19. Assessment of the shark stock complex in the Gulf of Alaska

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EXECUTIVE SUMMARY

The shark complex (spiny dogfish, Pacific sleeper shark, salmon shark and other/unidentified sharks) in the Gulf of Alaska (GOA) is assessed on a biennial stock assessment schedule. The GOA shark complex is a combination of Tier 5 (spiny dogfish) and Tier 6 species (all other sharks). The total OFL for the GOA shark complex is the sum of the Tier 5 and Tier 6 recommendations for each species. The Tier 5 spiny dogfish uses Model 15.3A based on a random effects smoother of the time series of trawl survey biomass to calculate harvest recommendations. Recommendations for the Tier 6 sharks are determined by average historical catches in the years 1997–2007.

Summary of Changes in Assessment Inputs

Changes to the input data

1. Total catch of GOA sharks from 2003 – 2020 has been updated (as of October 13, 2020).
2. All survey indices have been updated where data are available:
    - National Marine Fisheries Service (NMFS) bottom trawl through 2019
    - NMFS longline through 2020
    - International Pacific Halibut Commission (IPHC) longline through 2019
    - Alaska Department of Fish and Game (ADF&G) trawl through 2019 and longline through 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 GOA because the OFL has not been exceeded. Total shark catch in 2019 was 1,997 t and catch in 2020 was 1,117 t as of October 13, 2020. On average, 22% of the total annual catch occurs after October 1st each year.

For 2021 – 2022 we recommend that the shark complex be managed with spiny dogfish as a Tier 5 species using Model 15.3A and the remaining sharks as Tier 6 species using Model 11.0. **The recommended ABC is 3,755 t and OFL is 5,006 t for the shark complex.** This is a 54% decrease from the 2020 ABC of 8,184 t. This decrease is due to the decline in spiny dogfish biomass in the 2019 trawl survey. There are currently no directed commercial fisheries for shark species in federally or state managed waters of the GOA, and most incidental catch is discarded.

ABC and OFL calculations and Tier 5 recommendations for spiny dogfish for 2021 – 2022. Here the OFL is based on the random effects biomass (23,289 t) divided by catchability (q = 0.21) to equal an adjusted biomass of 110,900 t, which is then multiplied by the *F* rate of 0.04.

Spiny Dogfish Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021	2022
M (natural mortality rate)	0.097	0.097	0.097	0.097
Tier	5	5	5	5
Biomass (t)	54,301	54,301	23,289	23,289
F_{OFL}	0.04	0.04	0.04	0.04
$maxF_{ABC}$	0.03	0.03	0.03	0.03
F_{ABC}	0.03	0.03	0.03	0.03
OFL (t)	10,343	10,343	**4,436**	4,436
maxABC (t)	7,757	7,757	3,327	3,327
ABC (t)	7,757	7,757	**3,327**	3,327
Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

ABC and OFL Calculations and Tier 6 recommendations for Pacific sleeper sharks, salmon sharks and other sharks for 2021 – 2022.

Pacific sleeper, salmon and other sharks 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)	570	570	**570**	570
maxABC (t)	427	427	427	427
ABC (t)	427	427	**427**	427
Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

For the combined GOA shark complex:

GOA Shark Complex Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021	2022
Tier	5/6	5/6	5/6	5/6
OFL (t)	10,913	10,913	**5,006**	5,006
maxABC (t)	8,184	8,184	3,755	3,755
ABC (t)	8,184	8,184	**3,755**	3,755

Summaries for Plan Team

Species	Year	Biomass[1]	OFL[2]	ABC[2]	TAC	Catch[3]
Shark Complex	2019	54,301	10,913	8,184	8,184	1,997
	2020	54,301	10,913	8,184	8,184	1,117
	2021	23,289	5,006	3,755		
	2022	23,289	5,006	3,755		

[1]Spiny dogfish random effects modelled biomass only.
[2]ABC and OFL are the sum of the individual species recommendations, Tier 6 (Model 11.0) for Pacific sleeper shark, salmon shark, and other/unidentified sharks and Tier 5 (Model 15.3A) for spiny dogfish.
[3]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 GOA 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 has a different risk score 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

“In response, the Plan Team recommended: (1) Bringing forward a Pacific sleeper shark (PSS) stock structure document (across both FMPs) to the Joint Plan Team in September 2018 due to concerns that PSS in BSAI and GOA are one stock with a potentially small effective population size and that they are long-lived and slow maturing (2) Coordinating with AKRO catch accounting staff to extend the time series of PSS catch by number of animals back to 2003 (Catch by weight alone may miss high catches of small animals) (3) Continuing to work on PSS genetics (4) Developing ageing methods for PSS (5) Implementing a special project in the observer program to quantify sizes of PSS caught in hook-and-line fisheries” (GOA Plan Team, November 2017).

In response to points (1) and (3): The Pacific sleeper shark stock structure document is still in development. Genetics samples have, and are still being collected, but a number of challenges have prohibited completion of the genetic analyses. At this time, over 400 samples have been collected but are pending laboratory preparation prior to genome sequencing. We believe the genetic analyses are essential for evaluating stock structure and look forwards to completing this work. Along with the genetics work, we have begun extensive literature review of the Pacific sleeper shark and the Somniosidae family and we have begun analyses for the stock structure document.

In response to point (2): 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 can be extended to include years 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.

In response to point (4): 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, and therefore has utility for ageing Pacific sleeper sharks. Further, the species 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.

In response to point (5): We have an ongoing project with the North Pacific Observer Program to investigate the size of observed Pacific sleeper sharks in longline fisheries. This project has been ongoing since 2018, however, due to it being a low priority project for observers, the amount of data has been relatively small. We hope to have sufficient data returned by the end of the 2021 fishery to complete this analysis. A second project in cooperation with the Observer Program and AKRO staff was funded through the NOAA Catch Shares funding RFP. We will look at if Electronic Monitoring on the longline vessels can be used to better quantify catch of large sharks relative to the current at-sea observations. This project will begin in the 2021 longline fisheries and is planned for 2 years of data collection.

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

We opted to delay this analysis pending results of studies to expand biomass estimates into NMFS Areas 649/659. See responses to below comments.

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

See responses to below comments.

"The SSC also recommends that: (1) Authors continue exploration of spatiotemporal models, such as VAST, for spiny dogfish and various data limited assessment techniques for other sharks (2) Uncertainty in the estimate of q be included in future assessments, perhaps by bootstrapping data used to derive q and performing a number of model runs using a plausible range of q values to evaluate model sensitivity (3) Authors continue efforts to estimate biomass in NMFS areas 649 and 659, and that steps be taken to ensure future shark catches in Federal fisheries in 649 and 659 be fully accounted for in reporting (4) A small working group examine estimation approaches for 649/659 Federal fisheries catches and how they should be accounted within federal assessments, as recommended by the PT." (SSC, December 2018)

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

In response to point (2): Model 15.3A was brought forward in the 2018 GOA shark assessment (Tribuzio et al. 2018) and the uncertainty around q was discussed in the parameter estimates section. The uncertainty is based on the confidence interval around the vertical availability (Hulson et al. 2016). We presented a suite of models with a range of q values in Appendix 20A of Tribuzio et al. (2018).

Introduction

Alaska Fisheries Science Center (AFSC) surveys and fishery observer catch records provide biological information on shark species that occur in the Gulf of Alaska (GOA) (Table 19.1 and Figure 19.1). In total, 11 species have been reported in the GOA (Table 19.1). The three shark species most likely to be encountered in GOA fisheries and surveys are the Pacific sleeper shark (Somniosus pacificus), the Pacific spiny dogfish (*Squalus suckleyi)*, and the salmon shark (*Lamna ditropis*). These three species are the main focus of this assessment, as catches of the remaining species (common thresher shark *Alopias vulpinus*, brown cat shark *Apristurus brunneus*, white shark *Carcharodon carcharias*, basking shark *Cetorhinus maximus*, Tope or soupfin shark *Galeorhinus galeus*, bluntnose sixgill shark *Hexanchus griseus*, broadnose sevengill shark *Notorynchus cepedianus*, and blue shark *Prionace glauca*) are rare or anecdotal in the GOA.

General Distribution

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 (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 Bering Sea/Aleutian Islands (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 (Hulson et al. 2016), 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*.

Pacific Sleeper Shark

The Pacific sleeper shark is the most commonly encountered shark in the GOA, 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 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 0-1864 m (Carlisle et al. 2011).

Evidence of Stock Structure

The stock structures of the BSAI and GOA shark complexes were examined and presented to the joint Plan Teams in September 2012 (Tribuzio et al. 2012). Limited information is available to evaluate 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 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

Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity (Musick et al. 2000; Table 19.1 and Table 19.2). The productivity of shark populations is very low relative to most commercially exploited teleosts (Holden 1974, Compagno 1990, Hoenig and Gruber 1990). Shark reproductive strategies in general are characterized by long gestational periods (6 months - 2 years), with small broods of large, well-developed offspring (Pratt and Casey 1990). Because of these life history characteristics, many large-scale directed fisheries for sharks have collapsed, even where management was attempted (Castro et al. 1999). Ormseth and Spencer (2011) estimated the vulnerability of Alaska groundfish and found that the salmon shark, spiny dogfish, and Pacific sleeper shark were among the most vulnerable species in the GOA fishery management plan.

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 thermal clines (Bizzarro et al. 2017). The rate of migration is variable among individual spiny dogfish and within regions, but some individuals make extensive migrations, including across the Pacific basin (McFarlane and King 2003).

Spiny dogfish grow to a maximum size of 160 cm in the ENP (Compagno 1984). The estimated age-at-50% maturity of spiny dogfish in the GOA is 36 years for females and 21 years for males (Tribuzio and Kruse 2012), similar to estimates from 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).

Pacific Sleeper Shark

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

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

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

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

Salmon Shark

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

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

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

Fishery

Management History and Management Units

The shark complex is managed as an aggregate species group in the GOA Fishery Management Plan (FMP). Prior to the 2011 fishery, sharks were managed as part of the “Other Species” complex, with sculpins, squid, and octopus (skates were removed from the Other Species complex in 2003, Gaichas et al. 2003). The breakout was in response to the requirements for annual catch limits contained within the reauthorization of the Magnuson Stevens Fishery Conservation and Management Act. The NPFMC passed amendment 87 to the GOA FMP, requiring sharks to be managed as a separate complex and Annual Catch Limits (ACLs) be established annually by the SSC starting in the 2011 fishery. The total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limits (OFL) for the shark complex (and previously the Other Species complex) are set in aggregate (Table 19.3).

Directed Fishery, Effort and CPUE

Commercial

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

Recreational (provided by ADF&G)

Spiny dogfish, salmon shark, and Pacific sleeper shark are caught in the recreational fisheries of Southeast and Southcentral Alaska. The State of Alaska manages recreational shark fishing in state and federal waters, and most of the catch occurs in state waters. The shark fishery is managed under a statewide regulation (5 AAC 75.012), which was modified in 2010 to liberalize limits for spiny dogfish. Effective 2010, the bag and possession limit for spiny dogfish is five fish and there is no size or annual limit. For all other species of the orders Lamniformes, Carcharhiniformes, and Squaliformes, the daily bag limit is one shark of any size with an annual limit of two sharks per year. The season is open year-round. Pacific sleeper sharks are uncommon in the recreational catch and rarely retained, thus estimates are not presented here.

Information on sport catch is obtained from the following: (1) the ADF&G statewide harvest survey (SWHS); (2) mandatory charter logbooks; and (3) dockside monitoring in the Southcentral Region. The SWHS provides estimates of catch (both retained and discarded fish combined) and harvest (retained fish only) of all shark species combined, in numbers of fish. Mandatory charter logbooks provide estimates of statewide charter harvest of salmon sharks (numbers of fish) since 1998. Dockside monitoring in the Southcentral Region obtains reported retentions and discards and biological information for retained spiny dogfish and salmon shark.

Statewide estimates of discarded and retained sharks are available 1998–2019, and are presented in this report (Table 19.4). Sport angler catch of sharks (all species) is lowest in the Western GOA (0-410 animals) and all is discarded with exception of 2001 when about half of the catch was retained. Catch in the Central GOA is the highest, catching up to 46,403 sharks, followed by the Eastern GOA with up to 31,571 sharks being caught. In both the Central and Eastern GOA, the discard rate is >90%. Most anglers are not targeting sharks, and catch is generally incidental.

Charter sport fishing vessels are required to report any catch of salmon shark in the charter logbook. Catch estimates of salmon shark catch occurring in the charter vessel fleet are in addition to the catch estimated by the SWHS. Logbook data for salmon sharks have not been rigorously edited, but indicate annual statewide charter retention in the range of 1–246 fish over the years 1998–2019 (except 1999, Table 19.4). Charter retention of salmon sharks appeared to increase in the late 1990s in response to media attention, but has declined since the peak in 2006. Prior to 2010 the majority of the salmon shark catch occurred in the Eastern GOA, but since 2010 has been relatively split between the Central and Eastern GOA. There is very little to no salmon shark catch by charter fishing vessels in the Western GOA.

Spiny dogfish make up the vast majority of the recreational shark catch but are rarely targeted. Most of the catch is incidental to the sport halibut fishery. Catch rates can be quite high at certain times of the year, particularly in Cook Inlet, southwestern Prince William Sound, and Yakutat Bay. Anecdotal reports indicate that many spiny dogfish are handled poorly when released. Discard mortality is unknown, but probably substantial.

Current Incidental Fishery

Catches of sharks in the GOA are composed entirely of incidental catch. Aggregate incidental catches of the shark management category from federally prosecuted fisheries for Alaskan groundfish in the GOA are tracked in-season by NMFS AKRO (Table 19.3). The estimated catch of sharks is broken into four groups: spiny dogfish, Pacific sleeper shark, salmon shark and other/unidentified sharks (Table 19.5 and Figure 19.2). Historically, spiny dogfish are the primary species caught in the GOA. Pacific sleeper sharks, salmon sharks and other/unidentified sharks, are smaller components of the complex.

Estimated catch of spiny dogfish has historically been variable, with peaks in estimated catches often resulting from a small number of large observations (such as in 2006 and 2009, Table 19.5, and Figure 19.2). Catch in 2018 is the greatest of the historical time series for spiny dogfish (3,133 t, Table 19.5). Since 2013, estimated catch of spiny dogfish has been primarily occurs in the Pacific halibut (749 t, 44%, on average) and sablefish fisheries (528 t, 29%, on average, Figure 19.3). Smaller amounts of spiny dogfish catch have come from the flatfish (208 t, 13% on average since 2013) and Pacific cod fisheries (167 t, 11% on average, Figure 19.3). The restructured observer program has provided catch estimates from state waters which, when combined with the GOA catch, results in the Pacific halibut fishery being responsible for 45% of the spiny dogfish catch and the sablefish fishery 28% (on average since 2013, Table 19.6).

Pacific sleeper shark catch is lower than spiny dogfish and variable (Table 19.5 and Figure 19.2). On average since 2013, 37% (51 t) and 34% (32 t) of the catch has come from the flatfish and Pacific halibut fisheries, respectively (Figure 19.3). When catch from NMFS areas 649 and 659 (Table 19.6) are combined with the GOA catch, the Pacific halibut fishery is responsible for 50% (103 t) of Pacific sleeper shark catch, on average since 2003. Pacific sleeper shark catch in NMFS areas 649 and 659 also occurs in the Pacific cod and sablefish fisheries, however, it is variable from year to year.

Salmon shark are almost entirely caught in the pollock fishery (82 t, 87%, on average since 2013, Figure 19.3). Catch of the other/unidentified sharks is highly variable and inconsistent among target fisheries (Figure 19.3). There was an increase in the catch of other/unidentified sharks in 2018, specifically in the sablefish fishery in NMFS Area 650. There were substantially more blue sharks observed in longline gear in that area, likely resulting in the increased catch estimates. Catches of blue sharks tend to increase in warmer years, particularly in Southeast Alaska.

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 Pacific halibut and sablefish fisheries (about weeks 15-20) and late summer/early autumn walleye Pollock fisheries (about weeks 35-40, Figure 19.4). Over the last 10 years, about 22% of the catch occurs after data are queried for use in the assessment (approximately week 40, or October 1st of each year, Figure 19.4).

Distribution of Catch in Fisheries

The spatial distribution of catch varies for each of the four species in the shark complex (Figure 19.5). Catch distribution is likely more a function of the behavior of target fisheries and not indicative of areas of high biomass. From 2016 through 2019, spiny dogfish were caught primarily in NMFS areas 630 and 650 predominately off Kodiak Island in the Central GOA, with some catch spread along the shelf and little catch in 640 (Figure 19.6).

Observer catch data from the FMA website were mapped to analyze spatial distribution of catch. Data presented here represent non-confidential data aggregated by 400 km^2 grids from fisheries that occurred during 2016-2019. Observed bycatch of spiny dogfish in commercial fisheries in the GOA (Figure 19.6) occurs predominately off Kodiak Island in the Central GOA, with some catch spread along the shelf. Following observer restructuring, more observed sharks have been observed in the Eastern GOA and inside waters.

Due to confidentiality restrictions, the non-confidential observed bycatch of Pacific sleeper shark is limited (Figure 19.7) and less informative. Pacific sleeper shark are caught primarily in NMFS areas 620 and 630 (Figure 19.7). Catch occurs predominantly within Shelikof Strait in the Central GOA, and along the Alaska Peninsula.

The amount of salmon shark and unidentified shark bycatch within observed commercial fisheries is small and rarely available in non-confidential data. Therefore, we did not examine the spatial distribution of this catch.

Discards

Nearly all incidental shark catch is discarded. Mortality rates of discarded catch are unknown, but are conservatively estimated in this report as 100%. Discard rates for sharks are presented in Table 19.7. For all species, except for other/unidentified sharks, > 90% of sharks are discarded. The other/unidentified sharks are discarded at a lower rate, 59% on average over the last 10 years, which is <4 t on average. About 24 t of sharks are retained on average annually (~19 t is spiny dogfish), and nearly all is used for fishmeal (C. Tide, AKRO, pers. comm.).

