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

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

November 2018

EXECUTIVE SUMMARY

The shark complex (spiny dogfish, Pacific sleeper shark, salmon shark and other/unidentified sharks) in the Gulf of Alaska (GOA) is regularly assessed on a biennial stock assessment schedule. The 2017 assessment was delayed until 2018 to coincide with the Bering Sea Aleutian Islands (BSAI) shark stock complex assessment and in future years both assessments will be done in even years. GOA sharks have been a Tier 6 complex, but, the acceptable biological catch (ABC) and overfishing level (OFL) for spiny dogfish are calculated using a Tier 5 approach (termed Tier 6*) with the survey biomass estimates, as estimated with a random effects model, considered a minimum estimate of biomass. In this assessment the authors propose a new spiny dogfish model (Model 15.3A), which accounts for the proportion of the population not accessible to the survey, and thus moving the spiny dogfish to Tier 5. The total OFL for the GOA shark complex is the sum of the Tier 5 (spiny dogfish) and Tier 6 (all other sharks) recommendations. Recommendations are determined by average historical catches between the years 1997–2007 for the Tier 6 GOA sharks. For this summary, we have updated the time series of catch through October 9, 2018 to reflect any changes that might have occurred in the Catch Accounting System (for the years 2003–2018).

Summary of Changes in Assessment Inputs

Changes to the input data

1. Total catch for GOA sharks from 2003 – 2018 has been updated (as of October 9, 2018).
2. All survey indices have been updated where data are available:
    - National Marine Fisheries Service (NMFS) bottom trawl through 2017
    - NMFS longline through 2018
    - International Pacific Halibut Commission (IPHC) longline through 2017
    - Alaska Department of Fish and Game (ADF&G) trawl and longline through 2018

Changes in assessment methodology

For spiny dogfish, Model 15.3A incorporates the following changes from Model 15.1 (accepted in the last full assessment):

- The minimum biomass is adjusted by catchability (q) = 0.21, Model 15.1 assumes $q = 1$.
- The $F_{max} = 0.04$ is used as opposed to the value used in previous assessments (Tier 5 $F = M = 0.097$ in Model 15.1).

Summary of Results

There is no evidence to suggest that over fishing is occurring for any shark species in the GOA because the OFL has not been exceeded. Total shark catch in 2017 was 1,632 t and catch in 2018 was 2,141 t as of October 9, 2018.

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 8,184 t and OFL is 10,913 t for the shark complex.** This is an 81% increase over the 2018 ABC of 4,514 t. This increase is due to the structural changes between Model 15.1 and Model 15.3A. There are currently no directed commercial fisheries for shark species in federally or state managed waters of the GOA, and most incidental catch is not retained.

ABC and OFL Calculations and Tier 5 recommendations for spiny dogfish for 2019 – 2020. Here the OFL is based on the random effects biomass (54,301 t) divided by catchability (q = 0.21) to equal an adjusted biomass of 258,577 t, which is then multiplied by the *F* rate of 0.04.

Spiny Dogfish Quantity	As estimated or *specified last* year for: 2018	2019	As estimated or *recommended this* year for: 2019	2020
M (natural mortality rate)	0.097	0.097	0.097	0.097
Tier	6*	6*	5	5
Biomass (t)	56,181	56,181	54,301	54,301
F_{OFL}	0.097	0.097	0.04	0.04
$maxF_{ABC}$	0.073	0.073	0.03	0.03
F_{ABC}	0.073	0.073	0.03	0.03
OFL (t)	5,450	5,450	**10,343**	10,343
maxABC (t)	4,087	4,087	7,757	7,757
ABC (t)	4,087	4,087	**7,757**	7,757
Status	As determined *last* year for: 2016	2017	As determined *this* year for: 2017	2018
Overfishing	No	n/a	No	n/a

In the previous assessment spiny dogfish were termed a "Tier 6" because the trawl survey biomass was not considered reliable for the species. If the recommended model from this assessment is accepted, they would be a Tier 5 species.

ABC and OFL Calculations and Tier 6 recommendations for Pacific sleeper sharks, salmon sharks and other sharks for 2019 – 2020.

