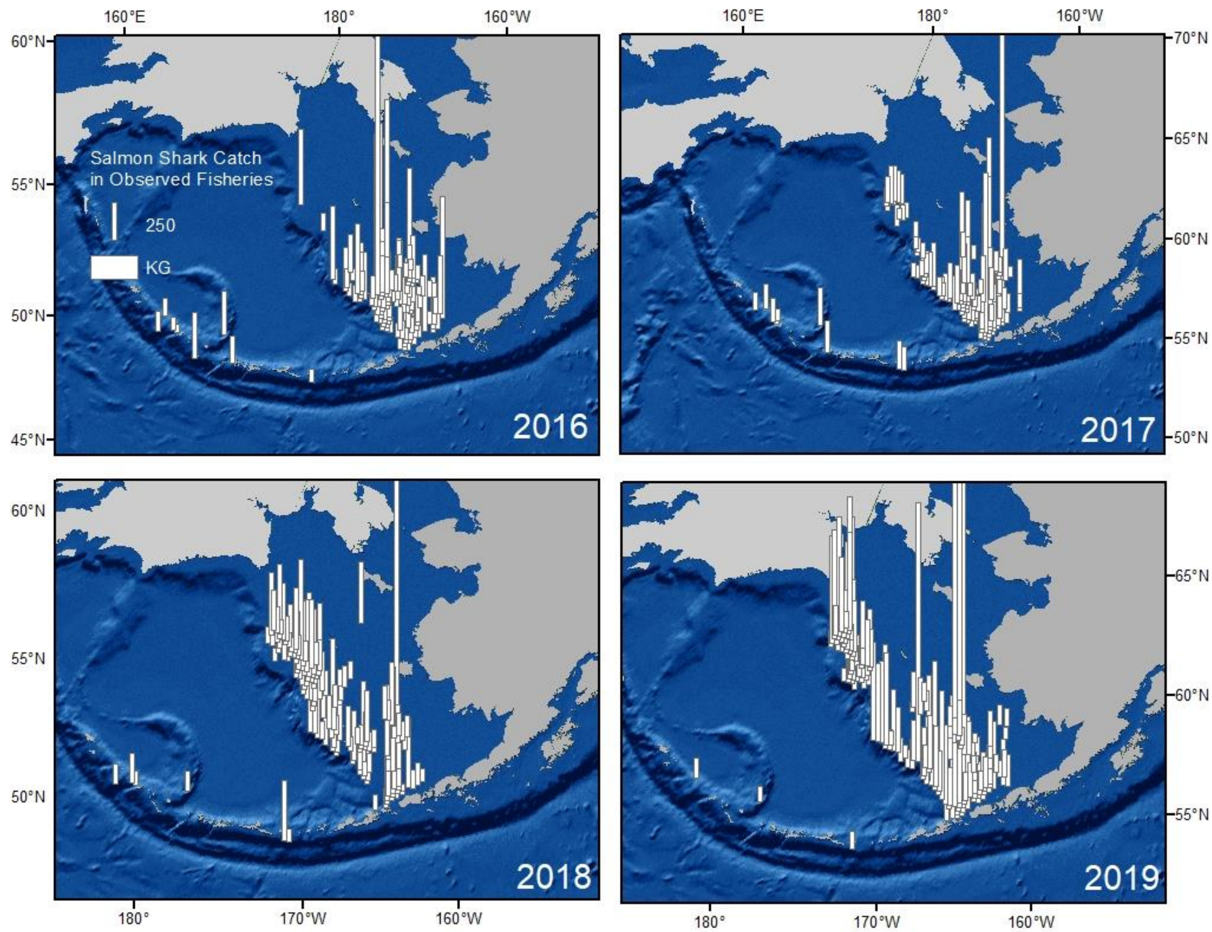

Figure 19.7. Spatial distribution of salmon shark catch in the BSAI from 2016–2019. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 13, 2020 (https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map).