Data

Data regarding sharks were obtained from the following sources:

Source	Data	Years
AKRO Catch Accounting System	Nontarget catch	2003–2020
AFSC Improved Pseudo Blend	Nontarget catch	1997–2002
NMFS Bottom Trawl Surveys –GOA	Biomass Index	1979–2019
NMFS Longline Surveys	Survey catch numbers, CPUE and RPN	1989–2020
IPHC Longline Surveys	Survey catch numbers, CPUE and RPN	1997–2019
ADF&G	Sport catch	1998–2019
ADF&G Southeast Longline Surveys	Survey catch numbers and CPUE	1998–2020
ADF&G Prince William Sound Longline Survey	Survey CPUE	1997–2006
ADF&G Prince William Sound Trawl Surveys	Survey CPUE	1999–2019

Fishery

This report summarizes incidental shark catches by species as four data time series: 1990–1998, 1997–2002, 2003–2012 and 2013–present. Shark catch by species was estimated by staff at the AFSC using a pseudo-blend approach (1990–1998, Gaichas et al. 1999), an improved pseudo-blend (1997–2002, Gaichas 2002), and since has been estimated by the NMFS AKRO Catch Accounting System (CAS). Data prior to 1997 are not used in this assessment and thus are not included. The 1990-1998 pseudo-blend catch estimates are reported in previous stock assessments for reference (Tribuzio et al. 2018). The improved pseudo-blend and CAS time series are used in this assessment (Figure 19.2 and Table 19.5). The observer program was restructured in 2013 and while the catch estimation procedure has been the same (CAS), the data inputs are now different. This restructuring increased observer coverage on vessels between 40 and 60 ft in length as well as incorporated those participating in the Pacific halibut IFQ fishery into the program. Because a large portion of shark catch originates from the vessels now included in the observer program, the catch time series beginning in 2013 may not be comparable to prior catch time series for sharks. While vessels participating in the Pacific halibut IFQ fishery in the BSAI are now included, the majority of the change in the composition of catch after observer restructuring went into effect was due to increased coverage in small vessels targeting Pacific cod (*Gadus macrocephalus*).

There are two major caveats with regards to the time series of shark catch: unobserved fisheries and bias in catch estimates. The catch estimates presented here do not include catches from unobserved fisheries.

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

Recent data also suggest a bias in the estimated catch for Pacific sleeper shark. Pacific sleeper shark are a large shark and difficult to bring on board most longline vessels. Any animals that are available for the observers to sample are generally small. Additionally, observers are limited to a 50 kg scale, and would need to take the time and have the space to cut anything heavier than 50 kg into smaller pieces to weigh. A special project to investigate the potential bias in the weight of animals that are measured compared to all of the pacific sleeper shark that were caught began in the 2018 and data collection will continue through the 2021 fishery. Preliminary results suggest that the average weight used to estimate the total catch underestimates the true size of the sharks being caught (Appendix 20A in Tribuzio et al. 2018).

The observer program was restructured in 2013 and it has likely resulted in changes in the estimates of shark catch, particularly in the Eastern GOA. Since 2013 there has been an increase in the proportion of total catch by sub-60 ft vessels in the GOA, and there was also an increase in the estimate of shark catch in the Pacific halibut target group. Further, vessels operating under Federal fisheries permits in Prince William Sound (NMFS area 649) and inside waters of Southeast Alaska (NMFS area 659) are now covered at a higher rate as a result of observer restructuring, and thus estimated catch from these two areas has increased. These catches do not count against the TAC, but should be monitored and are included in Table 19.3. The author is tasked with developing a working group to develop proposals for how best to account for catch occurring in federally managed fisheries occurring in NMFS Areas 649 and 659, but that do not count against the TAC.

Historical catch estimates for the shark complex are presented in Table 19.5. Catch by target fishery and area are shown in Figure 19.3 and Figure 19.5. Catch-at-length and catch-at-age data are not available from the fishery.

Survey

Catch at length

The spiny dogfish length frequency data presented here are from the AFSC bottom trawl surveys (GOA, Eastern Bering Sea shelf and slope and Aleutian Islands), AFSC and IPHC longline surveys and targeted research surveys. A formal stock assessment population model does not exist for the shark complex or any of the component species in the GOA; therefore, length frequency data are not used in the assessment specification procedures. Length data for spiny dogfish are part of standard collections on the AFSC longline and trawl surveys, as well as being regularly collected on the IPHC longline survey.

Length frequency data from the AFSC trawl and IPHC and AFSC longline surveys are presented for GOA spiny dogfish in Figure 19.8 (females) and Figure 19.9 (males). Female length data shows no significant difference in mean size between the surveys, however, the size distribution is shifted to larger animals on the IPHC and AFSC trawl surveys (Figure 19.8). The IPHC survey samples the entire U.S. and Canadian West Coast, therefore providing coast-wide regional comparisons of size frequencies

(Figure 19.10). Females are smaller in the GOA and BSAI as compared to Canada and the U.S. west coast, a trend is not seen in male length data (Figure 19.10).

Length data are limited for Pacific sleeper sharks, therefore lengths for the BSAI and GOA are combined for each data source (Figure 19.2, sexes combined). Genetic evidence suggests that the species is a continuous stock within the eastern North Pacific Ocean and therefore comparisons to other regions are valid. The authors have compiled length data for Pacific sleeper shark from standard and non-standard AFSC trawl surveys in the GOA and BSAI, the Northwest Fisheries Science Center (NWFSC) groundfish trawl survey off the U.S. West Coast, and International Pacific Halibut Commission (IPHC) longline surveys. The length data compiled thus far show that small animals (50 – 200 cm *TL*) are caught throughout their range along the North American coast, but within Alaskan waters, they tend to be larger in the GOA than in the Aleutian Islands or Bering Sea (Figure 19.11 and Figure 19.12), though most are still likely immature. In even years (BSAI surveys only) the AFSC trawl surveys catch smaller animals, many < 100 cm; while in odd years (GOA survey included) the surveys catch larger animals, some > 300 cm. None of the data sources report catching Pacific sleeper sharks at or greater than the reported size at maturity (365 cm for males, 397 cm for females). Catch of Pacific sleeper shark in the trawl surveys along the west coast of the U.S. is limited and no more than 10 sharks sampled in the last 10 years, thus a comparison to coast-wide sizes is not possible at this time.

Trawl Surveys

AFSC Trawl Survey Biomass Estimates

NMFS AFSC bottom trawl survey biomass estimates are available for the three primary shark species in the GOA (1984–2019, Table 19.8). Bottom trawl surveys were conducted on a triennial basis in the GOA in 1984, 1987, 1990, 1993, 1996, and a biennial survey schedule has been used since the 1999 survey. The surveys covered all areas of the GOA out to a depth of 1,000 m, with the following exceptions: the 1990, 1993, 1996, and 2001 surveys did not sample deeper than 500 m; the 2003, 2011, 2013, 2017 and 2019 surveys did not sample deeper than 700 m. Other important caveats are that the 2001 survey did not sample the Eastern GOA, thus removing an entire area of the estimation of biomass and the 2013, 2017 and 2019 surveys had a reduced number of stations, which likely increased uncertainty in biomass estimates. It is unlikely that these survey caveats would impact the estimation of shark biomass because most sharks are caught in strata shallower than 500 m, with the exception of the 2001 survey not sampling the Eastern GOA; however, it is important to note the potential for process error.

The 1984 survey results should be treated with some caution, as a different survey design was used in the eastern GOA. In addition, much of the survey effort in 1984 and 1987 was by Japanese vessels that used a very different net design than the standard used by U.S. vessels in the years since, introducing an element of uncertainty regarding the standardization of these two surveys.

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

Trawl survey catch of spiny dogfish is highly variable from year to year resulting in no obvious trend in biomass estimates (Table 19.8 and Figure 19.13). The 2007 biomass estimate of 162,759 t was followed by a drop to 27,880 t in 2009, and the coefficients of variation (CVs) range from 0.12–0.74 (Table 19.8 and Figure 19.13). The biomass of spiny dogfish has declined from the near record peak in 2013 of 160,384 t to 22,014 t (CV = 0.15) in 2019, its lowest value since 1990 estimate. Pacific sleeper sharks are caught in a small number of hauls each year and the bottom trawl survey is considered a poor indicator for this species (CVs range from 0.25-1.00). Trawl survey catch of Pacific sleeper sharks is highly variable. The highest the biomass estimate (70,933 t, CV = 0.57) occurred in 2015, followed by the lowest since 1990 in 2017, 6,561 t (CV = 1, Table 19.8 and Figure 19.13) in 2017. The number of hauls catching Pacific sleeper sharks has declined from 28 hauls in 2003 to just one haul in each of the last two surveys (Table 19.8). Salmon shark catch is rare in the trawl survey, and biomass estimates often have confidence intervals overlapping zero (Table 19.8). The biomass estimates for any of the species are not considered reliable.

<u>ADF&G Trawl Surveys</u>

Abundance indices from two large mesh trawl surveys were provided by ADF&G Southcentral Region: Kachemak Bay and Prince William Sound (1998–2018). The Kachemak Bay survey does not regularly encounter sharks. The Prince William Sound survey catches spiny dogfish semi-regularly and is included in this assessment for that species. There was a large spike in spiny dogfish CPUE in 2016, but otherwise the catches have been relatively stable (Figure 19.13).

Longline Surveys

<u>International Pacific Halibut Commission Annual Longline Survey</u>

The IPHC conducts a longline survey each year to assess Pacific halibut. This survey samples to depths of 500 m in the Aleutian Islands, Eastern Bering Sea, and the GOA in inside and outside waters, as well as areas south of Alaska. More information about this survey can be found in Goen et al. (2018). Total catch of sharks in the IPHC survey in weight and numbers is presented in Table 19.9.

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

Spiny dogfish IPHC RPNs have been increasing from the historic low in 2013 (Figure 19.13). Pacific sleeper shark RPNs declined steeply from 2001 through 2013 and dropped again in 2018 (Figure 19.14). Note that there are wide confidence intervals on the IPHC survey RPNs. Salmon shark are extremely rare in the IPHC survey, thus the RPNs do not provide useful information and are not presented.

The IPHC survey provides CPUE data coast-wide, allowing for regional comparisons of abundance trends, (i.e., BSAI, Canada = CAN, and the west coast of the U.S. = WC). Since 2013, the CPUE index for spiny dogfish in the BSAI has declined and leveled out, while it has increased in the GOA, where CPUE is higher (Figure 19.15). The index in Canada showed a similar pattern as the GOA, but delayed. The WC has less catch and more uncertainty. The indices for Pacific sleeper shark in the BSAI and GOA have declined from a high in 2000 and 2003, respectively (Figure 19.15), with a slight increase in the

BSAI in 2017. Catches are less common in CAN, but the current index is well below the historical high in 2000. Catches along the WC are rare and no trends are apparent.

AFSC Annual Longline Survey

The AFSC annual longline survey has a standard series of fixed stations spaced 30–50 km apart along the continental slope (each station samples depths from 150–1,000 m) and in select cross-shelf gullies. The U.S. time series starts in 1988, whereas the IPHC time series starts in 1998 and samples the continental shelf. Similar to the IPHC survey, the RPNs for spiny dogfish are variable and any trends are over short periods of time (e.g., the decline from 2006–2013, Figure 19.13). They are caught regularly at a small number of station. Pacific sleeper shark catch is rare on the AFSC longline survey and so those data are not presented.

ADF&G Longline Surveys

Staff from the ADF&G Southeast region provided data from two longline surveys: Chatham Strait and Clarence Strait. Further discussions will treat the Chatham Strait and Clarence Strait surveys as one Southeast Alaska (SEAK) inside waters survey. The spiny dogfish index in SEAK has trended downwards since 2009, and the Prince William Sound survey is highly variable (Figure 19.13).

The SEAK longline survey trend for Pacific sleeper shark mirrors the long decline in the IPHC survey data. There was also a sharp decline in the 2017 AFSC trawl survey (Figure 19.14). The downward trend in Pacific sleeper shark indices seen in these surveys indicate that either abundance is declining or sharks are becoming less available to the sampling gear. Some potential reasons could be that the number of immature sharks has declined, resulting in lower survey catch because smaller fish are likely more readily caught. Additionally, the depth distribution of the sharks may have changed making them less available to the surveys. One caveat with all three longline surveys is that hook competition has not been examined for sharks and so catch rates could fluctuate with the density of other species.

Distribution of catch in surveys

Due to the schooling nature of spiny dogfish, survey catch can be patchy, often with a small number of large spiny dogfish hauls. In most years spiny dogfish are caught mostly on the Fairweather grounds in northern Southeast Alaska and in Cook Inlet (Figure 19.16). Spiny dogfish are commonly caught at many of the IPHC stations across the GOA, and in inside waters of Southeast Alaska and Prince William Sound (Figure 19.17). Spatial distribution of spiny dogfish catch on the AFSC longline survey is more limited than the IPHC survey, due in part to fewer stations on the shelf (Figure 19.18). They are often caught at gully stations outside of Prince William Sound, Yakutat Bay and Southeast Alaska. Spiny dogfish catches on the ADF&G longline survey in inside waters of Southeast Alaska occur primarily in Clarence Strait (Figure 19.19).

The spatial distribution of Pacific sleeper shark catch on the bottom trawl survey is generally limited to Shelikof Strait and areas southwest of Kodiak Island (Figure 19.20). The IPHC and AFSC longline surveys also catch Pacific sleeper sharks often in Shelikof Strait, as well as scattered stations across the shelf (Figure 19.21 and Figure 19.22). Catch of Pacific sleeper shark by the IPHC occurs most frequently in Prince William Sound and inside waters of Southeast Alaska. In contrast to spiny dogfish, Pacific sleeper sharks are caught primarily in Chatham Strait during the SEAK longline survey (Figure 19.23).

Analytic Approach

Model Structure

Sharks in the GOA are managed under Tier 5 and 6 specifications. Pacific sleeper shark, salmon shark, and other/unidentified sharks are managed as Tier 6 species (harvest specifications based on the historical catch or alternatives accepted by the SSC), and no stock assessment modeling is performed. Species specific ABC and OFL estimates are based on the mean historical catch from 1997–2007. This approach has been used for these species since before there was a shark complex, thus to meet model numbering requirements, the Tier 6 models for these three species will be numbered Model 11.0, representing the first year that there was a shark complex TAC.

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

Spiny dogfish are managed as a Tier 5 species. Exploitable biomass is calculated using the accepted Model 15.3A, which uses the random effects model estimated biomass (B_{RFX}) adjusted by a catchability parameter to estimate an adjusted biomass (B_a, Tribuzio et al. 2018). The random effects modelling process incorporates the process errors (step changes) from one year to the next as the random effects, which are integrated over the process error variance as a free parameter. The observations can be irregularly spaced; therefore this model can be applied to datasets with missing data (e.g., 2001 when the survey did not sample the EGOA). Large observation errors increase errors predicted by the model, which can provide a way to weight predicted estimates of biomass. The random effects biomass model was fit separately by area (West, Central, and Eastern GOA) and then summed to obtain Gulfwide biomass (Table 19.10 and Figure 19.24). We fit the random effects model to regional data because the trawl survey did not sample the Eastern GOA in 2001, where a significant proportion of the spiny dogfish population resides within the GOA. The OFL is then calculated by multiplying the estimated exploitable biomass by the F_{OFL}.

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

Please see Survey Averaging Working Group document for more information on the random effects methodology and results across species (https://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2012/Sept/survey_average_wg.pdf).

Description of Alternative Models

None are presented this year.

Parameter Estimates

Life history parameters, where available, are presented for all the species in the complex in Table 19.1 and Table 19.2. Parameters include weight at length, length at age, natural mortality (M), maximum age and age at first recruitment, when available. Weight at length and average length parameters were derived from both directed research projects (all three species) and standard survey collections (spiny dogfish only). While generally not used to inform calculations of OFL and ABC, the information is indicative of the vulnerability of the species.

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

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

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

Results

Model Evaluation

None because no alternative models were presented.

Harvest Recommendations

We recommend continuing with Model 11.0 for Pacific sleeper shark, salmon shark, and other/unidentified sharks.

Species	Model	$\bar{C}_{1997-2007}$ (t)	OFL (t)	ABC (t)
Pacific Sleeper Shark	11.0	312	312	234
Salmon Shark	11.0	70	70	53
Other/Unidentified Sharks	11.0	188	188	141

We recommend continuing with Model 15.3A for spiny dogfish.

Model	F_{OFL}	B_{RFX} (95% CI)	Ba (95% CI)	OFL (95% CI)	ABC (95% CI)
15.3A	0.04	23,289 (10,066–53,880)	110,900 (47,934–256,571)	4,436 (1,917–10,263)	3,327 (1,438–7,697)

Amendment 56 Reference Points

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

Parameter	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other/Unid Sharks	Total Complex
Tier	5	6	6	6	5/6
Mean Catch		312	70	188	570
OFL	4,436	312	70	188	5,006
ABC	3,327	234	53	141	3,755
F_{OFL}	0.04				0.04
F_{ABC}	0.03				0.03
B_a	110,900				110,900
B_{RFX}	23,289 (10,066 – 53,880)				23,289 (10,066 – 53,880)
q	0.21				0.21

Specification of OFL and Maximum Permissible ABC

GOA Shark Complex Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year for: 2021	2022
Tier	5/6	5/6	5/6	5/6
OFL (t)	10,913	10,913	**5,006**	5,006
maxABC (t)	8,184	8,184	3,755	3,755
ABC (t)	8,184	8,184	**3,755**	3,755

Risk Table and ABC Recommendation

Overview

The following template is used to complete the risk table:

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

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

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

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

Assessment Considerations

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

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

The assessment risk level for the full complex is rated a Level 2, representing the most concerning value among the species.

Population Dynamics Considerations

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

Pacific sleeper shark stocks trends appear to be declining. Most of the surveys do not sample the species well, with the exception of the IPHC and ADFG Southeast Alaska longline surveys. Those indices are not included in considerations of OFL within this assessment. The Pacific sleeper shark indices from both surveys declined from their peak in the early 2000s (Figure 19.14). This trend is mirrored in other regions (e.g., BSAI, Canada and U.S. West Coast) within the IPHC survey range. It is unclear if the peak at the beginning of the time series was unusual, or if the current low state reflects low population size. We consider this a level 2 concern for Pacific sleeper shark because of the potential vulnerability to overfishing of the species and low productivity; however, we acknowledge that stock status is unknown.

The population dynamics risk level for the full complex is rated a Level 2, representing the most concerning value among the species.

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

Water temperatures may impact shark abundances, linked through prey availability, as opposed to direct impacts on growth or survival. Sharks are highly mobile and able to shift distributions with temperatures, and 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. Tagging data on all three species shows that they are all highly mobile, both horizontally and vertically, and able to move in response to temperature shifts (Hulbert et al. 2006, Tribuzio unpublished data, Weng et al. 2005).

Heat wave conditions occurred during 2020 but were not as severe as 2019 during the summer and fall in the GOA (Watson et al. 2020). Sea surface temperatures were about 1°C above normal in the western GOA and average in the eastern GOA during the 2020 summer (Alaska Center for Climate Assessment & Policy ACCAP, Thoman personal communication, Thoman and Walsh 2019). Inside waters of the GOA were slightly more anomalously warm than offshore temperatures (ACCAP). Offshore of Seward, waters above the continental shelf at GAK1 along the Seward GAK line remained anomalously warm (0.5°C) at 200-250 m depth in 2020 but cooler than 2019 (Danielsen and Hopcroft 2020). Along the GOA slope, 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). In the inside waters, Prince William Sound has remained warm since 2014 (Campbell and McKinstry 2020). However, for the inside waters of the eastern GOA, the top 20 m temperatures of Icy Strait in northern southeast Alaska during summer were slightly below average (8.8°C) in 2020 relative to the 23 year time series (1997-2019) (Fergusson personal communications). Overall, water temperatures in 2020 were warmer, but unlikely to cause substantial impacts to the stocks of the three species assessed in this stock.