Pacific sleeper, salmon and other sharks Quantity	As estimated or *specified last* year for: 2018	2019	As estimated or *recommended this* year for: 2019	2020
Tier	6	6	6	6
OFL (t)	570	570	**570**	570
maxABC (t)	427	427	427	427
ABC (t)	427	427	**427**	427
Status	As determined *last* year for: 2016	2017	As determined *this* year for: 2017	2018
Overfishing	No	n/a	No	n/a

Summaries for Plan Team

Species	**Year**	**Biomass**[1]	**OFL**[2]	**ABC**[2]	**TAC**	**Catch**[3]
Shark Complex	2017	56,181	6,020	4,514	4,514	1,632
	2018	56,181	6,020	4,514	4,514	2,141
	2019	54,301	10,913	8,184		
	2020	54,301	10,913	8,184		

[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 9, 2018.

Responses to SSC and Plan Team Comments on Assessments in General

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

We have adopted the requested model naming conventions.

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

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

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

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

The authors carefully reviewed the ESR for 2017. Sharks are included as part of the "Apex predator biomass" indicator in the Western and Eastern GOA, but with constant biomass, thus not indicative of shark biomass trends. Sharks have become a larger portion of the total discards in the GOA, but the ESR speculates that it is likely a function of changes in observer coverage.

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

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

> "*This request was recently clarified by the SSC by replacing the terms 'ecosystem status' and 'stock assessment status' with 'Ecosystem Status Report information' and 'Stock Assessment Information,' where the potential determinations for each will consist of 'Okay' and 'Not Okay,' and by issuing the following guidance:*
>
> - *The SSC clarifies that 'stock assessment status' is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.*
> - *Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the 'Okay' or 'Not Okay' determinations.*
> - *The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.*
> - *Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC.*"

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

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

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

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

Not applicable to this assessment

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

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

Not applicable to this assessment

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

Not applicable to this assessment

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

Not applicable to this assessment

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

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

At this time model-based estimates are not available for sharks. In the future, model-based estimates are anticipated to be produced by the Groundfish Assessment Program (GAP). When these estimates do become available for sharks, we will consider using the estimates if they can be tailored appropriately for sharks and provide an improvement over the design-based estimates. A working group was formed to investigate criteria for use of the model-based estimates in a variety of groundfish life histories. We will consult the guidelines from this working group for determining use of the model-based estimates for sharks when they become available.

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

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

SSC and Plan Team Comments Specific to this Assessment

"*The SSC requests that the average, maximum and median catches of the current time period be brought forward in the next assessment, with confidence intervals around the average catch alternative.*" (SSC, December 2015)

It is unclear what "current time period" refers to, so we are assuming "current time period used for Tier 6 calculations". The requested metrics are included in Table 20.6. Confidence intervals around the mean are included, however, they all overlap zero. Further, the assumption of a normal distribution is inappropriate as the catches are generally either bimodal or heavily skewed.

"*The SSC requests the author bring the status quo methodology forward, in addition to Fmax from the demographic model, next year and to include the methodology for the demographic model in an appendix. The*

SSC agrees with the use of M=0.097 for the Tier 5 harvest specifications for the interim." (SSC, December 2015)

The status quo spiny dogfish model (15.1) is included along with the author recommended model (15.3A) in the Harvest Recommendations section. The development of Model 15.3A was presented during the September 2018 Plan Team meeting and included here as Appendix 20A. The demographic model methods are included in Appendix 20B.

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

- *Incorporation of a net efficiency study (Hulson et al., in review) that uses tag data to estimate survey catchability,*
- *The SSC requested a comparison of CAS and HFICE estimates in 2014, and notes the authors plan to revisit this issue for the 2016 assessment cycle, as indicated in the assessment.*

The SSC appreciates the inclusion of catches for areas 649 and 659 in the document, but not including them in the assessment until biomass estimates are available for State waters. The SSC continues to recommend the author explore potential sources of estimating biomass in State waters if sharks are believed to be a single population in state and federal waters." (SSC, December 2015)

Results of Hulson et al. (2016) have been incorporated into estimates of catchability as presented during the September 2018 Plan Team meeting, and included here as Appendix 20A. The author recommended Model 15.3A incorporates catchability. The request to revisit HFICE was addressed in 2016. Catch from areas 649 and 659 will continue to be documented in this assessment in tables, but not included in the catch estimates used to calculate OFL/ABCs, nor do they count against the TAC/ABC/OFL. The authors are continuing to explore methods to expand biomass estimates to state waters and to include catch from NMFS areas 649 and 659 in the TAC.