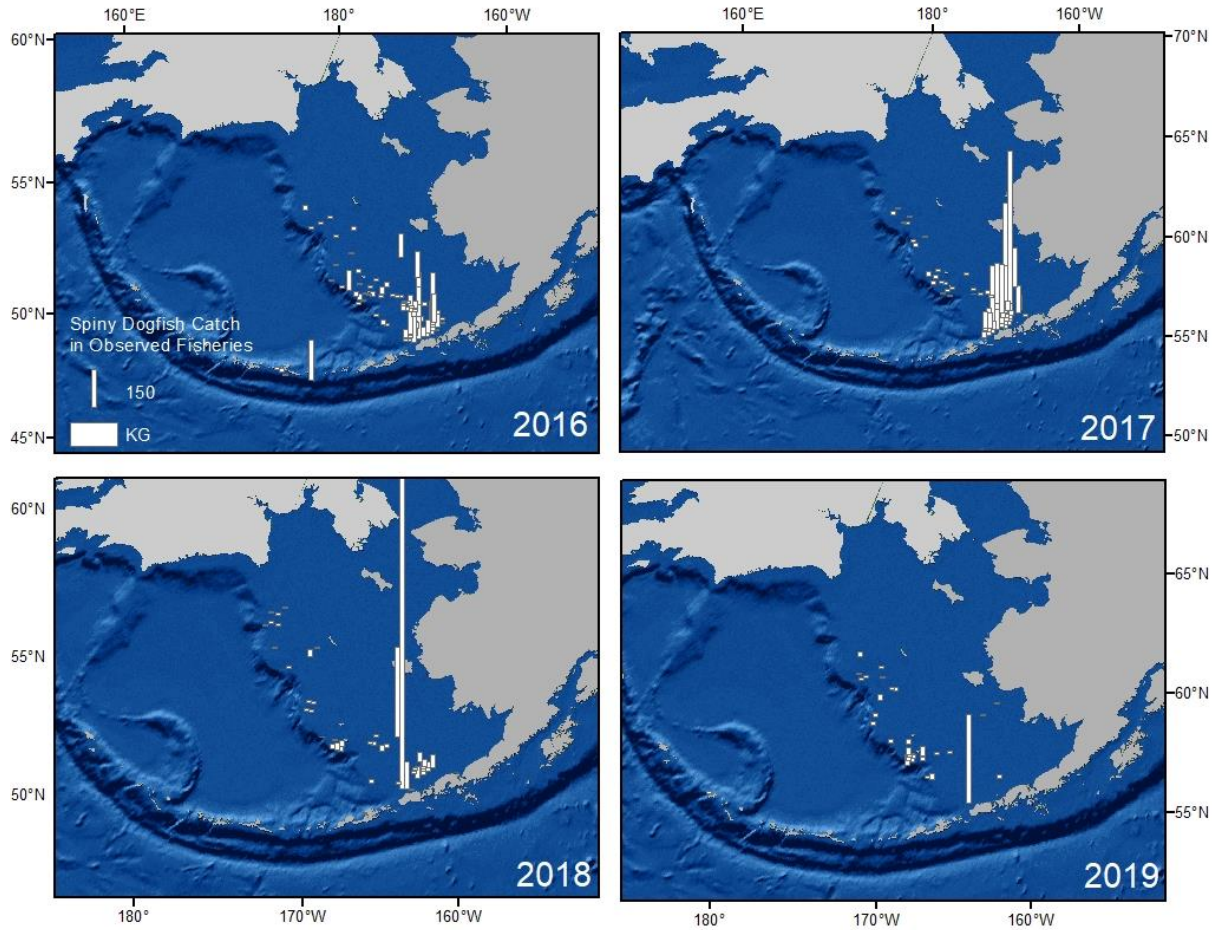

Figure 19.8. Spatial distribution of observed spiny dogfish catch in the BSAI from 2016–2019. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 13, 2020 (https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map).