Sharks depend upon prey availability and are opportunistic feeders. Preferred prey items vary by species and size. Small sharks feed on forage fish and shrimp. Larger sharks feed on larger fish. Primary prey include forage fish for spiny dogfish, squid for sleeper shark, and salmon for the salmon shark. There was little information on zooplankton, forage fish, and salmon in the GOA during 2020. Warm conditions tend to be associated with zooplankton communities, prey for forage fish, that are dominated by smaller and less lipid rich species (Kimmel et al. 2019). In the inside waters of Icy Strait, northern southeast Alaska, total zooplankton densities were at the 24 year mean and the lipid content of all zooplankton taxa combined examined during 2020 was average for the time series (1997-2020) and similar to 2019 (Fergusson and Rogers 2020). By taxa, lipid content was above average for the large calanoid copepods, average for hyperiid amphipods, but lower than average for euphausiids, small copepods and gastropods indicating average nutritional quality of the prey field possibly utilized by larval, juvenile, and adult rockfish (Fergusson and Rogers 2020). Adult salmon, prey for salmon shark, had low returns for GOA stocks in 2020 (Murphy et al. 2020).

The 2020 foraging conditions for sharks were likely average, although data limited, for the largely crustacean and fish eating sharks in the GOA. Given cooler conditions in 2020 than in 2019 and average densities and limited information on environmental linkages to shark abundances, we scored this category as Level 1, as normal concern. There are some indicators showing positive and negative signals relevant to the stock but the pattern was not consistent across all indicators, and the actual effect is unknown.

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 GOA, only spiny dogfish mean catch per trip showed any trend: variable catch but increasing on average since 2003. This trend somewhat mirrors total catch, however, when total catch is broken into pre- and post-observer restructuring, the catch trends are flat. When examining mean catch per trip of spiny dogfish by gear and target fishery, it is evident that the increasing trend is primarily in the longline fisheries for Pacific halibut and Pacific cod. There was no fishery for Pacific cod in the GOA FMP in 2020. This trend could be due in part to the increased observer coverage resulting from the 2013 observer restructuring. There has also been a substantial increase in the mean catch per trip of Pacific sleeper shark in the Pacific halibut longline fishery since 2017. In summary, if the mean catch of sharks per trip is considered an indicator of fishery performance, spiny dogfish catch is increasing in longline fisheries and Pacific sleeper shark has recently increased as well.

The ABCs for the shark complex have not been exceeded and have not limited other fisheries. 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 5/6 complex.

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

Ecosystem Considerations

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

Ecosystem Effects on Stock

Pacific sleeper shark

There are few formal diet studies on Pacific sleeper sharks, but most evidence collected to date suggests they are opportunistic feeders with a varied diet, fulfilling ecological roles as both active predators and facultative scavengers. Pacific sleeper sharks were once thought to be 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 (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. 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, and halibut (Tribuzio, unpublished data). Pinnipeds including harbor seals, California sea lions, 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 18-24 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 species that generally have the greatest shark catches, Pacific cod, sablefish and walleye pollock. It is assumed that all sharks presently caught in commercial fishing operations that are discarded do not survive. This could constitute a source of dead organic material to the ecosystem that would not otherwise be there, but also the removal of a top predator. Removing sharks can have the effect of releasing competitive pressure or predatory pressures on prey species. Studies have shown that removal of top predators may alter community structure in complex and non-intuitive ways, and that indirect demographic effects on lower trophic levels may occur (Ruttenberg et al. 2011).

Data Gaps and Research Priorities

Data limitations are severe for shark species in the GOA, making effective management of sharks extremely difficult. Gaps include inadequate catch estimation, unreliable biomass estimates, lack of fishery size frequency collections, and a lack of life history information including age and maturity, especially for Pacific sleeper sharks. It is essential to continue to improve the collection of biological data on sharks in the fisheries and surveys. Future shark research priorities will focus on the following areas:

1. Investigate concerns regarding accuracy of catch estimates for Pacific sleeper shark due to difficulty of obtaining accurate weights.
   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 movement patterns (i.e. tagging studies, genetics).
   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. Investigate improved data-limited assessment methods.
   a. Actions: Working with DLM experts to develop an appropriate assessment for the Tier 6 sharks
4. Investigate methods of improving the understanding of life history for Pacific sleeper shark
   a. Actions: Initiated a pilot study using eye lens ^{14}C for ageing, and have submitted a proposal to fund the full project.

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Tables

Table 19.1. Biological characteristics and depth ranges for shark species in the Gulf of Alaska. The life history data reported in this table are specific to the Northeast Pacific Ocean when available; however, some data sources are from other regions (e.g., North Atlantic) 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 "?". Species in bold are the primary species in this assessment.

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]
Alopias vulpinus	Common thresher shark	640[1]	≥38[10]	303 cm TL[11]	Predator[11]	2-7[11]	0-366[1]
Apristurus brunneus	Brown cat shark	71[1]	?	♀50.1 cm TL, ♂51.4 cm TL[12]	Benthic[13]	?	33-1,306[1]
Carcharodon carcharias	White shark	700[14]	≥30[15]	♀450 cm TL, ♂310 cm TL[16]	Predator[3]	6-10[17]	0-1,280[1]
Cetorhinus maximus	Basking shark	1,227[14]	?	♀8.1-9.8 m TL, ♂4.0-5.0 m TL[5]	Plankton[3]	34[18]	0-1,500[19]
Galeorhinus galeus	Tope (soupfin) shark	195[5]	59[20]	♀17 yr, 155 cm TL, ♂12 yr, 121 cm TL[20]	Predator/Benthic[21]	16-54[21]	0-1,100[22]
Hexanchus griseus	Bluntnose sixgill shark	550[14]	?	♀421 cm TL[23]	Predator[3]	22-108[23]	0-2,500[1]
Notorynchus cepedianus	Broadnose sevengill shark	296[24]	?	♀220-250 cm TL, ♂150-180 cm TL[25]	Predator/Benthic/Scavenger[5]	60-107[24]	0-570[22]
Prionace glauca	Blue shark	380[1]	25[26]	♀5-7 yr, 194 cm TL, ♂4-7 yr, 201 cm TL[26]	Predator[3]	4-135[26]	0-350[1]

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

Table 19.2. Life history parameters for spiny dogfish, Pacific sleeper, and salmon sharks. Top: Length-weight coefficients and average lengths and weights are provided for the formula $W = aL^b$, where W = weight in kilograms and L = PCL (precaudal length in cm). Bottom: Length at age coefficients from the von Bertalanffy growth model, where L_∞ is PCL or the TL_{ext} (total length with the upper lobe of the caudal fin depressed to align with the horizontal axis of the body).

Species	Area	Gear type	Sex	Average size PCL (cm)	Average weight (kg)	a	b	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	Age at first Recruit
Spiny Dogfish	M	93.7 (TL_{ext})	0.06	-5.1	0.097	NA
Spiny Dogfish	F	132.0 (TL_{ext})	0.03	-6.4		
Pacific Sleeper Shark	M	NA	NA	NA	NA	NA
Pacific Sleeper Shark	F	NA	NA	NA		
Salmon Shark	M	182.8 (PCL)	0.23	-2.3	0.18	5
Salmon Shark	F	207.4 (PCL)	0.17	-1.9		

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

Table 19.3. Time series of catch, total allowable catch (TAC), and acceptable biological catch (ABC) for sharks and Other Species in the Gulf of Alaska (GOA). Note that the decrease in TAC in 2008 was a regulatory change and not based on biological trends. The Other Species complex was dissolved and the shark complex was created for the 2011 fishery. Catches in state waters (Prince William Sound Inside, PWSI - NMFS area 649, and Southeast Inside, SEI - NMFS area 659) are also included, but are not used in calculations of ABC, nor do those catches count against the TAC. The column “Est. Shark Catch GOA” only includes catch which counts against the TAC while the “Total Shark Catch” includes the state waters catch.

Year	TAC	Other Sp. Catch	Est. Shark Catch GOA	Est. Shark Catch PWSI	Est. Shark Catch SEI	Est. Total Shark Catch	ABC	Management Method
1992	13,432	12,313	517				N/A	Other Species TAC (included Atka)
1993	14,602	6,867	1,027				N/A	Other Species TAC (included Atka)
1994	14,505	2,721	360				N/A	Other Species TAC
1995	13,308	3,421	308				N/A	Other Species TAC
1996	12,390	4,480	484				N/A	Other Species TAC
1997	13,470	5,439	1,041				N/A	Other Species TAC
1998	15,570	3,748	2,389				N/A	Other Species TAC
1999	14,600	3,858	1,037				N/A	Other Species TAC
2000	14,215	5,649	1,117				N/A	Other Species TAC
2001	13,619	4,801	853				N/A	Other Species TAC
2002	11,330	4,040	427				N/A	Other Species TAC
2003	11,260	6,266	715	26	9	750	N/A	Other Species TAC
2004	12,592	1,705	545	3	24	572	N/A	Other Species TAC*
2005	13,871	2,513	1,054	5	43	1,102	N/A	Other Species TAC
2006	13,856	3,881	1,557	13	82	1,652	N/A	Other Species TAC
2007	12,229	3,035	1,337	8	23	1,368	1,792	Other Species TAC
2008	4,500	2,967	616	1	5	622	1,792	Other Species TAC
2009	4,500	3,188	1,742	23	78	1,843	777	Other Species TAC
2010	4,500	1,724	695	10	7	712	957	Other Species TAC
2011	6,197	NA	529	4	4	537	6,197	Shark Complex TAC[#]
2012	6,028	NA	669	5	15	689	6,028	Shark Complex TAC
2013	6,028	NA	2,181	59	216	2,456	6,028	Shark Complex TAC
2014	5,989	NA	1,576	52	126	1,754	5,989	Shark Complex TAC
2015	5,989	NA	1,401	85	69	1,555	5,989	Shark Complex TAC
2016	4,514	NA	1,972	71	152	2,195	4,514	Shark Complex TAC
2017	4,514	NA	1,763	356	221	2,340	4,514	Shark Complex TAC
2018	4,514	NA	3,423	43	159	3,625	4,514	Shark Complex TAC
2019	8,184	NA	1,997	70	124	2,191	8,184	Shark Complex TAC
2020	8,184	NA	1,117	103	134	1,354	8,184	Shark Complex TAC

*Skates were removed from the GOA Other Species category in 2003.
[#]Other Species were broken up, Shark Complex is formed
Sources: TAC and Other Species catch from AKRO. Estimated shark catches from 1992-1996 from Gaichas et al. 1999, catches from 1997-2002 from Gaichas et al. 2003 and catches from 2003-2020 from AKRO Catch Accounting System (CAS, queried through AKFIN on Oct. 13, 2020).

Table 19.4. Estimated numbers of retained and discarded sharks in the Alaska Department of Fish and Game managed recreational fishery in the Gulf of Alaska. Estimates of total numbers, with discard rate in parentheses, are derived from the Statewide Harvest Survey. Salmon shark catch from the charter vessel fleet are all retained and numbers come directly from logbooks. Recreational catch of sharks does not count against the total allowable catch (TAC). Source: Sarah Webster, ADF&G. Note that these numbers have not been updated for this assessment.

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

Table 19.5. Estimated incidental catch (t) of sharks in the Gulf of Alaska (GOA) by species as of October 13, 2020. Catch from 1997 – 2002 was estimated by the pseudo-blend catch estimation procedure (Gaichas 2001, 2002); 2003 – 2020 from the Alaska Regional Office Catch Accounting System. Breaks in the table represent different catch estimation periods.

Year	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other Sharks	GOA Total
1997	658	136	124	123	1,041
1998	864	74	71	1,380	2,389
1999	314	558	132	33	1,037
2000	398	608	38	73	1,117
2001	494	249	33	77	853
2002	117	226	58	26	427
-	-	-	-	-	-
2003	357	270	35	53	715
2004	183	282	41	39	545
2005	443	482	60	69	1,054
2006	1,188	252	34	83	1,557
2007	794	295	141	107	1,337
2008	531	66	7	12	616
2009	1,653	56	9	24	1,742
2010	408	170	108	9	695
2011	491	26	7	5	529
2012	465	144	50	10	669
2013	2,078	94	3	6	2,181
2014	1,351	72	147	6	1,576
2015	952	70	362	17	1,401
2016	1,801	74	90	7	1,972
2017	1,610	130	13	10	1,763
2018	3,133	260	6	24	3,423
2019	1,875	92	15	15	1,997
2020	983	98	31	5	1,117

Table 19.6. Estimated catch of Pacific sleeper shark and spiny dogfish in the inside waters of Prince William Sound (PWSI, NMFS area 649) and Southeast Alaska (SEI, NMFS area 659). These catch estimates do not count against the total allowable catch (TAC). Salmon shark and Other/Unidentified sharks are not included because catch is rare. Data are from the Alaska Regional Office Catch Accounting System (queried through AKFIN on Oct 13, 2020).

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

Table 19.7. Estimated discard rates of sharks (by species) caught in the Gulf of Alaska. Years with no data are left blank. Data queried through AKFIN on Oct 13, 2020

Year	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/ Unidentified shark	All Sharks
2003	98%	100%	100%	93%	98%
2004	96%	100%	100%	91%	98%
2005	98%	99%	98%	69%	97%
2006	96%	99%	97%	78%	96%
2007	96%	100%	100%	90%	97%
2008	93%	98%	94%	59%	93%
2009	98%	98%	99%	7%	97%
2010	95%	95%	98%	24%	94%
2011	98%	94%	98%	14%	97%
2012	97%	100%	99%	46%	97%
2013	99%	100%	100%	55%	99%
2014	99%	99%	100%	55%	99%
2015	99%	100%	100%	63%	99%
2016	99%	100%	99%	70%	99%
2017	98%	99%	73%	32%	98%
2018	99%	100%	93%	77%	99%
2019	98%	100%	91%	87%	98%
2020	97%	95%	92%	91%	97%
Mean	98%	99%	94%	59%	98%

Table 19.8. Gulf of Alaska, Alaska Fisheries Science Center trawl survey estimates of individual shark species total biomass (t) with coefficient of variation (CV) and number of hauls with catches of sharks. Data updated October 13, 2020 (RACEBASE, queried through AKFIN).

		Spiny Dogfish			Pacific Sleeper Shark			Salmon Shark			
Year	**Total # of Survey Hauls**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls w/Catch**	**Biomass**	**CV**	**Hauls w/Catch**	**Biomass**	**CV**	**Total Shark Biomass**
1984	929	125	10,143	0.21	1	163	1.00	5	7,849	0.52	18,155
1987	783	122	10,107	0.27	8	1,319	0.43	15	12,623	0.56	24,049
1990	708	114	18,947	0.38	3	1,651	0.66	13	12,462	0.30	33,061
1993	774	166	33,645	0.20	13	8,657	0.50	9	7,729	0.36	50,030
1996	807	99	28,478	0.74	11	21,101	0.36	1	3,302	1.00	52,881
1999	764	168	31,743	0.14	13	19,362	0.40	0	0	0.00	51,105
2001[*,#]	489	75	31,774	0.45	15	37,695	0.36	0	0	0.00	69,469
2003	809	204	98,744	0.22	28	52,116	0.25	2	3,613	0.71	154,472
2005	837	156	47,939	0.17	25	57,022	0.26	1	2,455	1.00	107,416
2007	816	161	162,759	0.35	15	41,849	0.41	2	12,340	0.75	216,948
2009	823	176	27,880	0.12	8	39,688	0.45	0	0	0.00	67,568
2011[$]	670	97	41,093	0.22	5	29,496	0.54	1	3,766	1.00	74,355
2013[$]	548	58	160,384	0.40	6	40,848	0.46	1	3,978	1.00	205,211
2015	771	81	51,916	0.25	6	70,933	0.57	2	5,931	0.88	128,780
2017[$]	536	112	53,978	0.19	1	6,561	1.00	0	0	0.00	60,540
2019[$]	541	110	22,014	0.15	1	4,878	1.00	0	0	0.00	26,892

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

Table 19.9. Research survey catch of sharks 1977 - 2019 in the Gulf of Alaska. The Alaska Fisheries Science Center (AFSC) longline (LL) and International Pacific Halibut Commission (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 catch weight (t) is directly from the survey fish tickets. Beginning in 2010 all research and other non-commercial catch is provided by the Alaska Regional Office.

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	0.14					
1978	1.44					
1979	1					
1980	0.86					
1981	2.23					
1982	0.36					
1983	1.03					
1984	3.12					
1985	0.96					
1986	1.38					
1987	3.55					
1988	0.27					
1989	0.87	751				
1990	3.52	583				
1991	0.15	2,039				
1992	0.12	3,881				
1993	5.03	2,557				
1994	0.43	2,323				
1995	0.57	3,882				
1996	3.48	2,206				
1997	0.52	2,822				
1998	0.58	7,701		42,361		
1999		1,185		21,705		
2000		1,212		29,257		
2001	0.45	1,726		34,227		
2002		1,576		22,028		
2003	7.36	2,372		68,940		
2004		1,964		48,850		
2005	7.13	3,775		44,082		
2006	0	6,593		41,355		
2007	14.06	3,552		34,023		
2008	0.73	3,606		24,655		
2009	4.03	4,709		29,299		
2010	0.07	2,622	6.18		391.48	9.65
2011	2.71	2,103	4.12		149.44	5.67
2012	0	1,835	5.30		187.30	6.06
2013	8.54	1,012	2.56		288.26	5.32
2014	1.94	2,843	8.09		147.92	14.69
2015	4.62	2,386	5.10		230.08	9.42
2016	0	2,259	4.86		318.16	4.64
2017	2.27	3,129	8.32		169.26	5.97
2018	0	811	2.11		129.22	10.01
2019	1.16	2,076	5.24		248.74	7.46

Table 19.10. Biomass of spiny dogfish estimated using a the random effects model with 95% confidence intervals (CI).