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

There was no GOA shark assessment in September 2017. In this assessment, we have continued to bring forward the $F_{OFL} = F_{max}$ estimated from the demographic model (See the Analytic Approach section) as well as an improved estimate of biomass. The methods for improving biomass were presented and discussed during the September 2018 Plan Team meeting and are detailed in Appendix 20A of this document. The author recommended model incorporates both the $F_{OFL} = F_{max}$ and improved biomass estimates.

"*In response, the Plan Team recommended:*

- *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*
- *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)*
- *Continuing to work on PSS genetics*
- *Developing ageing methods for PSS*
- *Implementing a special project in the observer program to quantify sizes of PSS caught in hook-and-line fisheries*" (GOA Plan Team, November 2017)

The stock structure document for Pacific sleeper shark was delayed as the genetic analysis is still underway (Items #1 and #3). We continue to work with AKRO to extend catch estimates back to 2003, but it is not yet available (Item #2). A pilot study was begun to examine Carbon-14 levels in the eye lens of Pacific sleeper sharks, which may be used to assess the age of the fish (Item #4). A special project with the observer program is underway in the 2018 fishery and will likely be continued into the 2019 fishery (Item #5). Preliminary results were presented during the September 2018 Plan Team (included here in Appendix 20A), which suggest that the size of Pacific sleeper sharks being caught by the longline fleet is underestimated, resulting in underestimates of total catch.

"*The Team recommends the author continue with efforts to estimate catch by numbers including expanding the time series back to 2003 and pursue investigations into the average weight estimates used for larger sharks as well as instances where no weights are available for observed sharks.*" (GOA Plan Team, November 2017)

See above response.

"*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)

We plan to explore the VAST modelling approach for spiny dogfish in the next full assessment, along with incorporating the IPHC longline survey index into the random effects model.

"*The Teams encourage continued exploration of utilizing data limited methods for this assessment.*" (GOA Plan Team, September 2018)

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

In response to both of the above comments, we plan to do an extensive exploration of the data-limited methods for the shark complexes, which would be available for other Tier 5/6 assessments.

"*In September, the author introduced an alternative method for management of spiny dogfish. This method would use VAST to combine longline and bottom trawl datasets. If adopted, the stock could potentially be moved from tier 6 management to tier 5 management. The SSC encourages further exploration of this method."* (SSC, October 2018)

To clarify, VAST has not been used for spiny dogfish and was not presented during the September 2018 Plan Team meeting. We do intend to investigate incorporating the IPHC longline survey index in the random effects biomass model as well as VAST for the next full assessment

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 20.1 and Figure 20.1). The three shark species most likely to be encountered in GOA fisheries and surveys are the Pacific sleeper shark (*Somniosus pacificus)*, the spiny dogfish (*Squalus suckleyi)*, and the salmon shark (*Lamna ditropis*).

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

General Distribution

Spiny Dogfish

Spiny dogfish occupy shelf and upper slope waters from the Bering Sea to the Baja Peninsula in the eastern North Pacific and south through the Japanese archipelago in the western North Pacific. They are considered more common off the U.S. west coast and British Columbia (BC) than in the GOA or BSAI (Hart 1973, Ketchen 1986, Mecklenburg et al. 2002). In Alaska, they are more common in the GOA than in the BSAI. Spiny dogfish inhabit both benthic and pelagic environments with a maximum recorded depth of 677 m (Tribuzio, unpublished tagging data). Spiny dogfish are commonly found in the water column and at surface waters (Hulson et. al 2016).

Pacific Sleeper Shark

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

Salmon Shark

Salmon sharks range in the North Pacific from Japan through the Bering Sea and Gulf of Alaska (GOA) to southern California and Baja, Mexico. They are considered common in coastal littoral and epipelagic waters, both inshore and offshore. Salmon sharks tend to be more pelagic and surface oriented than the other shark species in the GOA, spending 72% of their time in water less than 50 m depth (Weng et al. 2005). While some salmon sharks migrate south during the winter months, others remain in Alaska waters throughout the year (Hulbert et al. 2005, Weng et al. 2005).