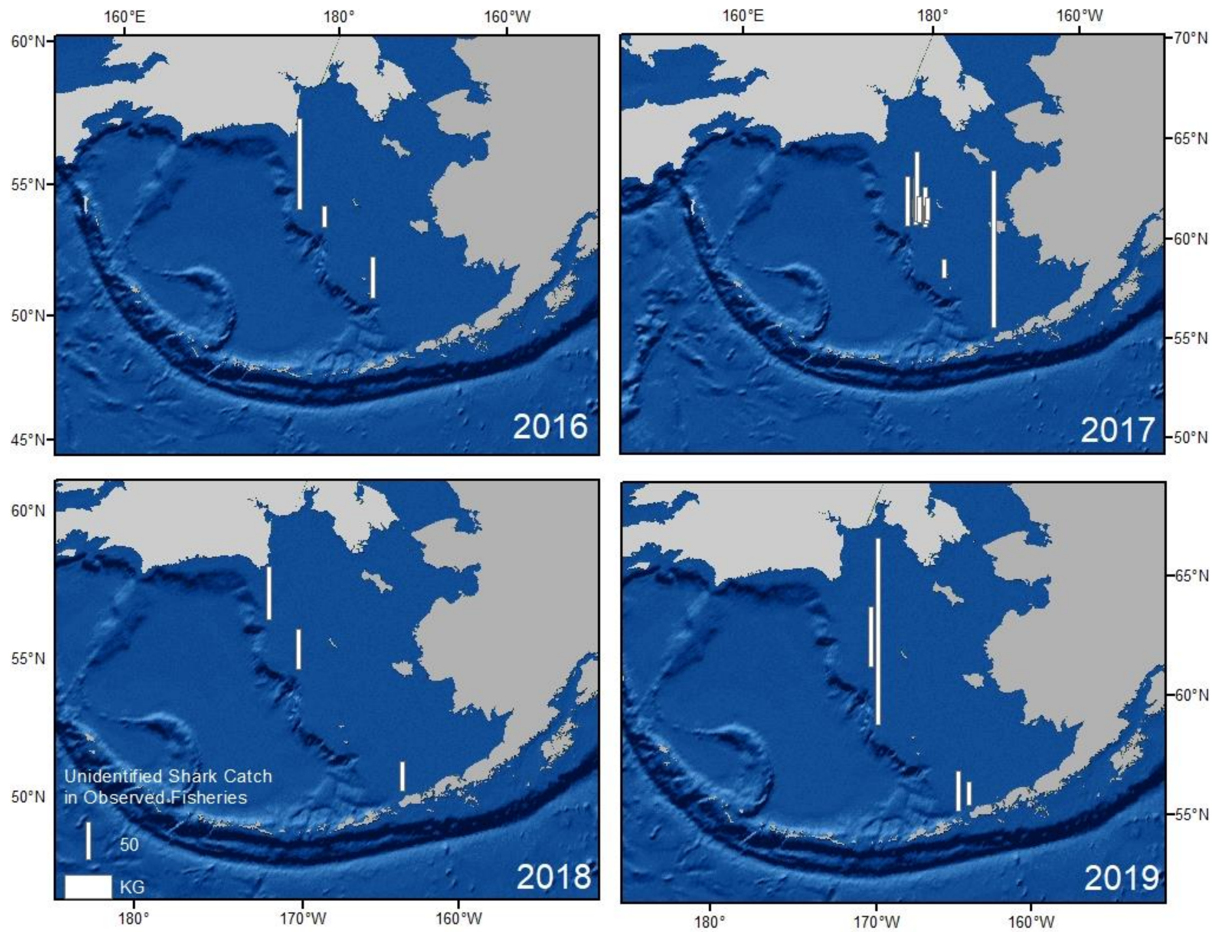

Figure 19.9. Spatial distribution of observed unidentified shark catch in the BSAI from 2016–2019. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into $400km^2$ grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 13, 2020 (https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map).

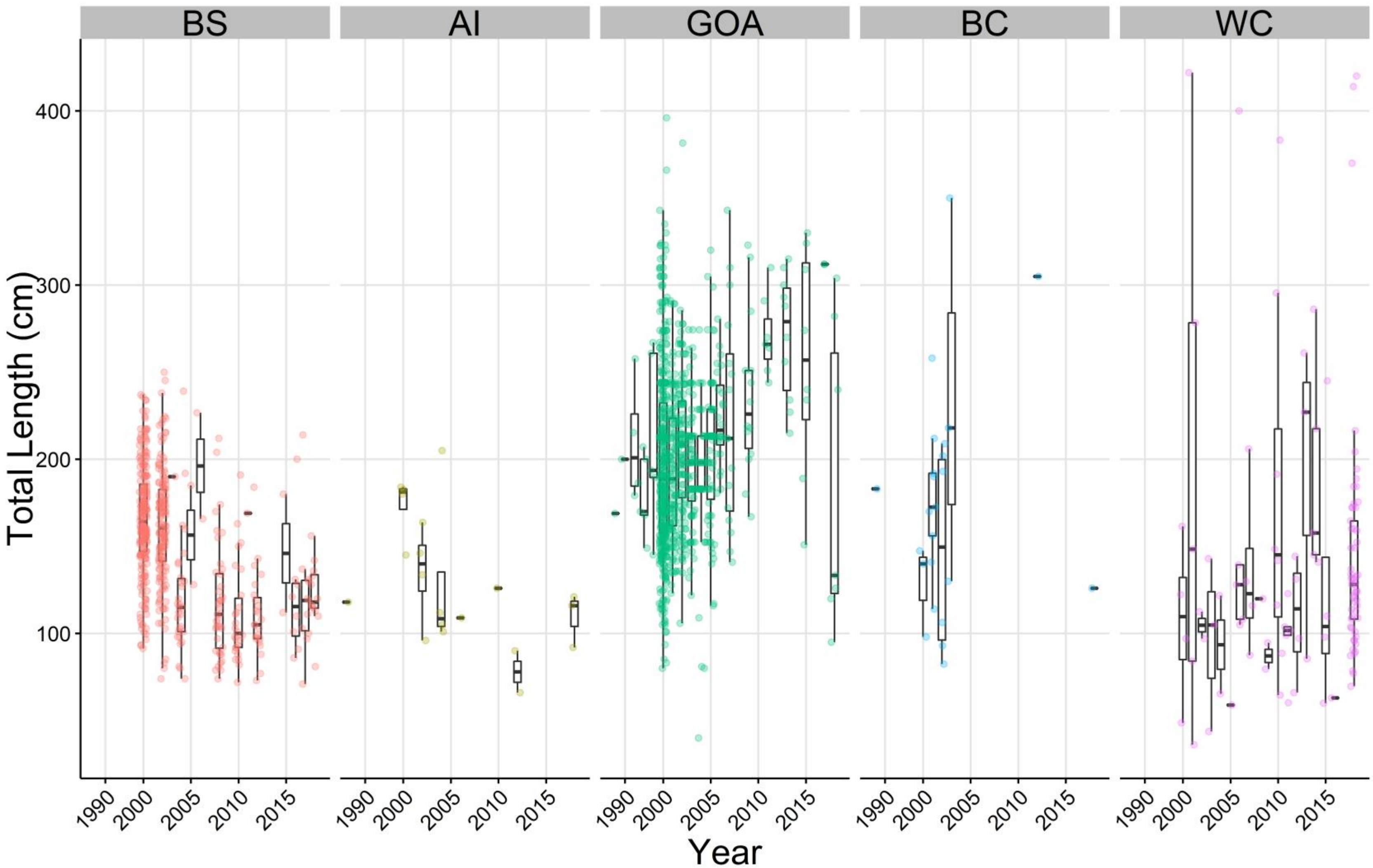

Figure 19.10. Size distribution of Pacific sleeper shark collected in the Aleutian Islands (AI), Bering Sea (BS), Gulf of Alaska (GOA) and the U.S. West Coast (WC). Data is compiled from standard NMFS groundfish trawl surveys, non-standard NMFS surveys (i.e., opportunistic sample collection), directed research surveys, and special projects on IPHC surveys.