Year	Western	Central	Eastern	Total GOA	Lower 95% CI	Upper 95% CI
1984	64	2,140	7,915	10,120	6,880	14,886
1985	128	2,135	7,708	9,972	4,588	21,676
1986	256	2,131	7,507	9,894	4,527	21,622
1987	511	2,126	7,311	9,948	6,319	15,662
1988	430	3,582	5,826	9,838	4,867	19,888
1989	362	6,036	4,642	11,040	5,390	22,611
1990	305	10,169	3,699	14,173	8,081	24,857
1991	256	9,143	6,775	16,174	7,880	33,200
1992	215	8,220	12,410	20,845	10,440	41,621
1993	181	7,391	22,728	30,300	20,917	43,890
1994	192	5,939	22,381	28,512	12,540	64,824
1995	203	4,773	22,039	27,015	10,477	69,658
1996	216	3,835	21,702	25,753	10,979	60,404
1997	207	6,181	19,735	26,123	10,652	64,063
1998	199	9,962	17,946	28,107	13,546	58,318
1999	191	16,056	16,320	32,566	24,992	42,436
2000	189	21,901	20,099	42,189	21,797	81,658
2001	188	29,874	24,753	54,816	28,435	105,670
2002	135	37,427	30,486	68,048	34,745	133,274
2003	97	46,891	37,546	84,533	58,857	121,411
2004	81	30,168	35,667	65,916	36,316	119,640
2005	67	19,409	33,882	53,359	39,246	72,547
2006	80	22,486	50,113	72,679	37,894	139,395
2007	96	26,051	74,118	100,266	59,791	168,139
2008	127	17,512	36,496	54,135	28,701	102,106
2009	169	11,771	17,971	29,911	23,852	37,508
2010	176	13,487	22,281	35,944	19,713	65,537
2011	184	15,452	27,625	43,261	29,697	63,020
2012	192	16,965	46,474	63,631	31,650	127,929
2013	201	18,626	78,185	97,011	53,554	175,730
2014	205	19,147	52,645	71,996	35,438	146,269
2015	209	19,683	35,448	55,340	36,280	84,414
2016	198	22,208	29,529	51,935	27,985	96,384
2017	187	25,058	24,599	49,844	35,719	69,554
2018	176	18,590	15,150	33,916	18,835	61,073
2019	166	13,792	9,330	23,289	17,675	30,686
2020	166	13,792	9,330	23,289	10,066	53,880
2021	166	13,792	9,330	23,289	7,100	76,390
2022	166	13,792	9,330	23,289	5,297	102,392

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

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

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

Figures

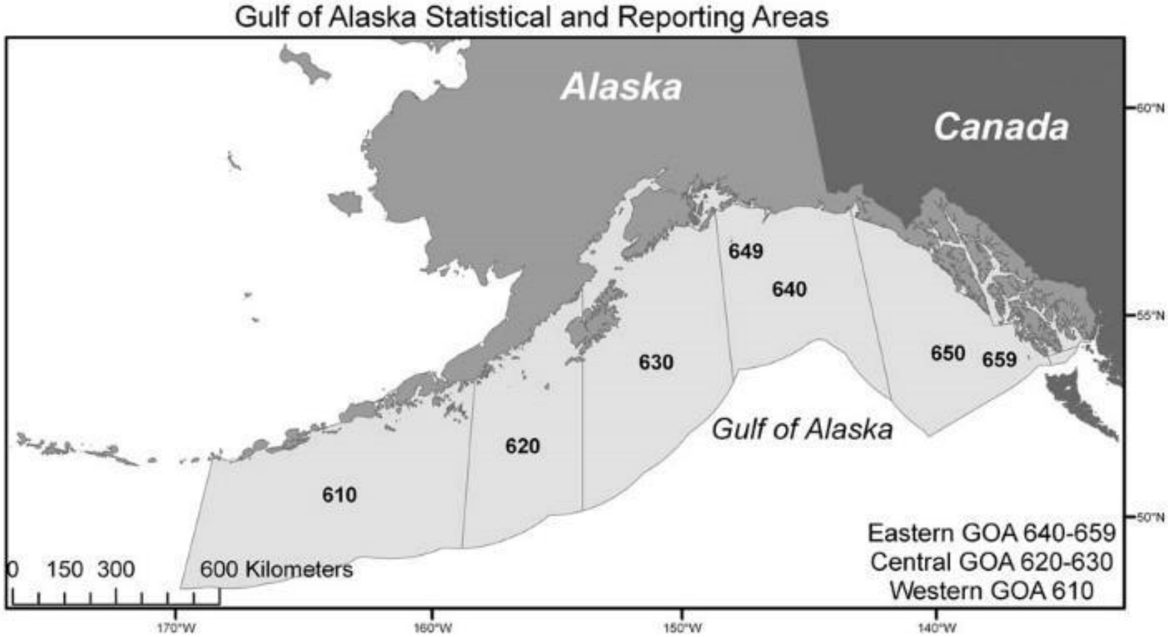

Figure 19.1. NMFS statistical and regulatory areas in the Gulf of Alaska, NMFS Area 649 is Prince William Sound and 659 is Southeast Alaska.

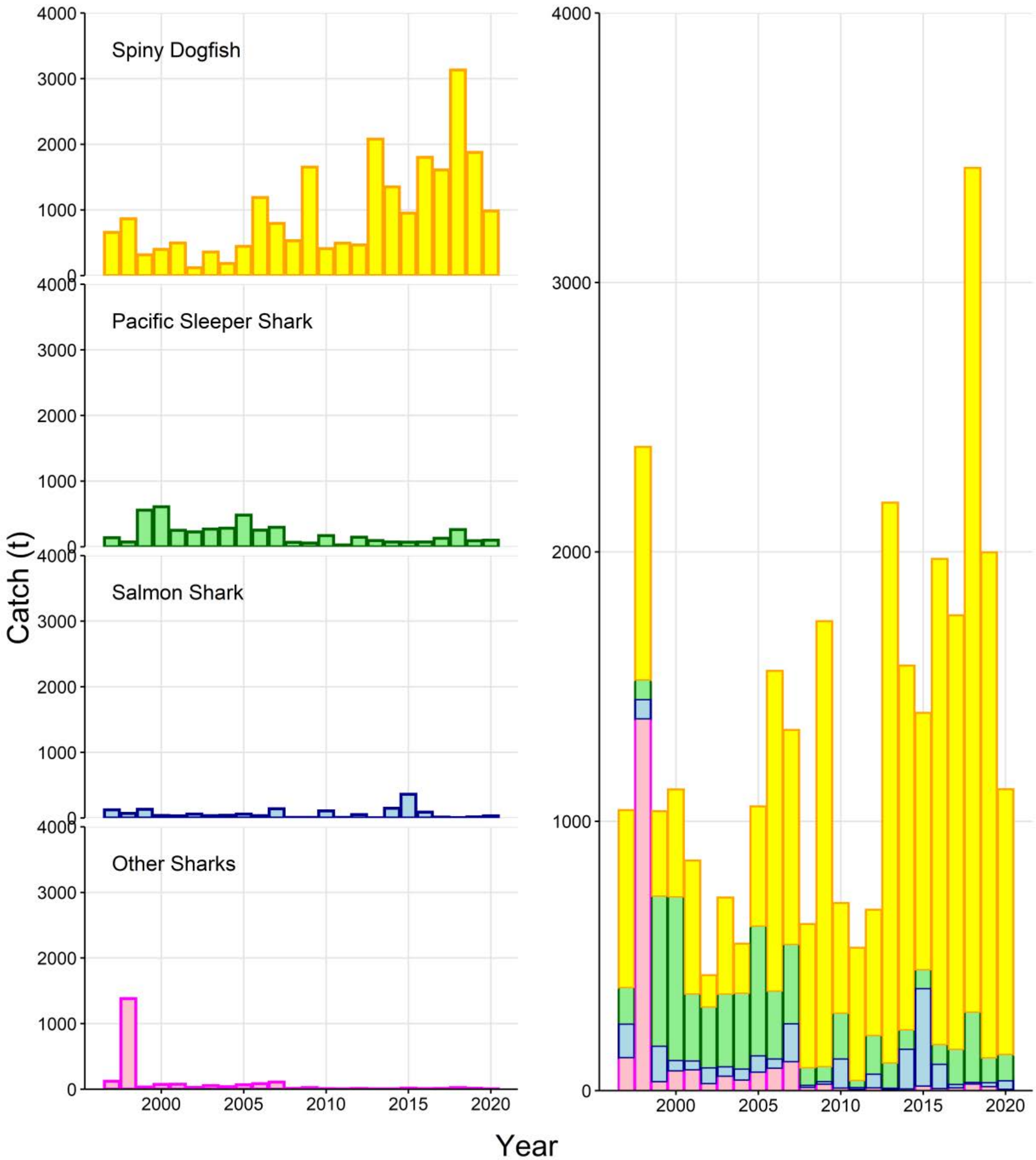

Figure 19.2. Estimated incidental catch (t) of sharks in the Gulf of Alaska (GOA) by species. 1997–2001 catch estimated with improved pseudo-blend (Gaichas 2002); and 2003–2020 was estimated by the Alaska Regional Office Catch Accounting System (queried through AKFIN on October 13, 2020).

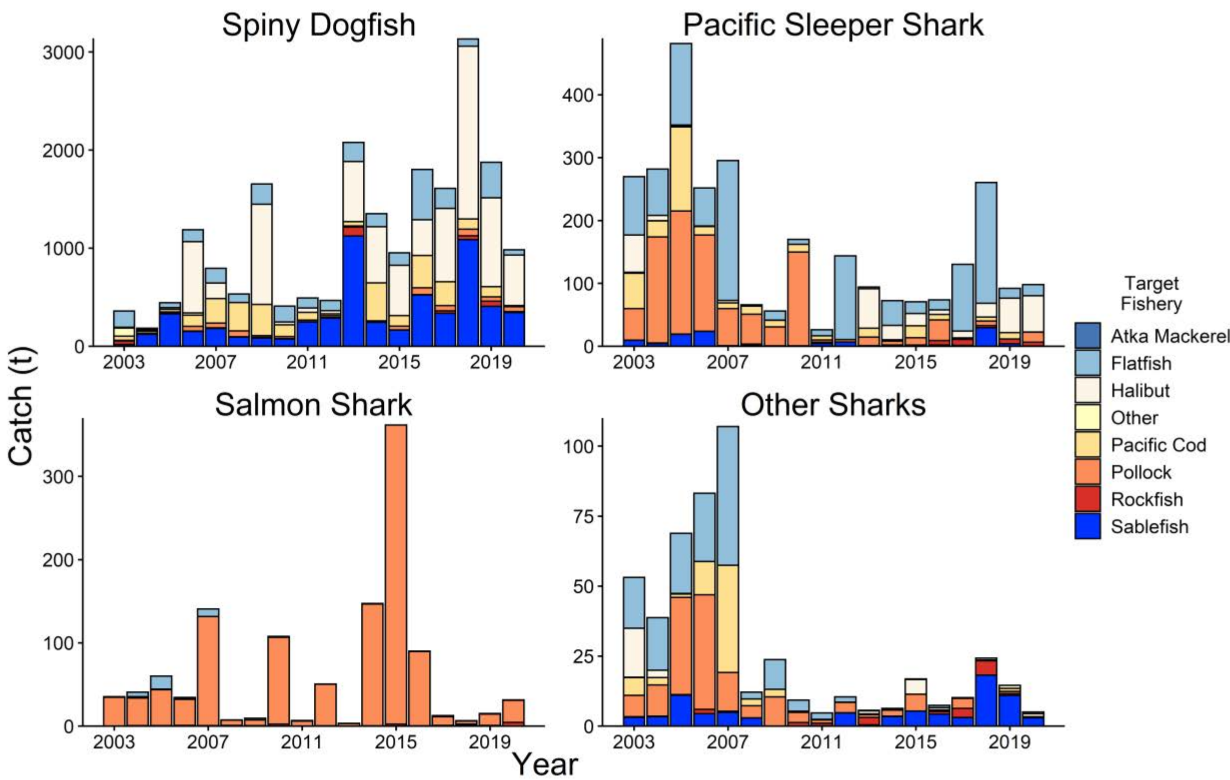

Figure 19.3. Estimated catch of sharks by target fishery in the Gulf of Alaska, from 2003–2020, These data are form the Alaska Regional Office Catch Accounting System queried through AKFIN on October 13, 2020.

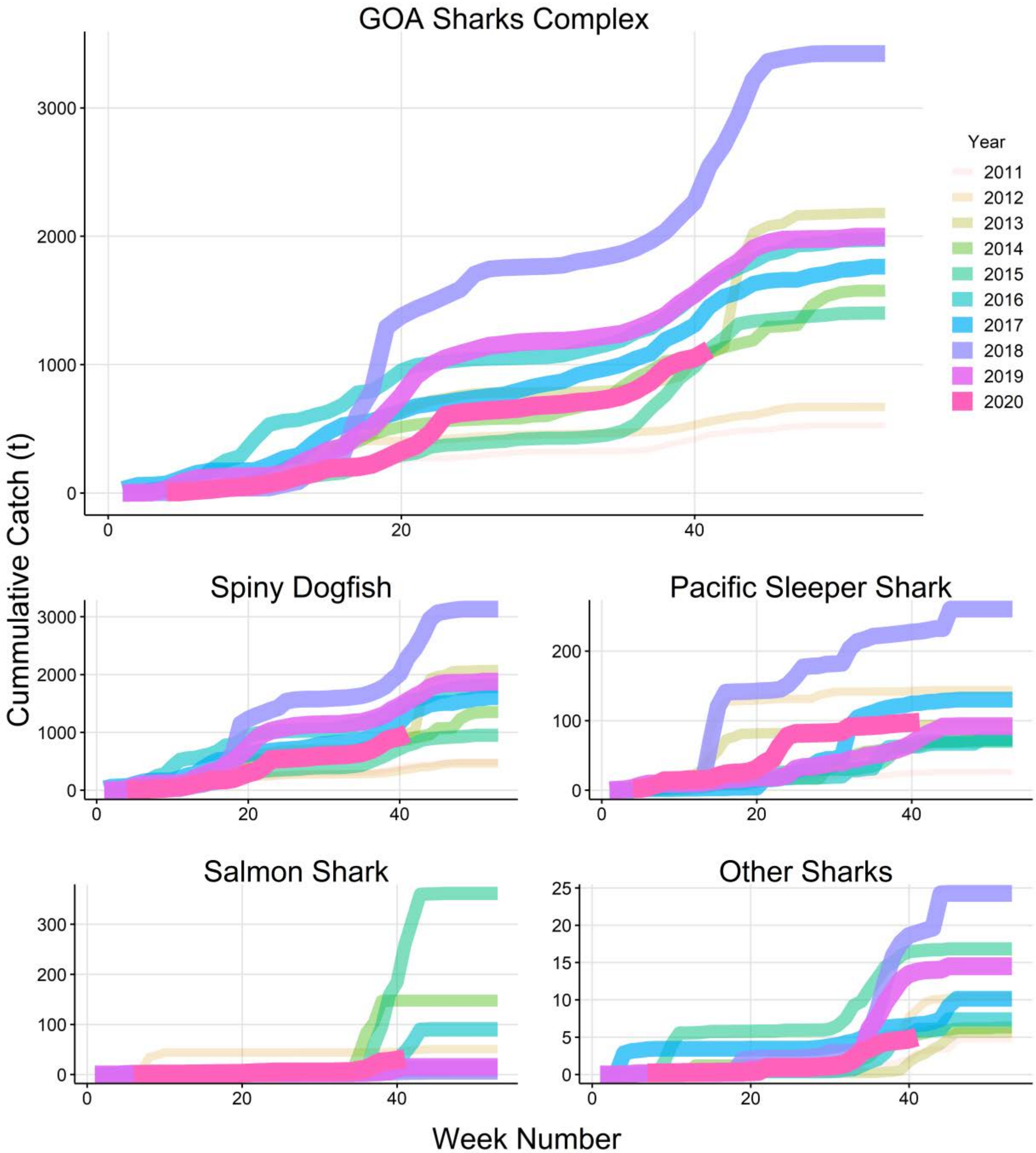

Figure 19.4. Cumulative catch in tons of all sharks in the Gulf of Alaska FMP From 2011-2020. Data are provided by the AKRO, queried through AKFIN October 13, 2020.

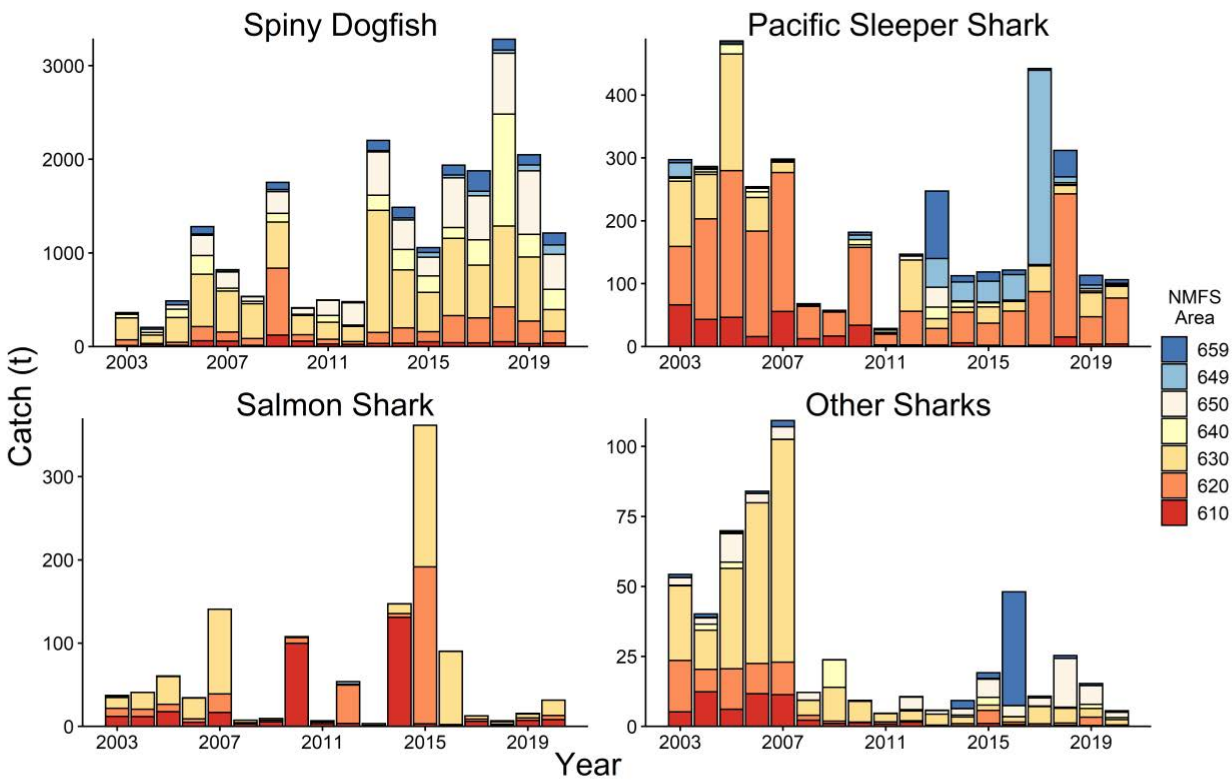

Figure 19.5. Estimated catch of sharks by NMFS area in the Gulf of Alaska from 2003–2020, Alaska Regional Office Catch Accounting System queried through AKFIN on October 13, 2020. Catch occurring in NMFS areas 649 (Prince William Sound) and 659 (Southeast Alaska inside waters), those areas in shades of blue, are presented here to show presence of catch, but do not count against the total allowable catch (TAC). Only areas in shades of yellow/red count against the TAC.