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 species. Sharks are generally long-lived and slow growing. There is insufficient life history data for any of the species to compare between or within the GOA and BSAI. Genetic studies conducted on spiny dogfish have indicated that there is no significant stock structure within the GOA or BSAI (Ebert et al. 2010, Verissimo et al. 2010).

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

Life History Information

Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity (Table 20.1 and Table 20.2). 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 sharks were 3 of the 4 most vulnerable species, with salmon shark the least vulnerable shark at 1.96 (lower scores are less vulnerable), spiny dogfish at 2.10, and Pacific sleeper shark at 2.24, the most vulnerable of all species analyzed.

Spiny Dogfish

Eastern North Pacific (ENP) spiny dogfish grow to a maximum size of 160 cm (Compagno 1984), with the maximum size observed in the GOA 125 cm (Tribuzio and Kruse 2012). Recent studies estimated ages-at-50% maturity to be 36 years for females and 21 years for males (Tribuzio and Kruse 2012), which is similar to estimates from BC of 35 years and 19 years respectively (Saunders and McFarlane 1993). Longevity in the ENP is between 80 and 100 years (Campana et al. 2006). Growth coefficients (κ) for this species are among the slowest of all shark species, $\kappa = 0.03$ for females and 0.06 for males (Tribuzio et al. 2010b).

The mode of reproduction for spiny dogfish is aplacental viviparity. Embryos are nourished by their yolk sac while being retained in utero for 18–24 months. In the GOA, pupping may occur during winter months, based on the size of embryos observed during summer and fall sampling (Tribuzio and Kruse 2012). Ketchen (1972) reported timing of parturition in BC to be October through December, and in the Sea of Japan, parturition occurred between February and April (Kaganovskaia 1937, Yamamoto and Kibezaki 1950). Off of Washington State, spiny dogfish have a long pupping season, which peaks from October to November (Tribuzio et al. 2009). Pupping is believed to occur in estuaries and bays or mid-water over depths of approximately 165 - 370 m (Ketchen 1986). Small juveniles and young-of-the-year tend to inhabit the water column near the surface or in areas not fished commercially and are, therefore, not available to commercial fisheries until they grow or migrate to fished areas (Beamish et al. 1982, Tribuzio and Kruse 2012). The average litter size is 8.5 pups for spiny dogfish in the GOA (Tribuzio and Kruse 2012), 6.9 in Puget Sound, WA (Tribuzio et al. 2009), and 6.2 in BC (Ketchen 1972). The number of pups per female also increases with the size of the female, with estimates ranging from 0.20 - 0.25 more pups for every centimeter in length (Ketchen 1972, Tribuzio et al. 2009, Tribuzio and Kruse 2012).

Pacific Sleeper Shark

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

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

Size at maturity is estimated based on limited reports of mature animals. Published observations suggest that mature female Pacific sleeper sharks are in excess of 365 cm *TL*, mature male Pacific sleeper sharks are in excess 397 cm *TL*, and the size at birth is approximately 40 cm *TL* (Gotshall and Jow 1965, Yano et al. 2007). The reproductive mode of sleeper sharks is thought to be aplacental viviparity. Three mature females 370 - 430 cm *TL* were opportunistically sampled off the coast of California. One of these sharks had 372 large vascularized eggs (24 - 50 mm) present in the ovaries (Ebert et al. 1987). Another mature Pacific sleeper shark 370 cm *TL* long was caught off Trinidad, California (Gotshall and Jow 1965) with ovaries containing 300 large ova. Two 74 cm sharks have been 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 35 m depth off Hiraiso, Ibaraki, Japan (Yano et al. 2007). Additionally, three small sharks, 65 - 75 cm *TL*, have been sampled in the Northwest Pacific, but the date of sampling was not reported (Orlov and Moiseev 1999). In summer 2005, an 85 cm *PCL* (pre-caudal length, measured from the tip of the snout to the dorsal pre-caudal notch, at the base of the tail) female was caught during the annual AFSC longline survey near Yakutat Bay and in spring 2009 another 85 cm *PCL* female was caught by a commercial halibut fisherman inside Chatham Strait in Southeast Alaska (Tribuzio unpublished data). Because of a lack of observations of mature and newly born sharks, and the absence of dates in literature, the spawning and pupping seasons are unknown for sleeper sharks.