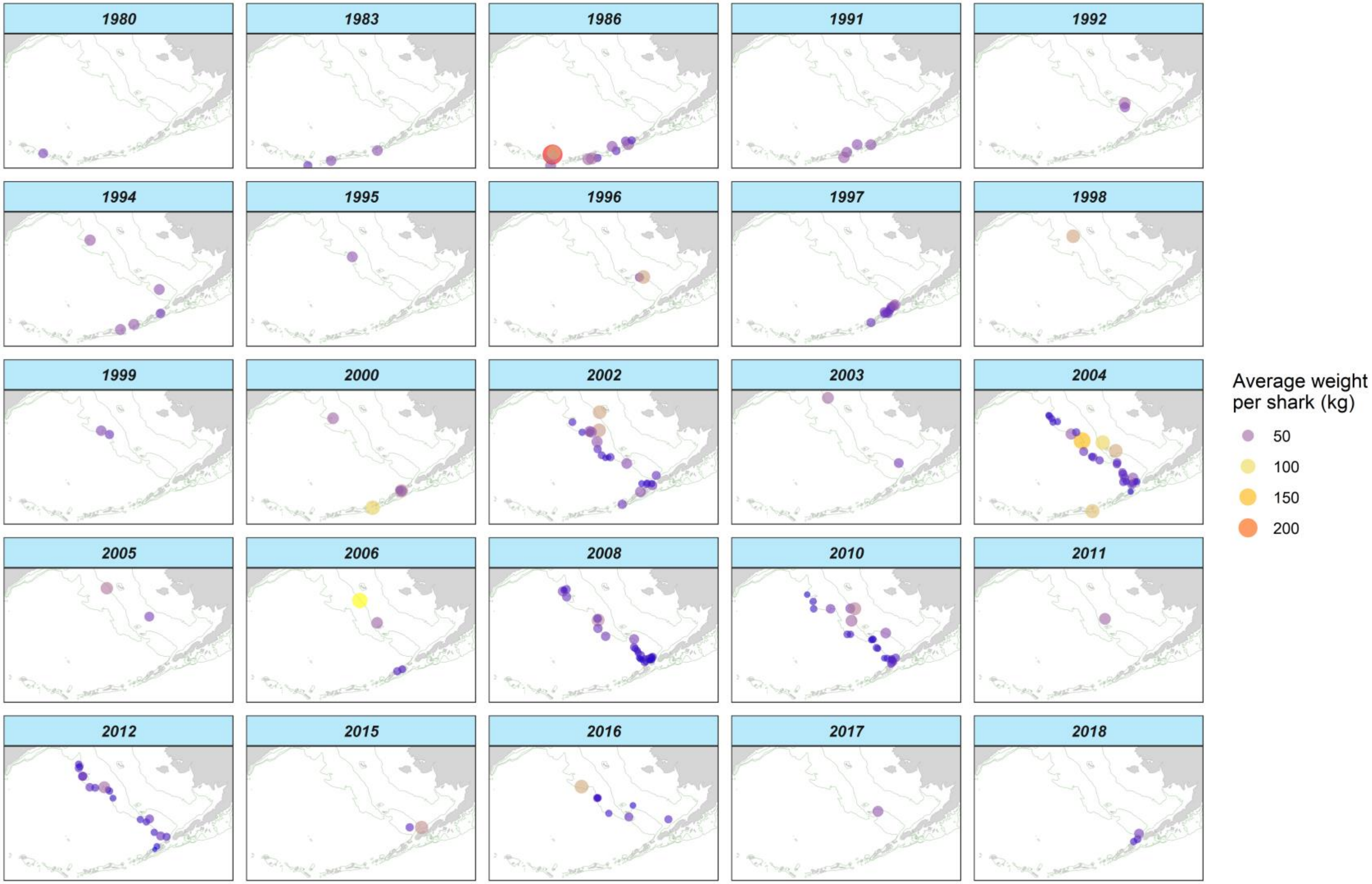

Figure 19.11. Average weight of Pacific sleeper shark per haul captured during the Alaska Fisheries Science Center Bottom Trawl Surveys. Only years with catches are shown.