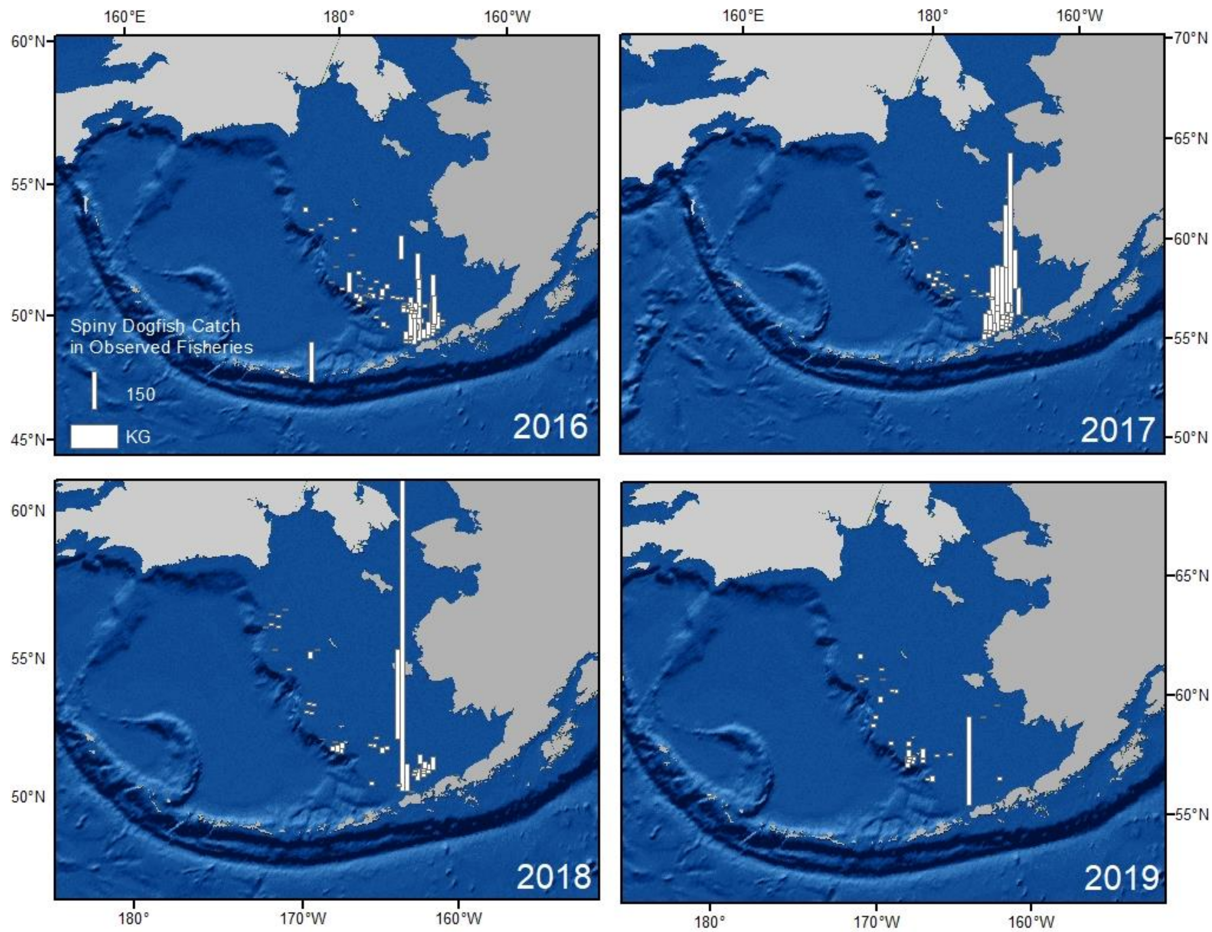

Figure 19.6. Spatial distribution of observed spiny dogfish catch in the Gulf of Alaska from 2016–2019. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400 km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 13, 2020 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

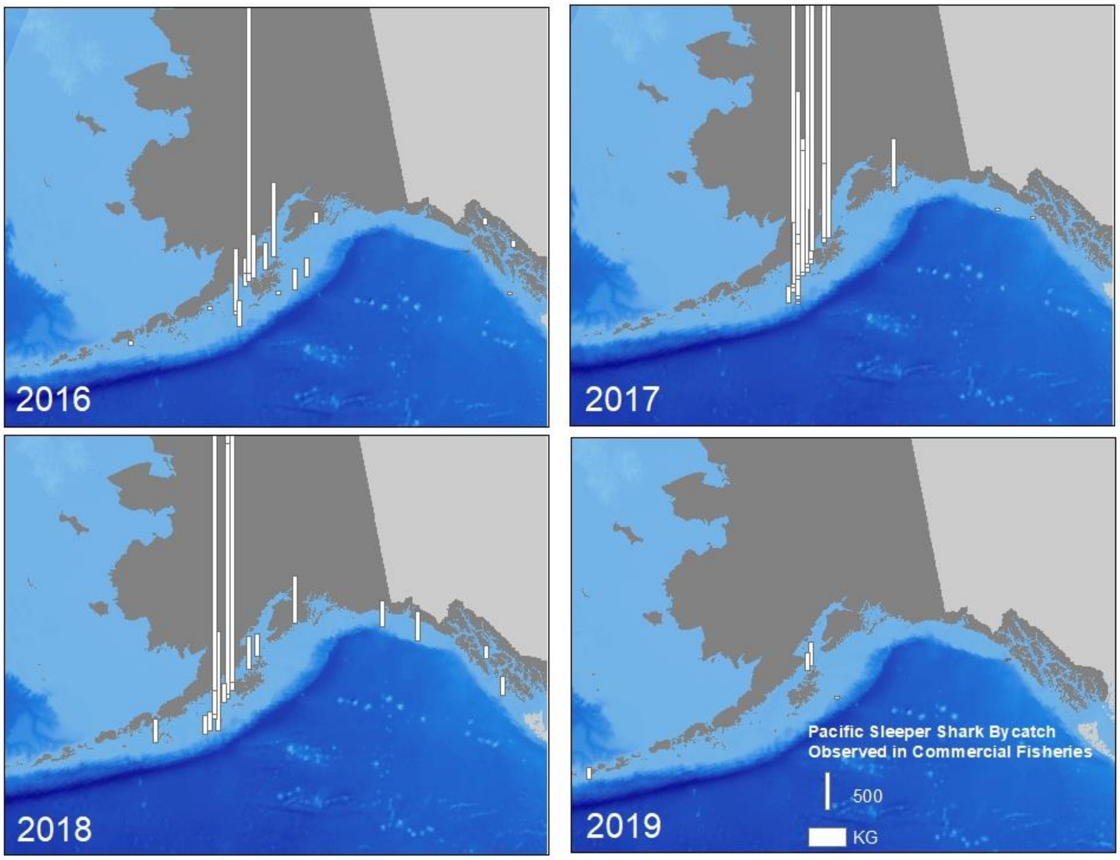

Figure 19.7. Spatial distribution of observed Pacific sleeper shark catch in the Gulf of Alaska from 2016-2019. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400 km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 13, 2020 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

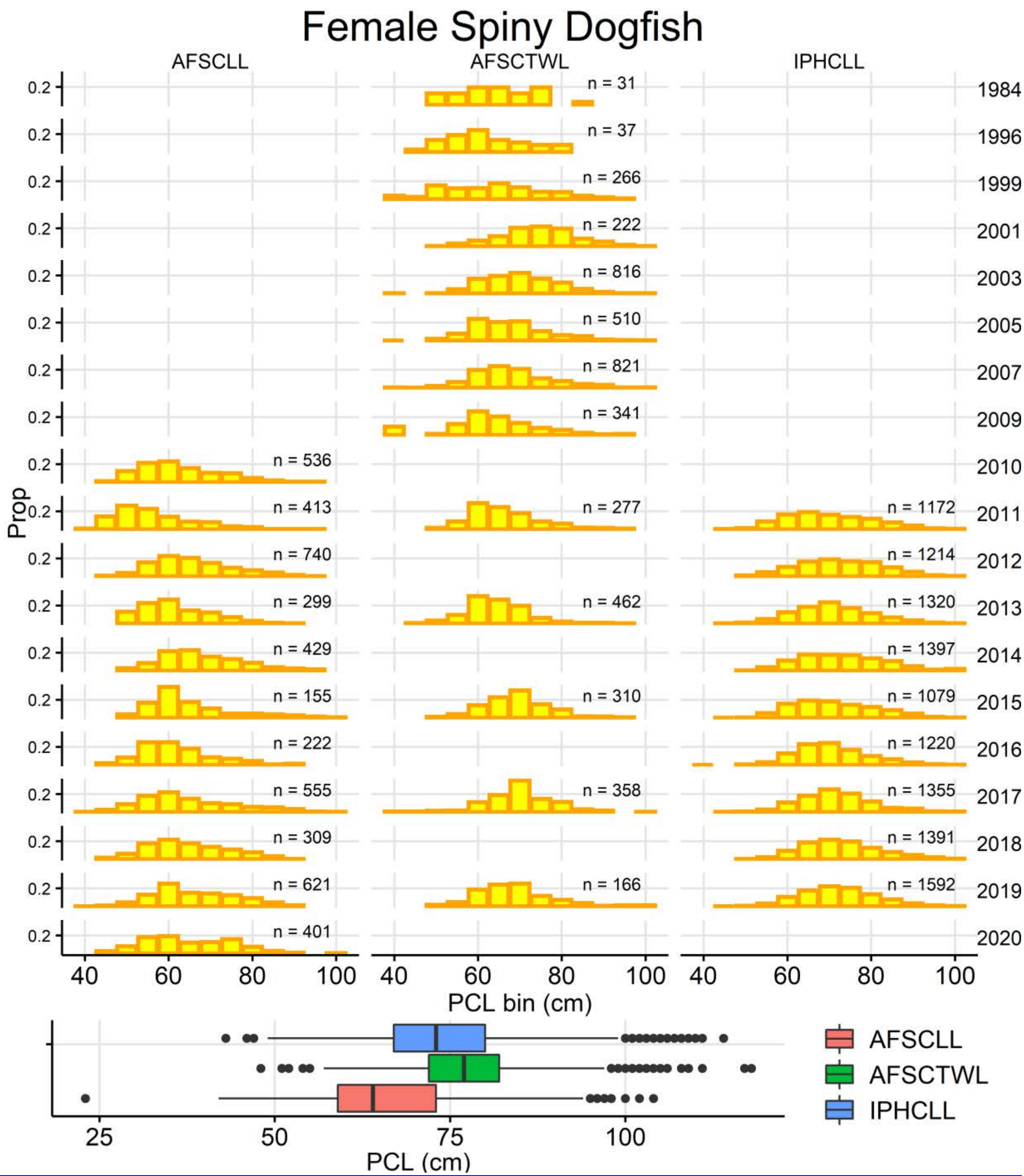

Figure 19.8. Time series of observed length frequencies and sample sizes (n) for female spiny dogfish from the three primary surveys operating in the Gulf of Alaska: Alaska Fisheries Science Center longline survey (AFSCLL) and trawl survey (AFSCTWL), and the International Pacific Halibut Commission longline survey (IPHCLL). The bottom panel shows the overall median and interquartile ranges of the length data for each survey.

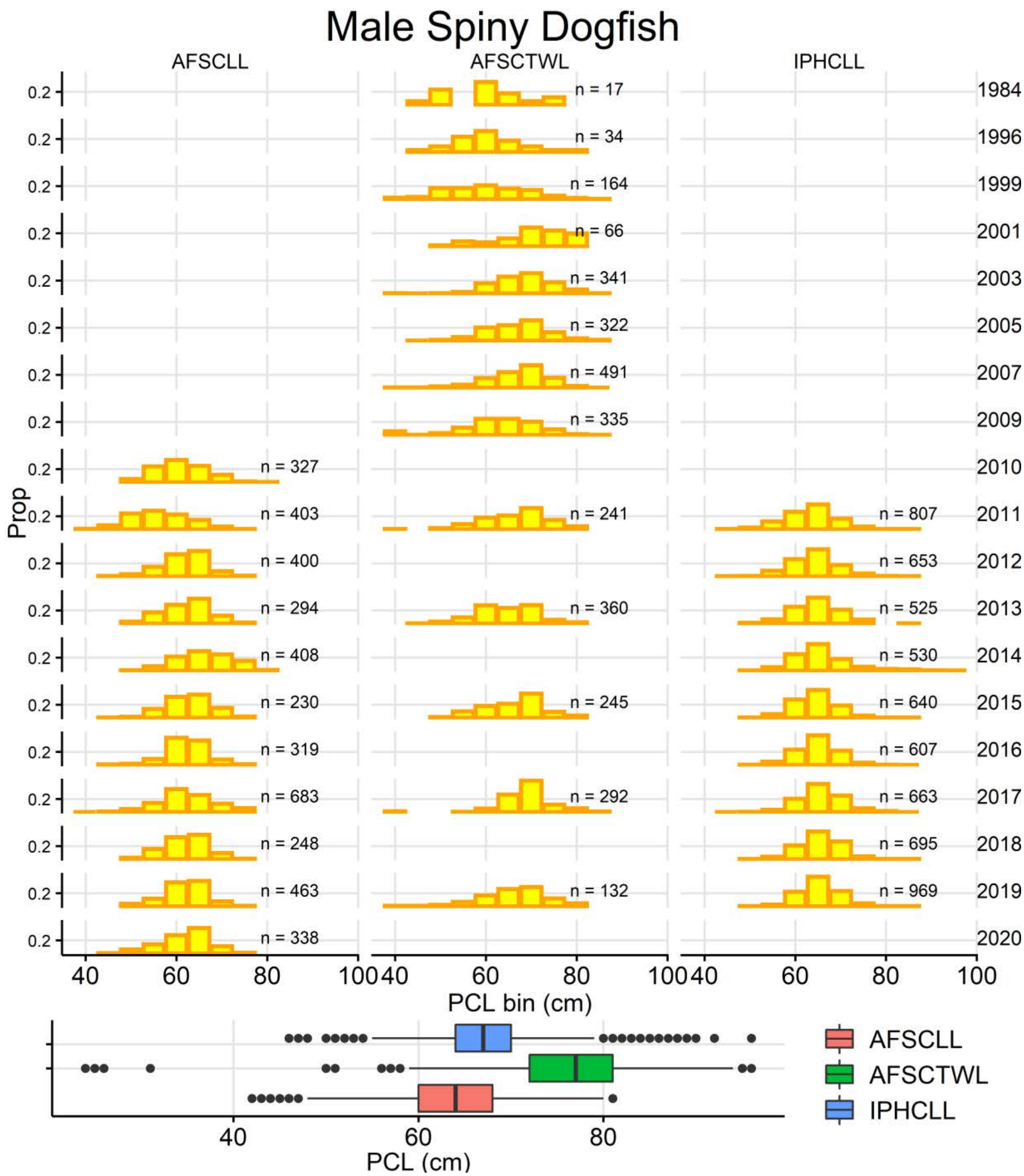

Figure 19.9. Time series of observed length frequencies and sample sizes (n) for male spiny dogfish from the three primary surveys operating in the Gulf of Alaska: Alaska Fisheries Science Center longline survey (AFSCLL) and trawl survey (AFSCTWL), and the International Pacific Halibut Commission longline survey (IPHCLL). The bottom panel shows the overall median and interquartile ranges of the length data for each survey.

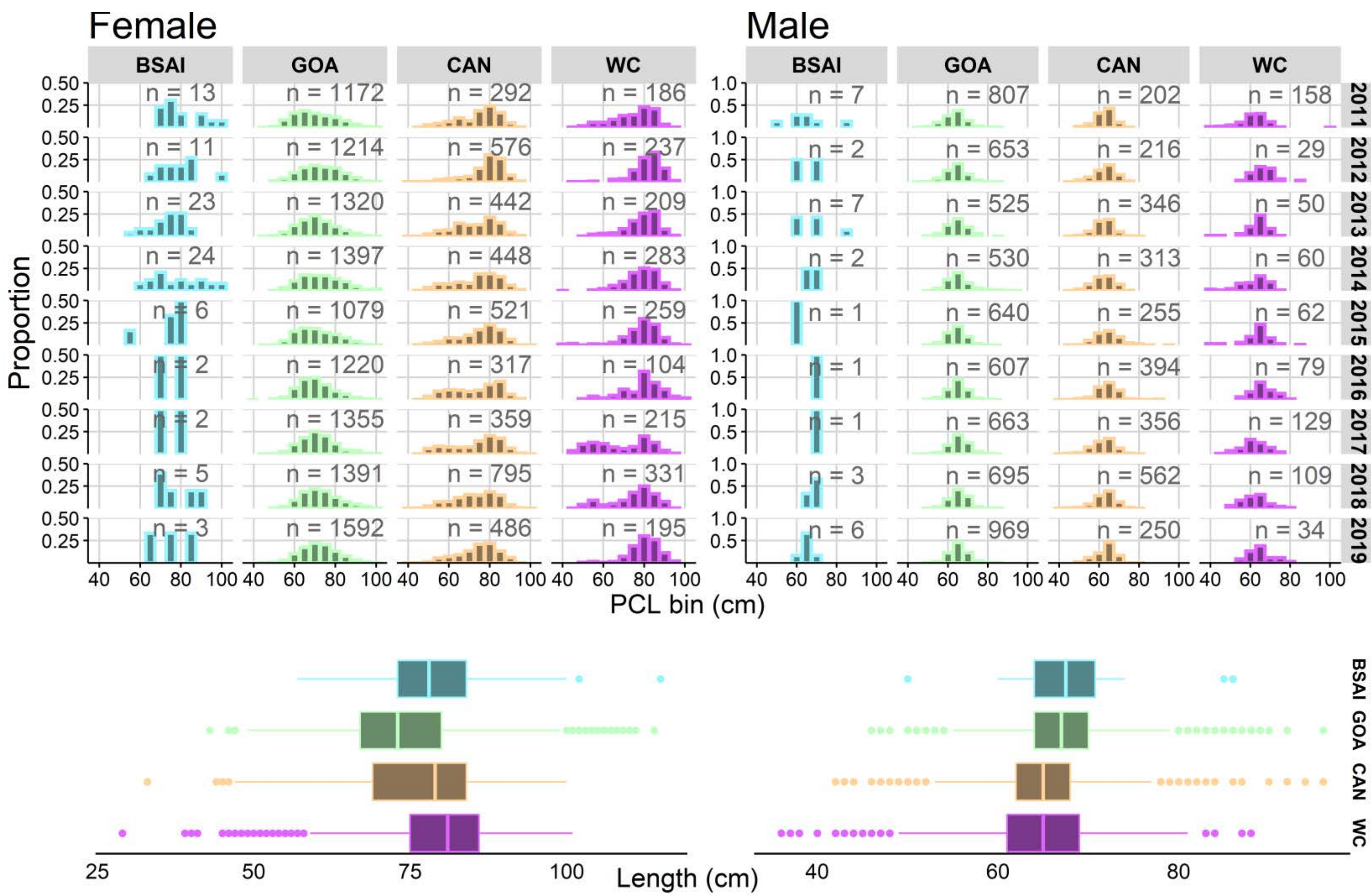

Figure 19.10. Time series of observed length frequencies and sample sizes (n) for female (left panel) and male (right panel) spiny dogfish sampled in the International Pacific Halibut Commission longline survey by region of capture. BSAI = Bering Sea and Aleutian Islands, GOA = Gulf of Alaska, CAN = Canadian west coast and WC = U.S. west coast. The bottom panel shows the overall median and interquartile ranges of the length data for each survey.