The authors have compiled length data for Pacific sleeper shark from standard and non-standard AFSC trawl surveys in the GOA and BSAI, the Northwest Fisheries Science Center (NWFSC) groundfish trawl survey off the U.S. west coast, and International Pacific Halibut Commission (IPHC) surveys. The length data compiled thus far show that small animals (50 – 200 cm total length) are caught coast wide; larger fish, those >200 cm *TL,* have never been recorded in the BSAI and animals up to 400 cm *TL* have been caught, in small numbers, in all other regions (Figure 20.2). One study has examined the sizes of Pacific sleeper shark caught in the GOA, eastern Bering Sea (AFSC trawl survey data for both regions), western Bering Sea, along the Kamchatka Peninsula and in the Sea of Okhotsk (Russian survey and fishery data), and found that there were very few fish greater than 200 cm (Orlov and Baitalyuk 2014). These data indicate that the animals caught in the BSAI are all young and small, some possibly even being neonates, and are all likely immature. In all of the other regions, the animals being caught are also primarily small, but occasionally larger and possibly mature animals are captured.

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

Salmon Shark

Like other lamnid sharks, salmon sharks are active and highly mobile, maintaining body temperatures as high as 21.2ºC above ambient water temperatures and appear to maintain a constant body core temperature regardless of ambient temperatures (Goldman et al. 2004). Adult salmon sharks typically range in size from 180–210 cm *PCL* (Goldman and Musick 2006) in the eastern North Pacific and can weigh upwards of 220 kg. Length-at-maturity in the WNP has been estimated to occur at approximately 140 cm *PCL* for males and 170–180 cm *PCL* for females (Tanaka 1980). These lengths correspond to ages of approximately five years and 8–10 years, respectively. Length-at-maturity in the ENP has been estimated to occur between 125–145 cm *PCL* (3–5 years) for males and between 160–180 cm *PCL* (6–9 years) for females (Goldman and Musick 2006). Tanaka (1980) (see also Nagasawa 1998) states that maximum age from vertebral analysis for WNP salmon shark is at least 25 years for males and 17 years for females and growth coefficients are 0.17 and 0.14 for males and females, respectively. Goldman and Musick (2006) gave maximum ages for ENP salmon shark (also from vertebral analysis) of 17 years for males and 30 years for females, with growth coefficients of 0.23 and 0.17 for males and females, respectively. Salmon sharks in the ENP and WNP attain the same maximum length (approximately 215 cm *PCL* for females and about 190 cm *PCL* for males). However, males past approximately 140 cm *PCL* and females past approximately 110 cm *PCL* in the ENP are of a greater weight-at-length than their same-sex counterparts in the WNP (Goldman and Musick 2006).

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

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 (http://www.fakr.noaa.gov/sustainablefisheries/amds/95-96-87/amd87.pdf) 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 20.3).

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) provides estimates of catch (both retained and discarded fish combined) and harvest (retained fish only) of all shark species combined, in numbers of fish; (2) the mandatory charter logbook provides estimates of statewide charter harvest of salmon sharks (numbers of fish) since 1998; and (3) dockside monitoring in the Southcentral Region obtains reported retentions and discards and biological information for retained spiny dogfish and salmon shark.

Statewide estimates of retained sharks are available 1998–2014, and are presented in this report (Table 20.4). Due to staffing changes at ADF&G, updated estimates were not available for this assessment. Estimated annual retention of sharks (all species combined) was 0 in all years except 2001 in the Western GOA, 126–1,353 fish (CV = 14–49%) in the Central GOA, and 46–748 fish (CV = 24–74%) in the Eastern GOA (Table 20.4). In addition to the retention estimates, numbers of fish discarded were obtained by subtracting estimated retention from estimated catch. Standard errors are not available for the release numbers. Estimated numbers of sharks discarded annually ranged from 0–410 in the Western GOA, 5,189–45,209 in the Central GOA, and about 4,234–30,161 in the Eastern GOA. The contrasting retention and discard numbers indicate that most sharks are caught incidentally and are released.