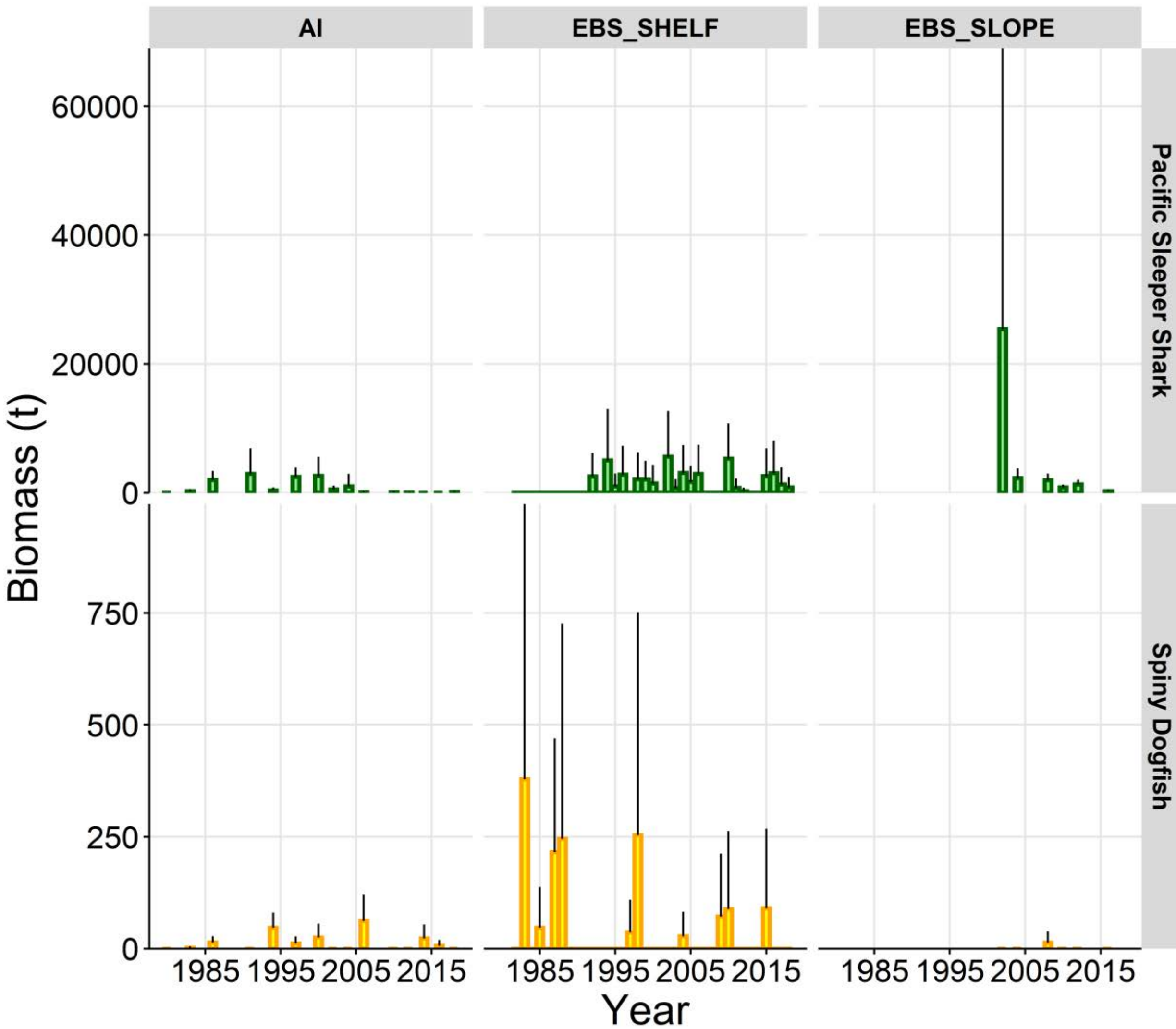

Figure 19.12. Time series of biomass estimates (t) of sharks in the AFSC eastern Bering Sea (EBS) slope, shelf, and Aleutian Islands (AI) bottom trawl surveys. Error bars are 95% confidence intervals. Scales on the y-axes differ for each species.