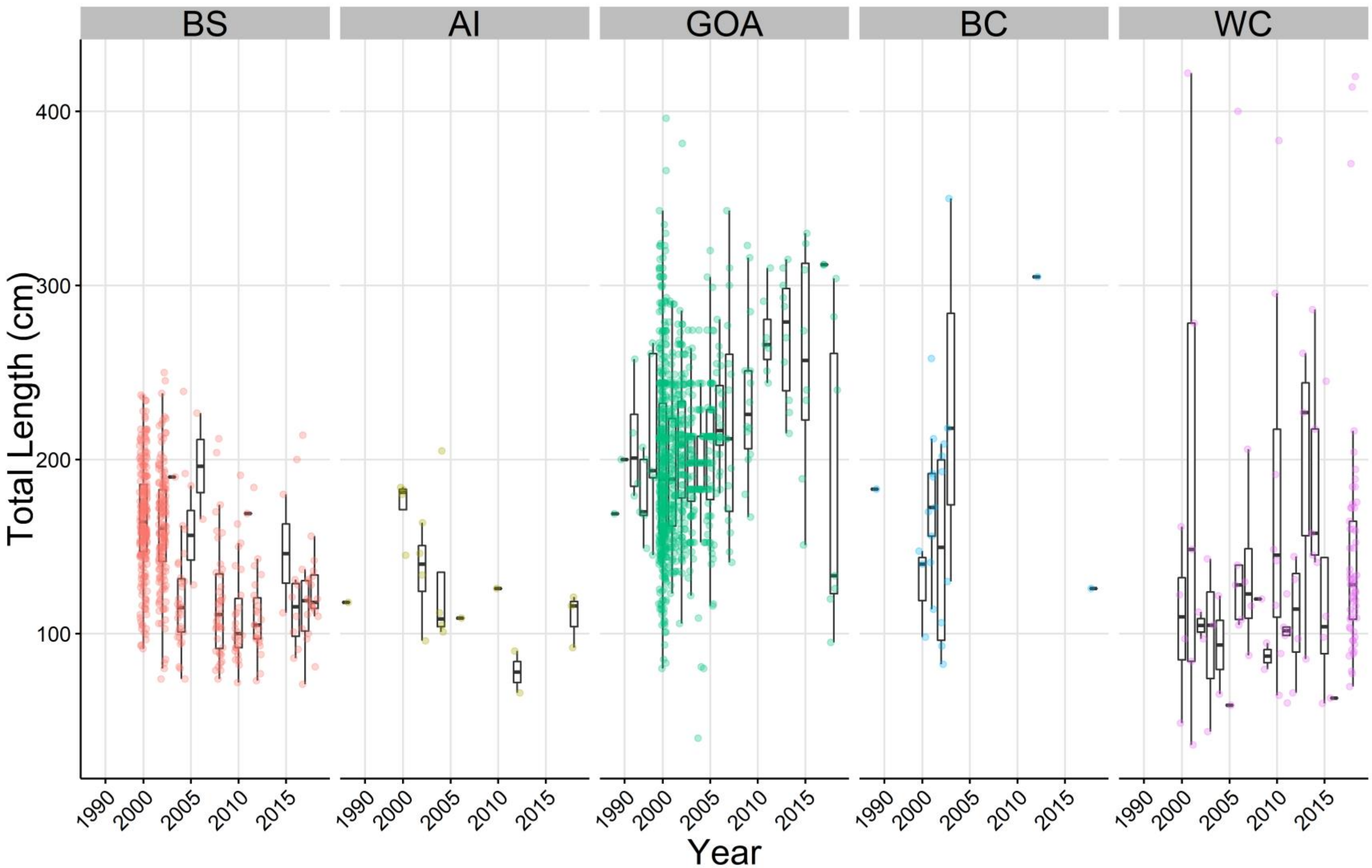

Figure 19.11. Size distribution of Pacific sleeper shark collected in the Aleutian Islands (AI), Bering Sea (BS), Gulf of Alaska (GOA) and off the U.S. West Coast (WC). Data are compiled from standard NMFS groundfish trawl surveys, non-standard NMFS surveys (i.e., opportunistic sample collection), directed research surveys, and special projects on IPHC surveys.

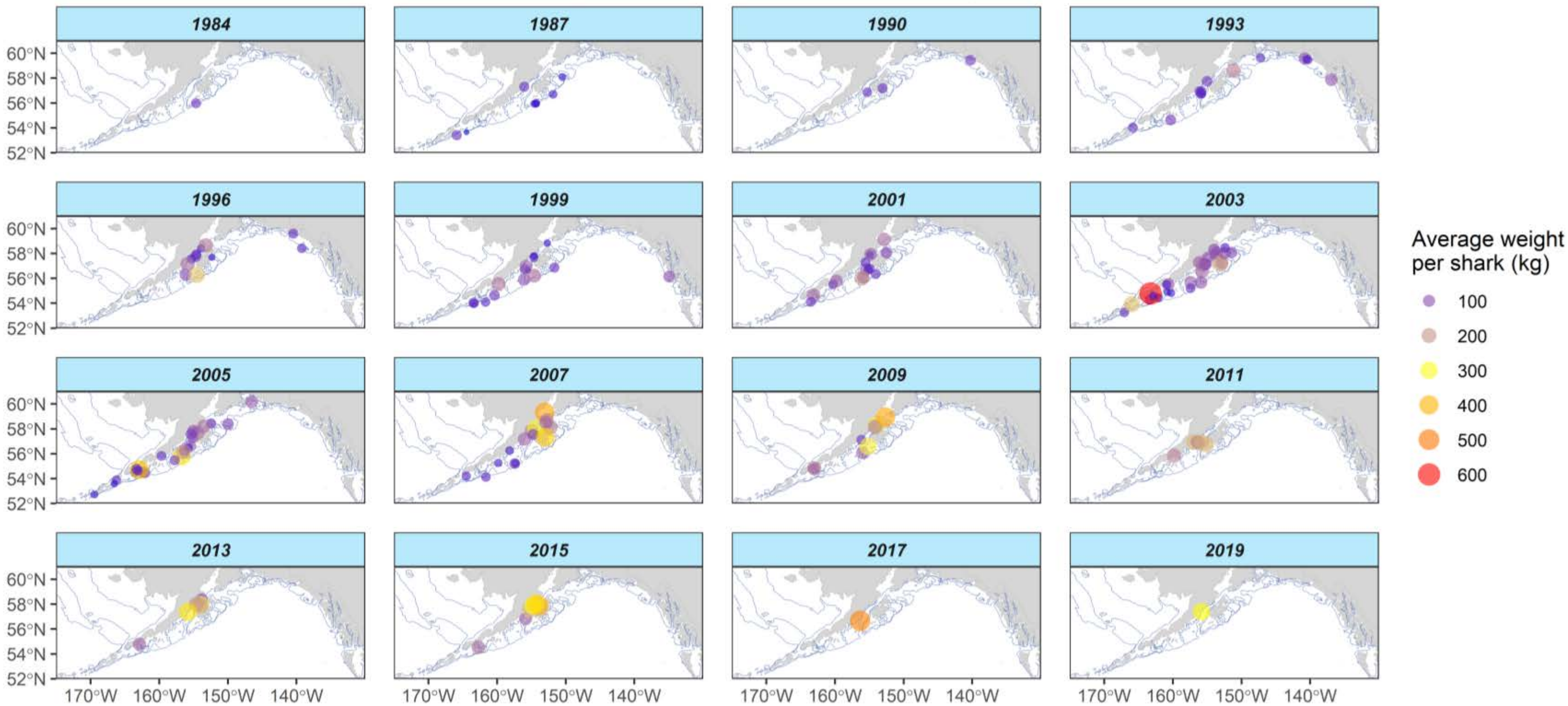

Figure 19.12 Average weight of Pacific sleeper shark per haul captured during the Alaska Fisheries Science Center Bottom Trawl Surveys. Only years with catches are shown.

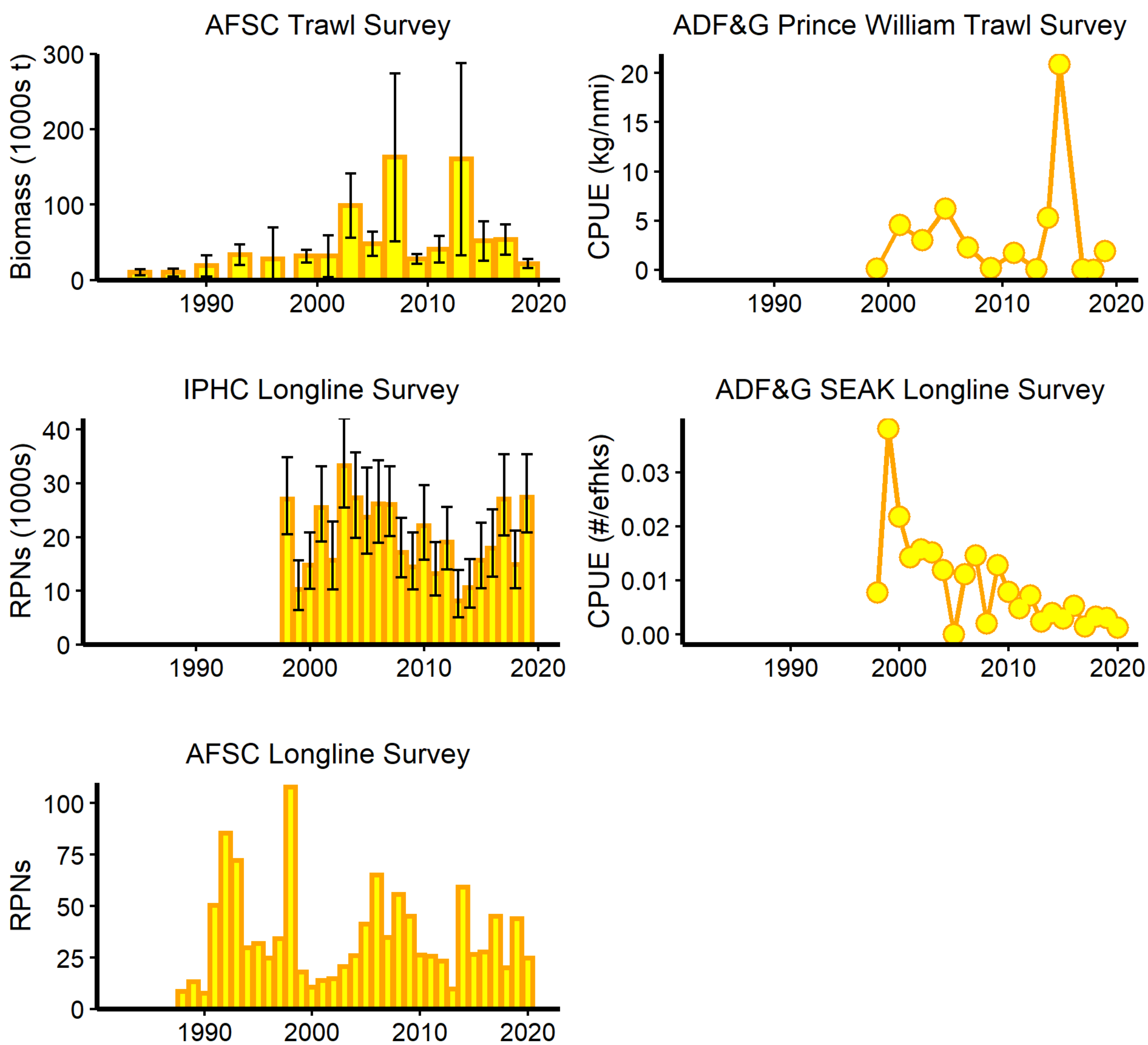

Figure 19.13. Time series of survey indices available for spiny dogfish in the Gulf of Alaska. Catch per unit of effort (CPUE) is available for Alaska Department of Fish and Game (ADF&G) surveys in Prince William Sound (PWS, number of fish /100 hooks) and Southeast Alaska (SEAK, number of fish/effective hooks). The Alaska Fisheries Science Center (AFSC) trawl survey provides an index of biomass. The AFSC and International Pacific Halibut Commission (IPHC) longline surveys provide relative population numbers (RPNs).

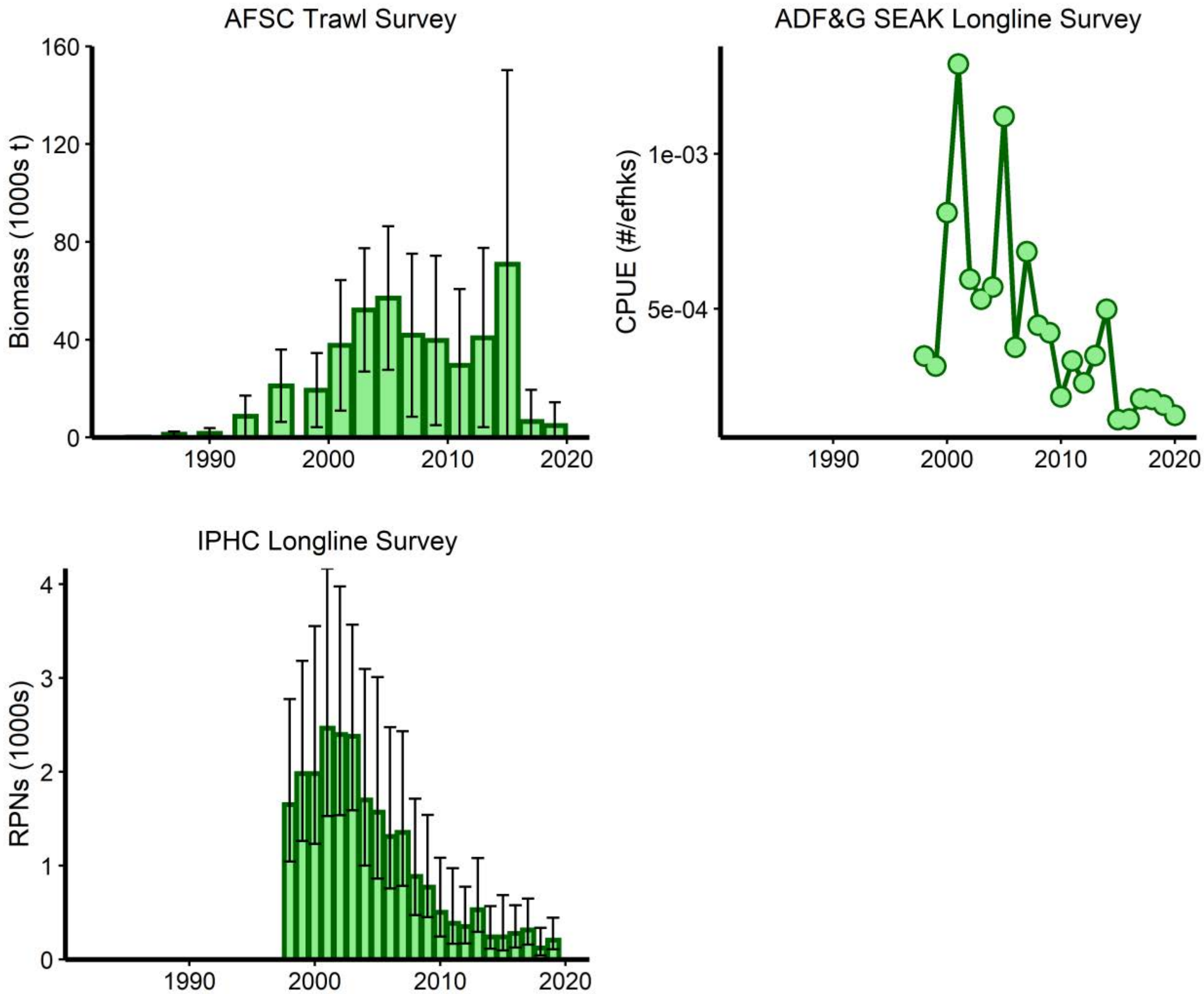

Figure 19.14. Survey indices available for Pacific sleeper shark in the Gulf of Alaska. Catch per unit of effort (CPUE) is available for Alaska Department of Fish and Game (ADF&G) surveys in Prince William Sound (PWS) and Southeast Alaska (SEAK). The Alaska Fisheries Science Center (AFSC) trawl survey provides an index of biomass. The International Pacific Halibut Commission (IPHC) longline survey provides relative population numbers (RPNs).