There is a relatively small directed sport fishery for salmon sharks in Southcentral Alaska, mostly occurring in Prince William Sound. The fishery is primarily a charter boat fishery, with retention on charter boats accounting for over 90% of reported retention from dockside surveys. Logbook data for salmon sharks have not been rigorously edited, but indicate annual statewide charter retention in the range of 7–284 fish over the years 1998–2014 (except 1999, Table 20.4). 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. Average length (TL_{nat}) of salmon sharks sampled from retained sport catch in Southcentral Alaska from 1998–2014 ranged from 207–236 cm. Average predicted round weight ranged from 117–158 kg. Females have dominated the retained catch each year (56–97%, 1998–2011). Since 2011, only three salmon sharks have been sampled by dockside creel census samplers, all male. Ages of fish sampled from 1997–2000 ranged from 5–17 years. Ages have not been reported from samples since 2000.

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. Only 85 spiny dogfish were retained and sampled from the Southcentral Alaska sport fishery from 1998 through 2014 (Table 20.4). The mean total length (TL_{nat}) of these fish was 93 cm and mean predicted round weight was 4.1 kg.

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 20.5. Generally, > 90% of sharks are discarded. About 27 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.).

Historical Catch

Historical catches of sharks in the GOA are composed entirely of incidental catch. This report summarizes incidental shark catches by species as four data time series: 1990–1998, 1997–2002, 2003–2012 and 2013–present (Table 20.6, Figure 20.3). 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). The observer program was restructured in 2013 and while the catch estimation procedure has been the same (CAS), the data going in are now different. There is a two year overlap (1997–1998) between the two catch estimation methodologies, in which the catches estimated from the earlier method were considerably lower than catches estimated by the later method. Therefore, these two data series are not directly comparable; however, the earlier time series is still valuable as an indicator of trends. 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 20.3 and Table 20.6). 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 from that fleet. Based on anecdotal reports, both spiny dogfish and Pacific sleeper shark catch were caught often in the Pacific halibut IFQ fleet. Vessels larger than 40 ft LOA 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 LOA 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, nor are they observed. 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. The second problem is that observers are limited to a 50 kg scale, and would need to take the time and space to cut anything larger than 50 kg into smaller pieces to weigh. A special project to investigate the potential bias in the size of animals available to be measured compared to those actually caught began in the 2018 fishery. Preliminary results were presented to the September meeting of the Joint Plan Teams and suggest that the average weight that feeds into the total catch estimate is underestimating the true size of the sharks being caught (See Appendix 20A). This project has been requested to continue into the 2019 fishery.

The restructured observer program likely resulted in changes in the estimates of shark catch, particularly in the Eastern GOA. Since 2013 in the GOA there was an increase in the proportion of total catch caught in the under 60 ft vessel category, 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 the Prince William Sound (NMFS area 649) and the 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 20.3.

The estimated catch of sharks is broken into four groups: spiny dogfish, Pacific sleeper shark, salmon shark and other/unidentified sharks (Figure 20.3). Historically, spiny dogfish are the primary species caught in the GOA (Table 20.6, Figure 20.3). Pacific sleeper sharks, salmon sharks and other/unidentified sharks, are smaller components of the complex (Table 20.6, Figure 20.3).

Estimated catch of spiny dogfish has historically been variable, with peaks in estimated catches often resulting from a small number of large observer observations (such as in 2006 and 2009, Table 20.6, Table 20.7 and Figure 20.3). Catch in 2013, the first year of the restructured observer program, was the greatest of the historical time series for spiny dogfish (2,072 t, Table 20.6). Since 2013, estimated catch of spiny dogfish was primarily in the Pacific halibut (677 t, 42%, on average) and sablefish fisheries (463 t, 29%, on average, Table 20.7). Smaller amounts of spiny dogfish catch have come from the pollock (203 t, 13% on average since 2013) and flatfish fisheries (200 t, 13% on average, Table 20.7). The restructured observer program has provided catch estimates from inside 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 26% (on average since 2013, Table 20.8).