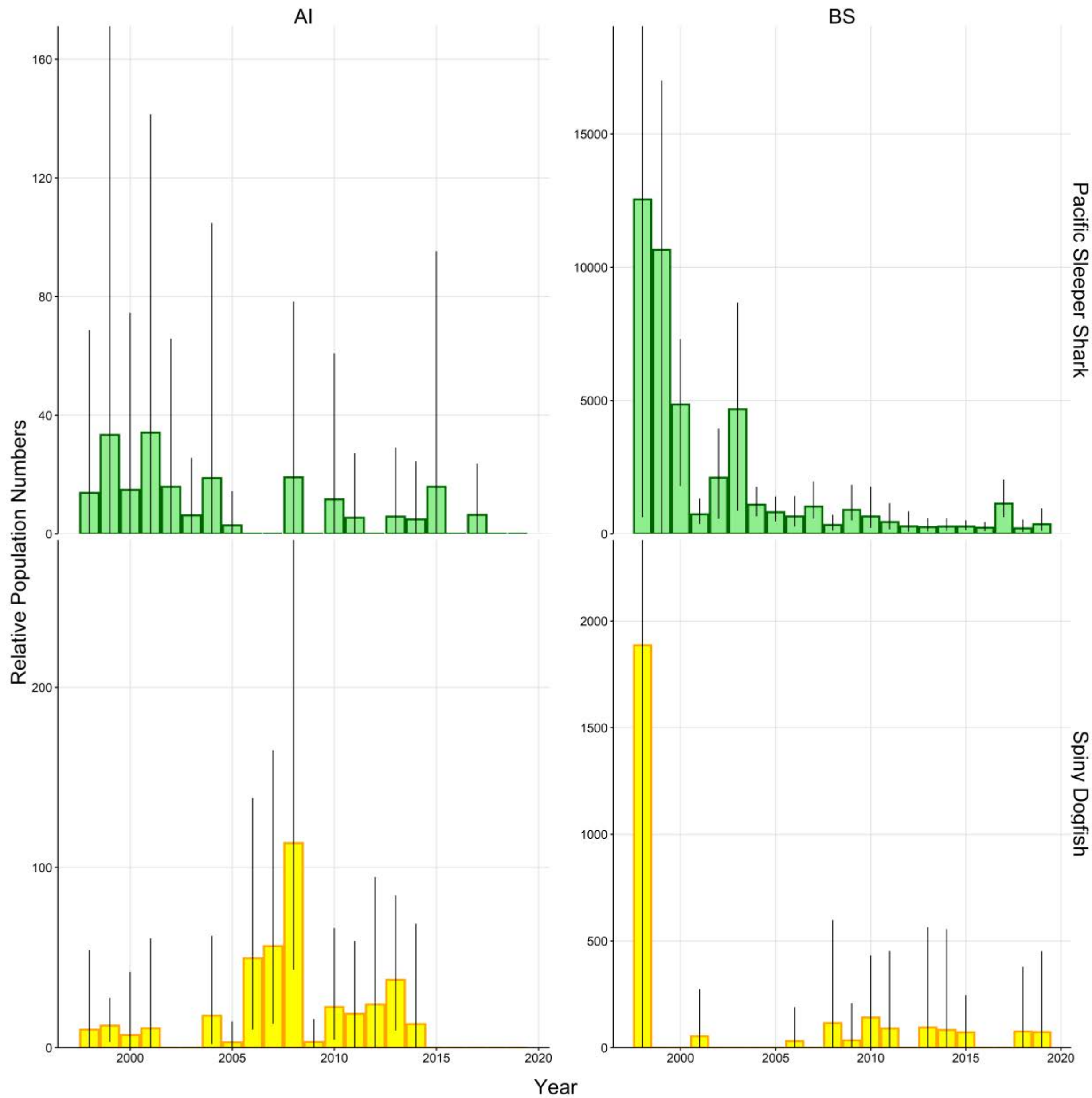

Figure 19.13. Estimated relative population numbers with bootstrapped 95% confidence interval, where the unit was the station, from the IPHC annual longline survey in the BSAI for Pacific sleeper sharks (top) and spiny dogfish (bottom). Scales on the y-axes differ for each species.