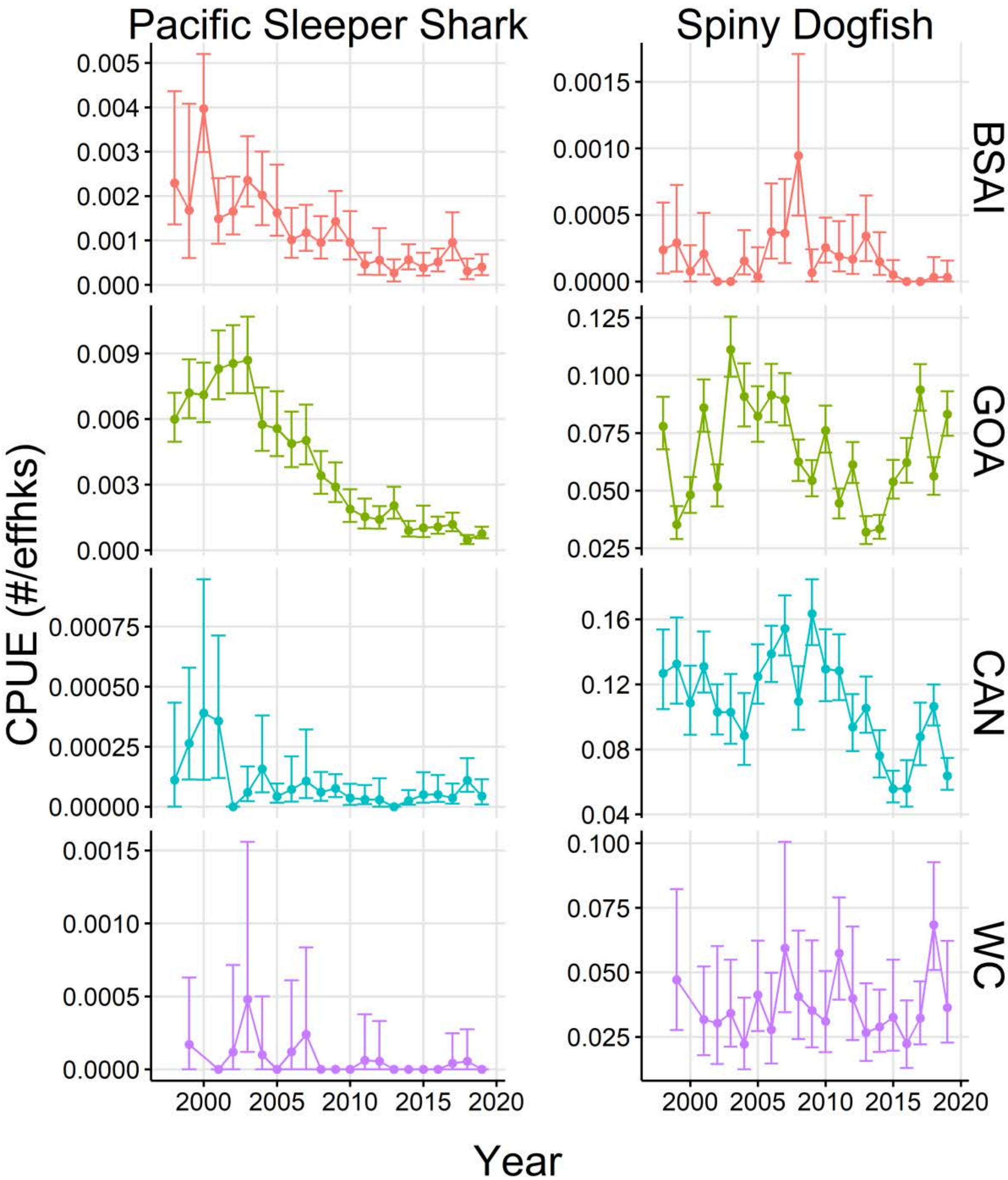

Figure 19.15. Catch per unit of effort (CPUE) with bootstrapped 95% confidence intervals for each region of the International Pacific Halibut Commission annual longline survey. BSAI = Bering Sea and Aleutian Islands, GOA = Gulf of Alaska, CAN = Canada, and WC = the west coast of the United States.

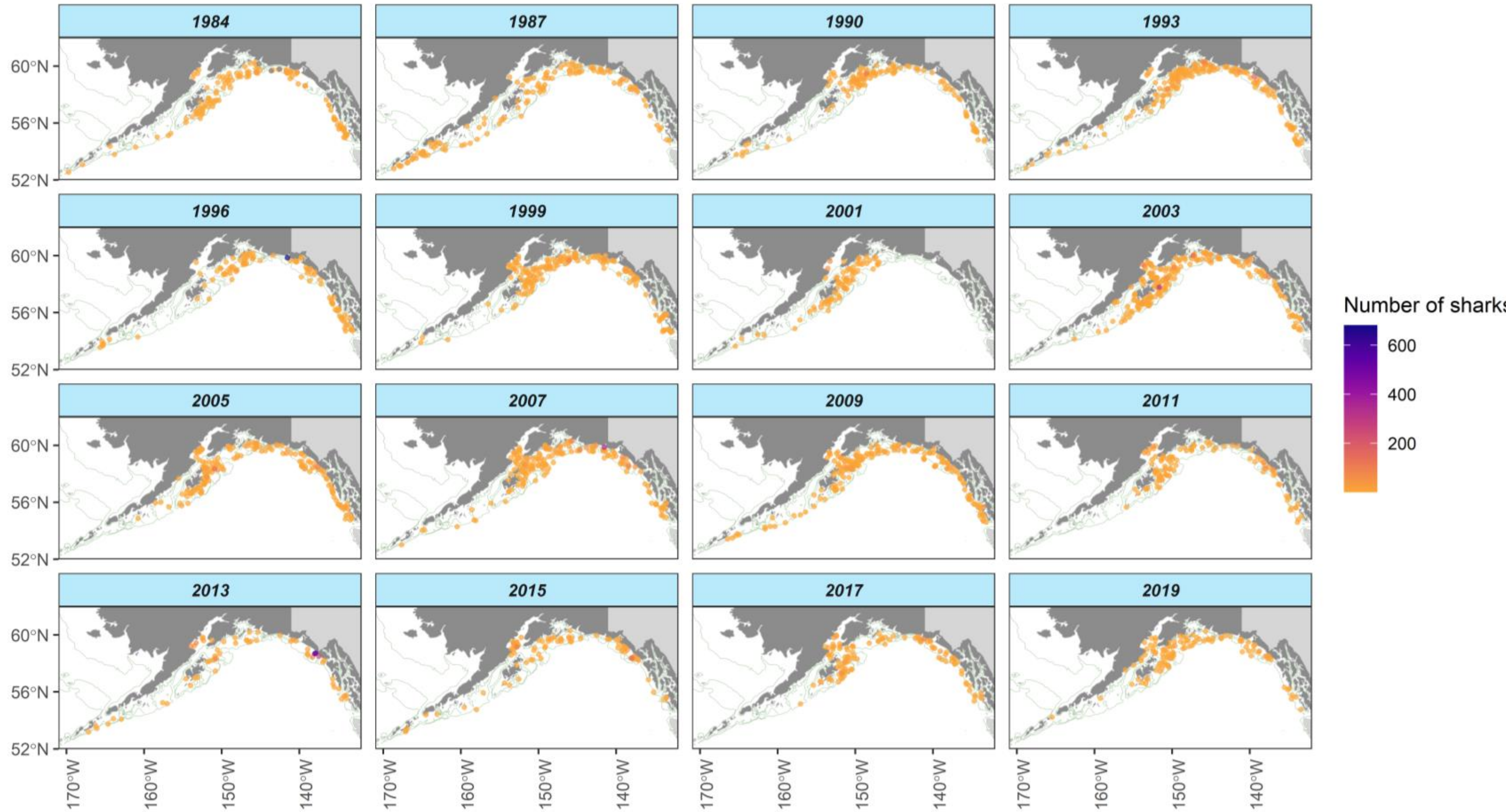

Figure 19.16. Spatial distribution of the catch of spiny dogfish during the Alaska Fisheries Science Center biennial Gulf of Alaska trawl surveys. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

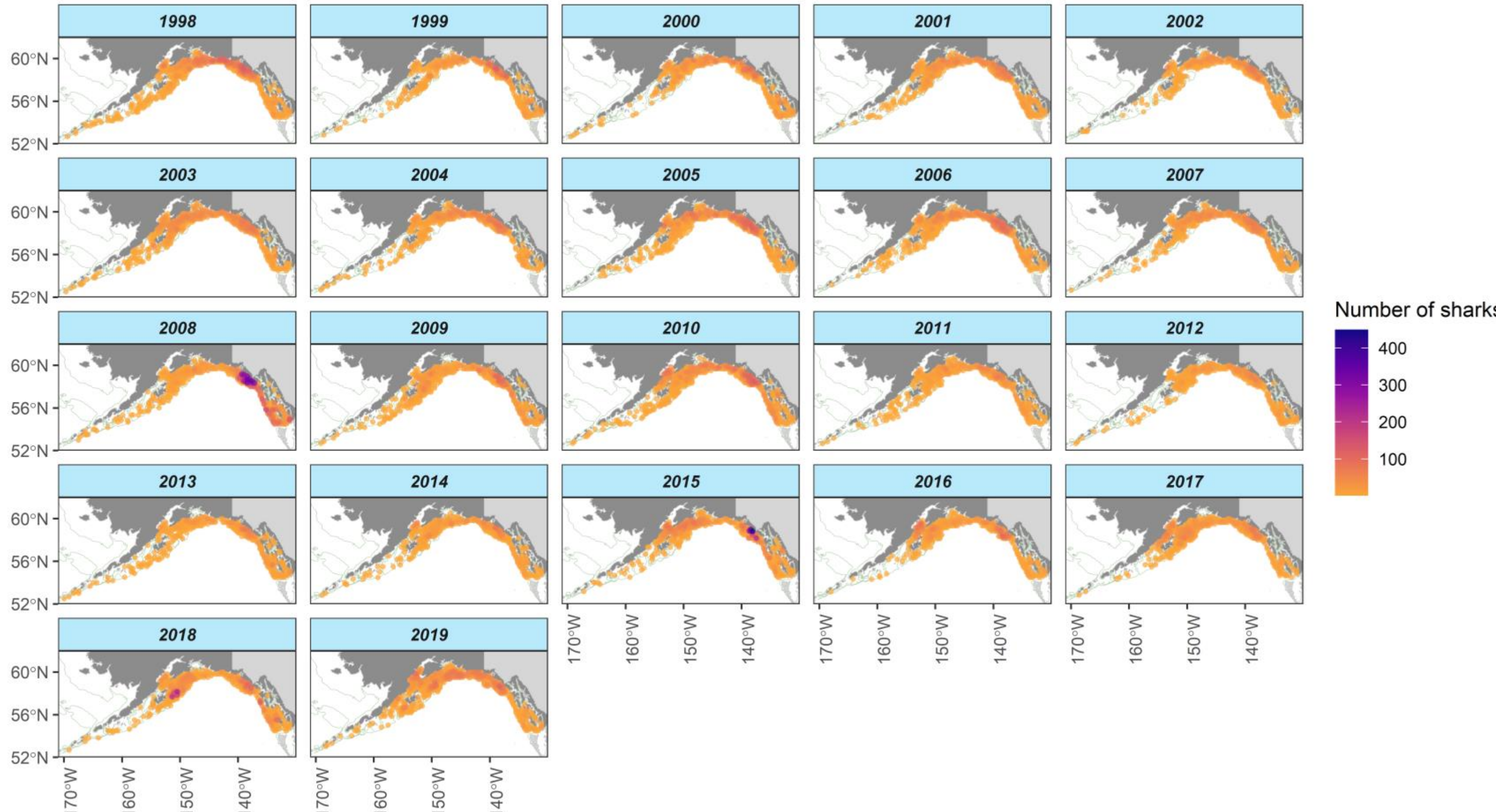

Figure 19.17. Spatial distribution of the catch of spiny dogfish during the International Pacific Halibut Commission (IPHC) longline surveys in the Gulf of Alaska. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

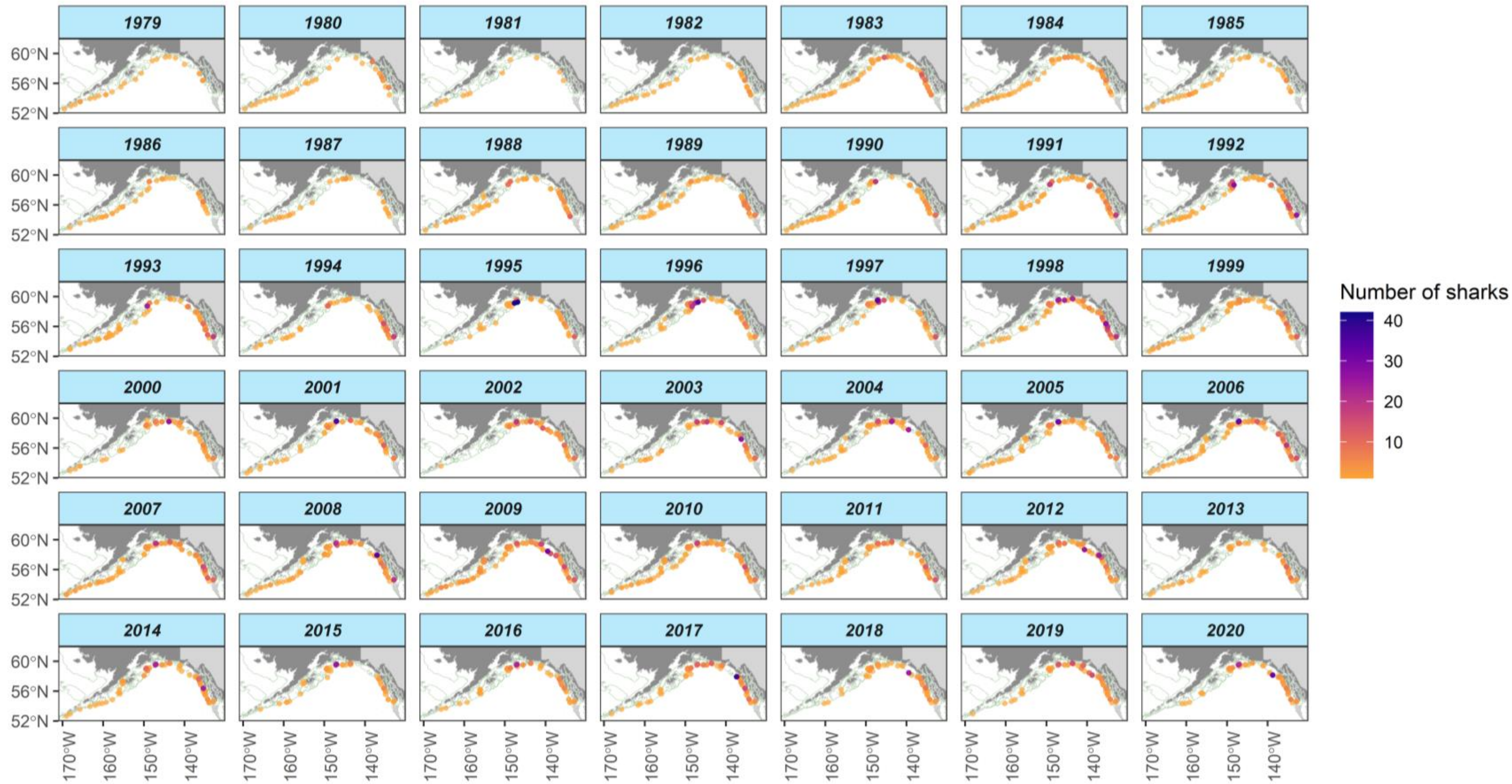

Figure 19.18. Spatial distribution of the catch of spiny dogfish during the Alaska Fisheries Science Center longline surveys in the Gulf of Alaska. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

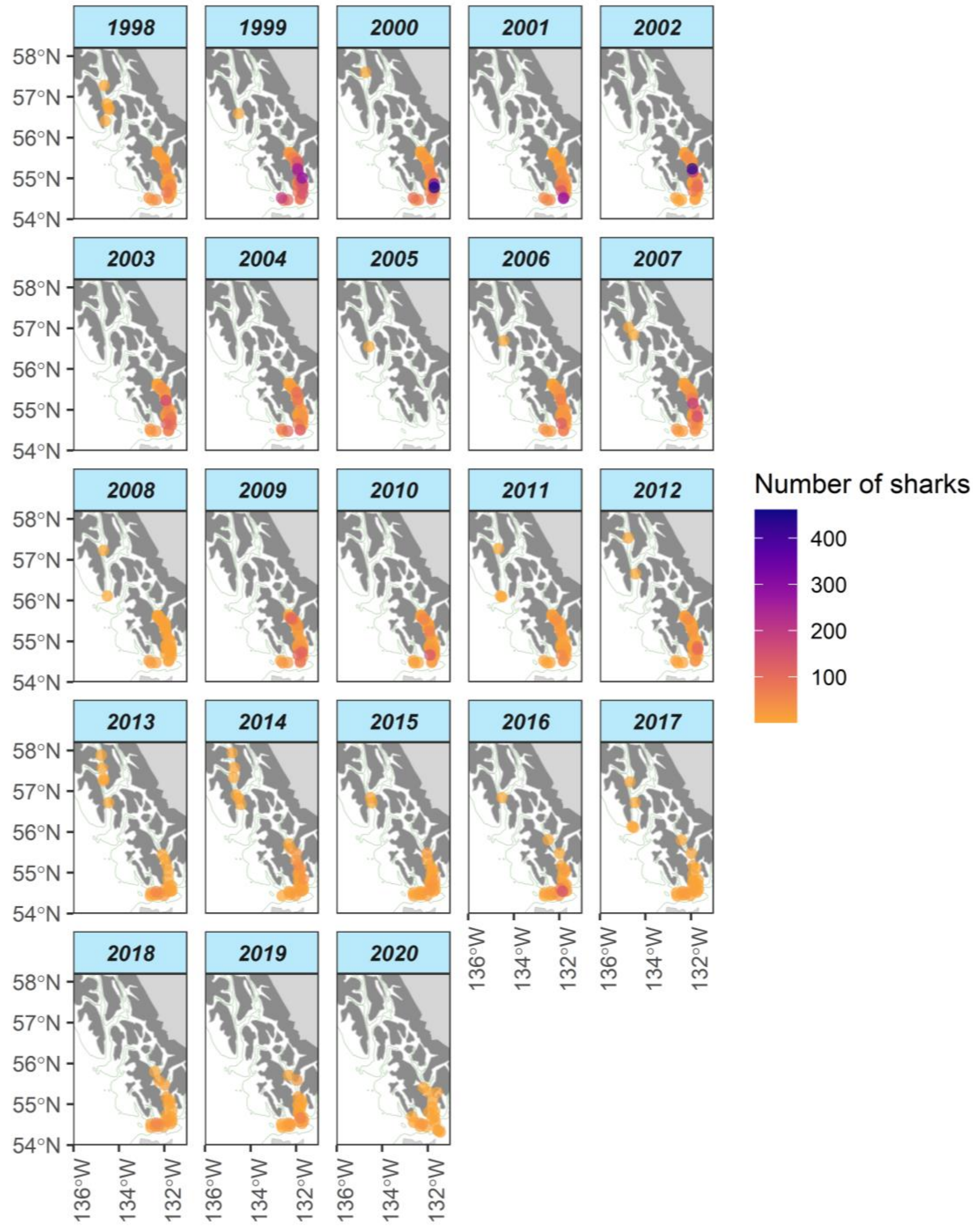

Figure 19.19. Spatial distribution of the catch of spiny dogfish during Alaska Department of Fish and Game (ADFG) longline surveys in Southeast Alaska. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

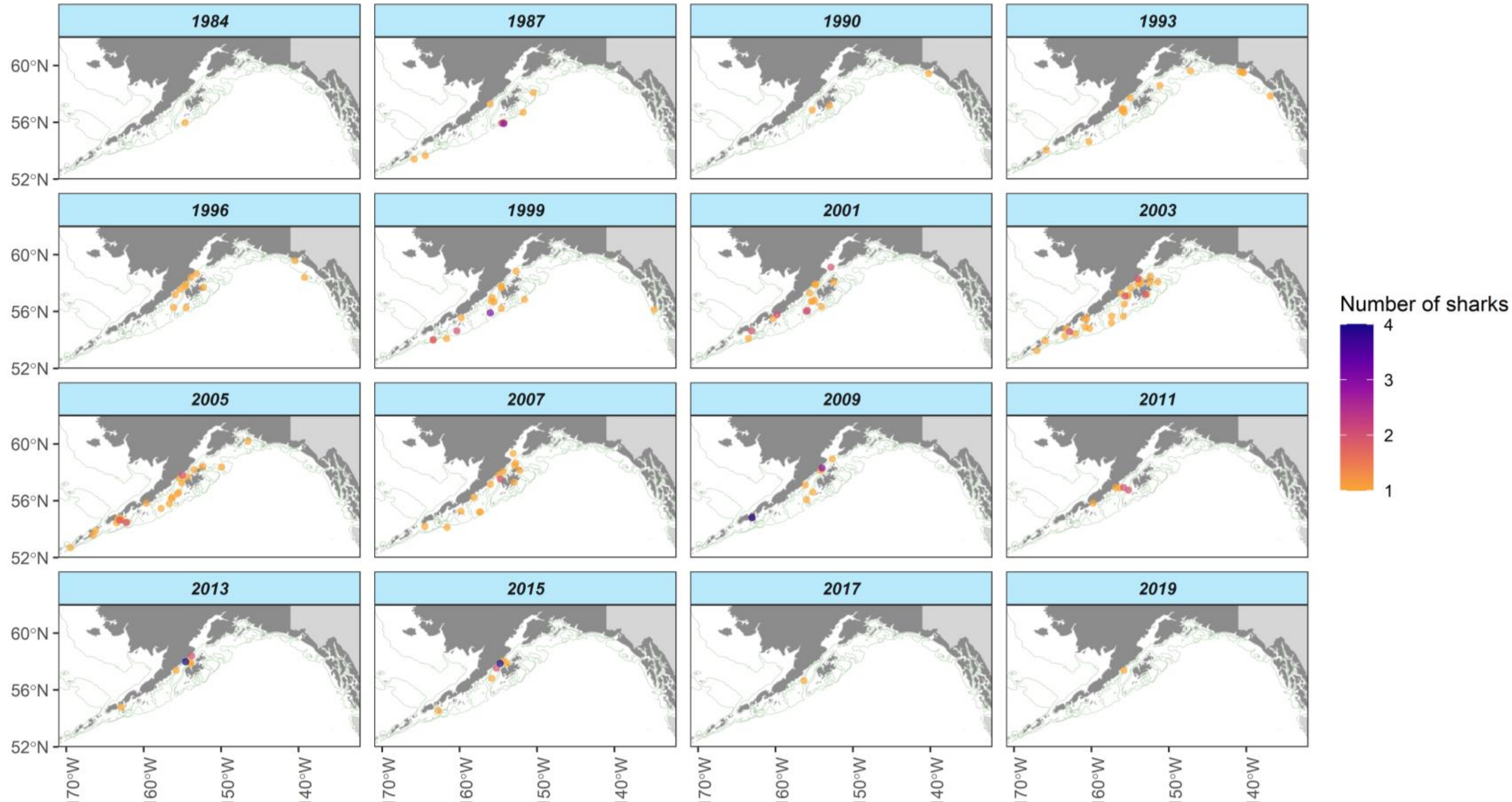

Figure 19.20. Spatial distribution of the catch of Pacific sleeper shark during the Alaska Fisheries Science Center biennial Gulf of Alaska trawl surveys. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

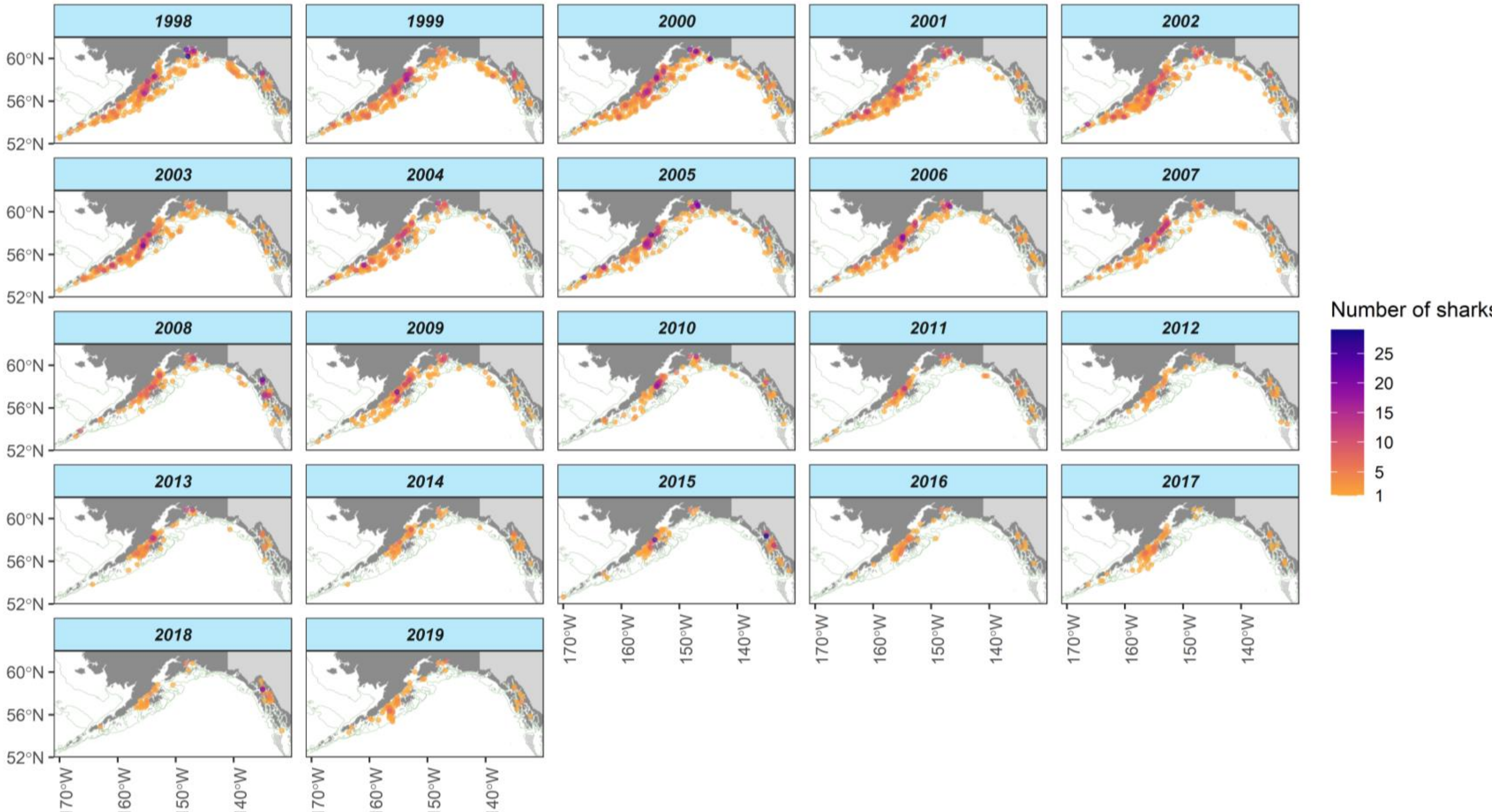

Figure 19.21. Spatial distribution of the catch of Pacific sleeper shark during the International Pacific Halibut Commission (IPHC) longline surveys in the Gulf of Alaska. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

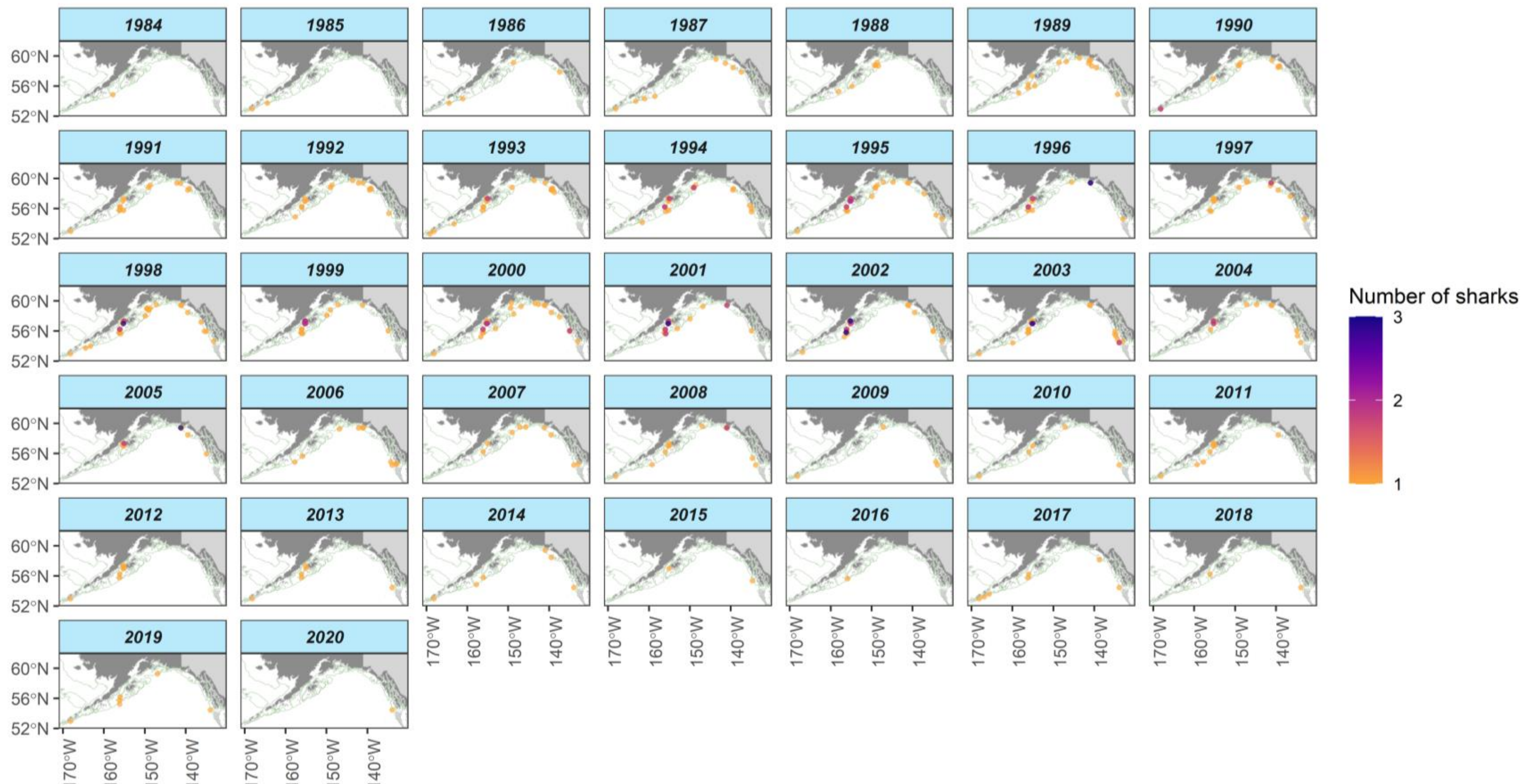

Figure 19.22. Spatial distribution of the catch of Pacific sleeper shark during the Alaska Fisheries Science Center longline surveys in the Gulf of Alaska. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

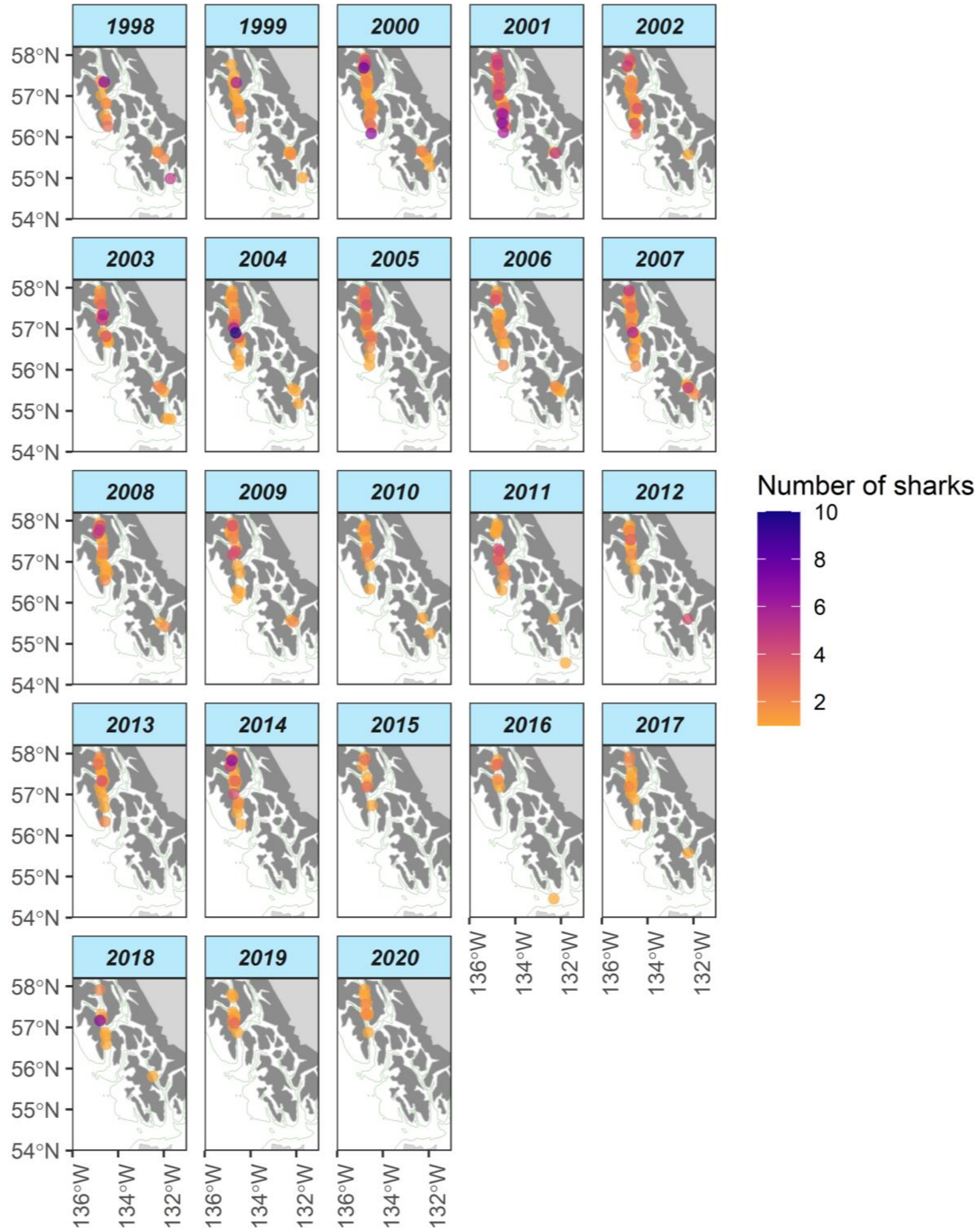

Figure 19.23. Spatial distribution of the catch of Pacific sleeper shark during the Alaska Department of Fish and Game (ADFG) longline surveys in Southeast Alaska. Color represents the number of sharks caught. Each point represents one survey haul and hauls with zero catch were removed for clarity.

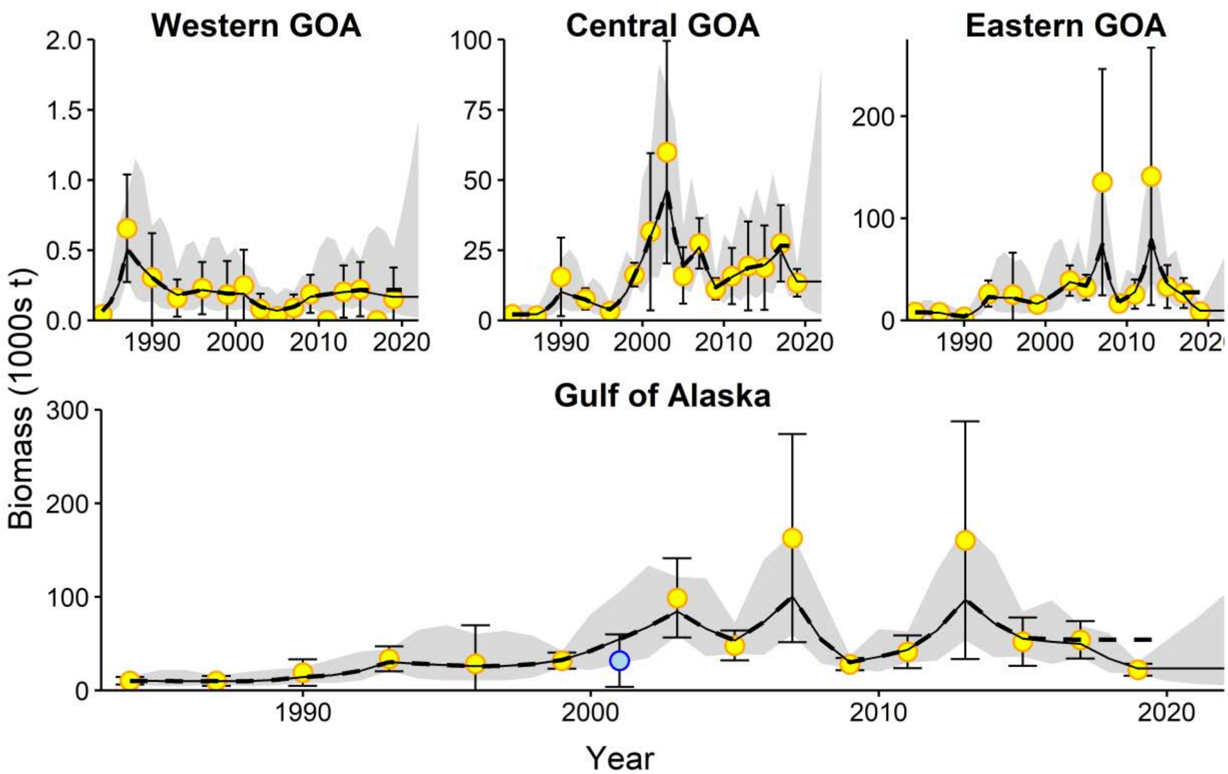

Figure 19.24. Fit of the random effects survey averaging model to the Alaska Fisheries Science Center Gulf of Alaska (GOA) trawl survey biomass estimates by regulatory area (Western GOA, Central GOA, and Eastern GOA) for spiny dogfish. The yellow points are the survey biomass with 95% confidence intervals, the black line is the random effects estimated biomass, and the shaded areas are the confidence intervals of the random effects biomass. The blue point is the year in which the survey did not sample the Eastern GOA. The black dashed line shows the random effects model output from the previous assessment, which did not include the 2019 survey data.