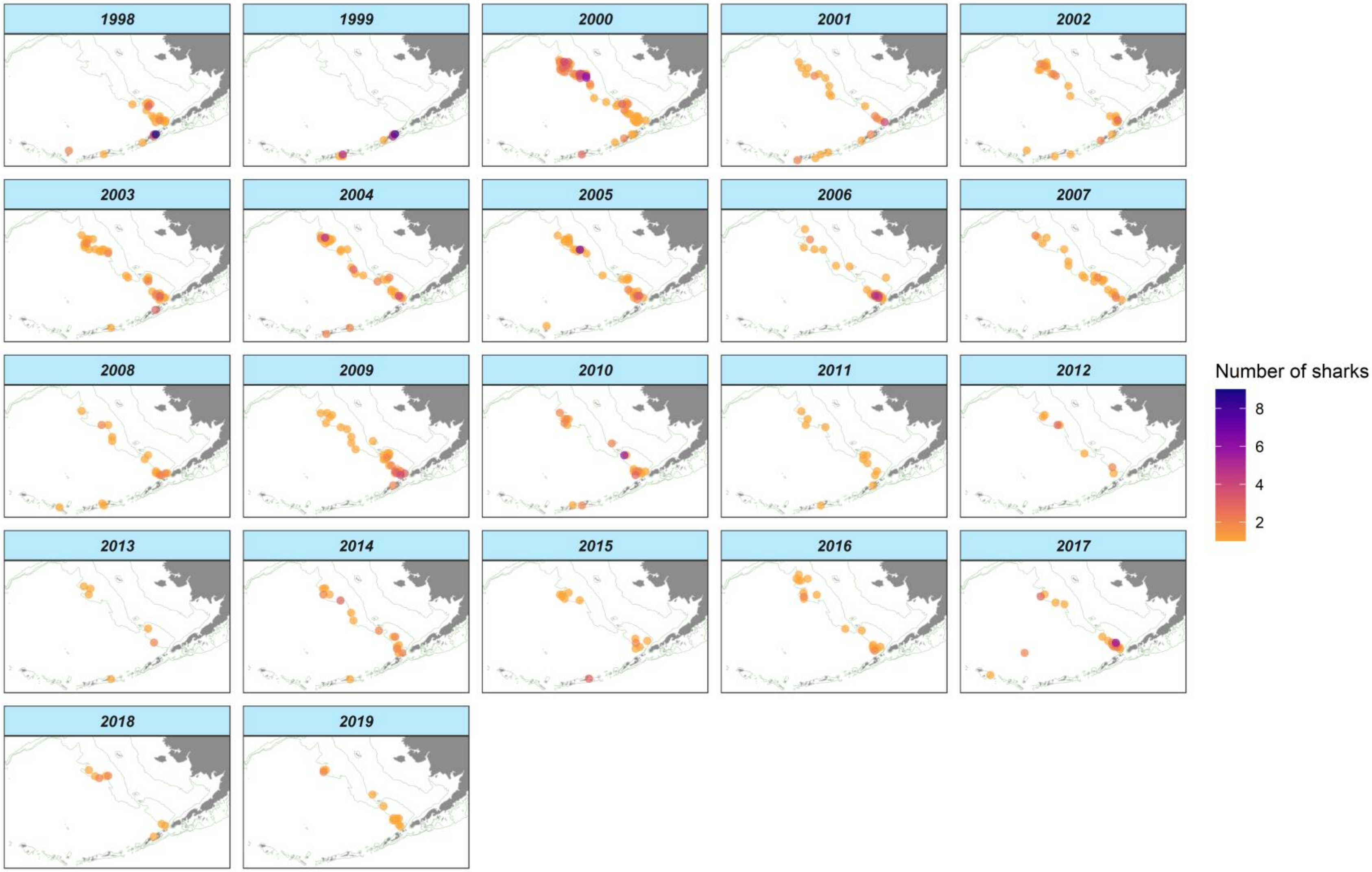

Figure 19.14. Spatial distribution of the catch of Pacific sleeper shark during the IPHC longline surveys. Color of the dot represents the number of sharks caught at a station. Stations with zero catch were removed for clarity.

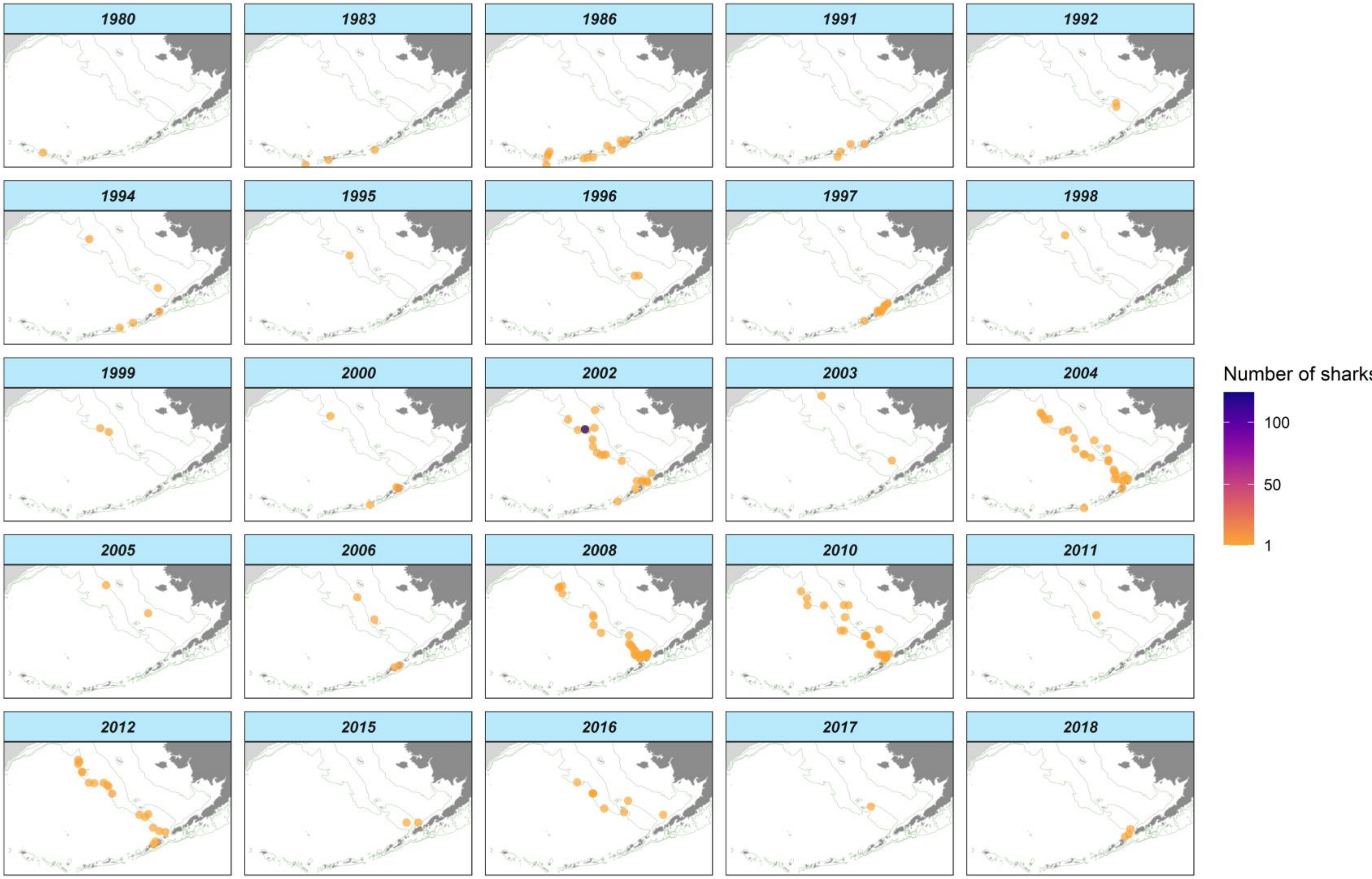

Figure 19.15. Spatial distribution of the catch of Pacific sleeper shark during the AFSC bottom trawl surveys. Color of the dot represents the number of sharks caught at each station. Stations with zero catch were removed for clarity. Years with no survey or no catches are not included.

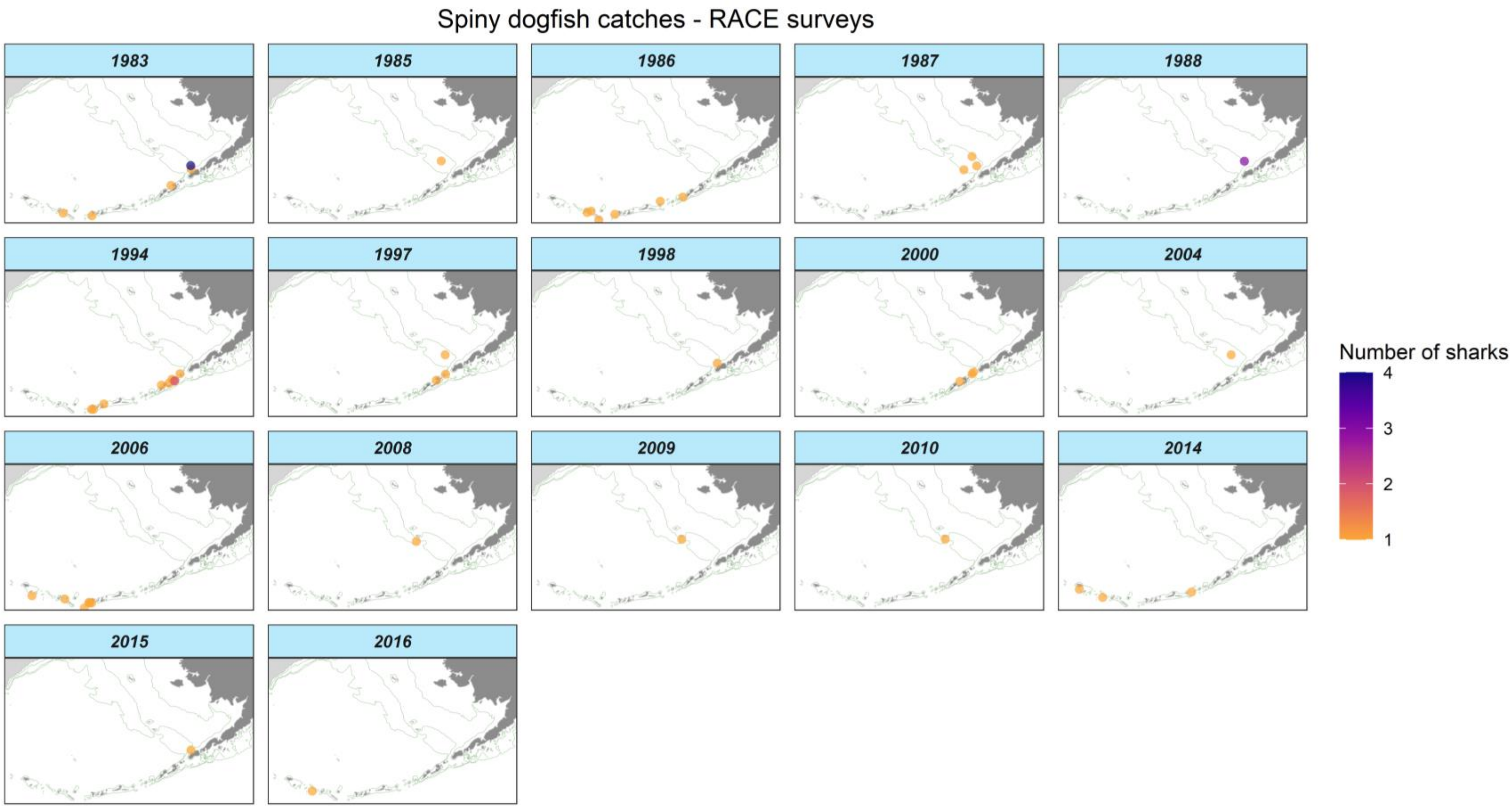

Figure 19.16. Spatial distribution of the catch of spiny dogfish during IPHC longline surveys. Color of the dot represents the number of sharks caught at each station. Stations with zero catch were removed for clarity. Years with no survey or no catches are not included.