Pacific sleeper shark estimated catch has been below average since 2005 (Table 20.6 and Figure 20.3). On average since 2013 56% (62 t) and 22% (26 t) of the catch has come from the flatfish fisheries and Pacific halibut fisheries, respectively (Table 20.9). Catch in the flatfish fisheries for 2017 and 2018 increased nearly eight times over the 2013–2016 catch. If catch in NMFS areas 649 and 659 (Table 20.8) were included within the total GOA catch, the Pacific halibut fishery represents 47% (136 t) of Pacific sleeper shark catch, on average. Catch of Pacific sleeper shark in NMFS areas 649 and 659 also often 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 (101 t, 99%, on average since 2013, Table 20.10). Catch of the other/unidentified sharks is highly variable and inconsistent with regards to which fisheries they are usually reported from (Table 20.11). The large increase in catch of other/unidentified sharks in the sablefish fishery in 2018 is likely a result of an increase in the number of blue sharks observed.

Distribution of Catch in Fisheries

Spatial distributions of catch of each of the four species in the shark complex are different (Figure 20.4). Catch distribution is likely more a function of the behavior of the fisheries that catch the species and not indicative of areas of high biomass. Spiny dogfish are generally caught primarily in NMFS area 630 and 650, with little catch in 640. Pacific sleeper shark are caught primarily in NMFS areas 620 and 630, while salmon sharks are in 610 and other/unidentified sharks in 630, with the exception of 2018 with the increased catch in 650.

Observer catch data from the FMA website (http://www.afsc.noaa.gov/FMA/spatial_data.htm) was 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 2014 - 2017. Observed bycatch of spiny dogfish in commercial fisheries in the GOA (Figure 20.5) occurs predominately off Kodiak Island 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 20.6) and less informative. 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.

Data

Data regarding sharks were obtained from the following sources:

Source	Data	Years
AKRO Catch Accounting System	Nontarget catch	2003–2018
AFSC Psuedo Blend	Nontarget catch	1990–1998
AFSC Improved Pseudo Blend	Nontarget catch	1997–2002
NMFS Bottom Trawl Surveys –GOA	Biomass Index	1979–2017
NMFS Longline Surveys	Survey catch numbers, CPUE and RPN	1989–2018
IPHC Longline Surveys	Survey catch numbers, CPUE and RPN	1997–2017
ADF&G	Sport catch	1998–2014
ADF&G Southeast Longline Surveys	Survey catch numbers and CPUE	1998–2018
ADF&G Prince William Sound Longline Survey	Survey CPUE	1997–2006
ADF&G Large Mesh Trawl Surveys	Survey CPUE	1989–2018

Fishery

Catch data by species from 1997–2007 is used for the harvest recommendations for Pacific sleeper shark, salmon shark and other/unidentified sharks (Table 20.6).

Catch at length (Fishery and Survey)

The data presented here are from the AFSC bottom trawl surveys (GOA, Eastern Bering Sea shelf and slope and Aleutian Islands), AFSC and International Pacific Halibut Commission (IPHC) longline surveys, targeted research surveys, as well as special projects conducted by the Observer Program (Figure 20.7 - Figure 20.10). 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 specifications procedures. Length data collections are part of standard collections on the AFSC longline (spiny dogfish only) and trawl surveys, as well as regularly collected on the IPHC longline survey (spiny dogfish only), thus a time series of length frequency data for spiny dogfish and Pacific sleeper sharks are being created. We include BSAI data for Pacific sleeper sharks because genetic evidence suggests that the species is a continuous stock within the eastern North Pacific Ocean. Catch of salmon shark is extremely rare in surveys and length frequencies are not presented.

Length frequency data are presented for GOA spiny dogfish in Figure 20.7 (females) and Figure 20.8 (males). The three surveys provide a large sample size of spiny dogfish. Observer length data is limited and a special project was conducted during the 2018 fishery, but those data are still being debriefed and not entered for this assessment. There are no significant differences in mean size between the surveys for females, however, the distributions of sizes on the IPHC and AFSC trawl survey are shifted to larger animals than the AFSC longline survey and the sizes from the observer special projects. The IPHC survey provides length data coastwide, which provides regional comparisons of size frequencies (Figure 20.9). Data from females suggests that animals sampled in the GOA and BSAI are smaller than those along the Canadian and U.S. west coast, a trend not seen in male length data (Figure 20.9).

There is very little length data for Pacific sleeper sharks (~1,400 total lengths over all surveys, all areas, and all years, compared to ~1,400 each year from one survey for spiny dogfish), therefore, lengths for the BSAI and GOA are combined for each data source (Figure 20.10, sexes combined). Despite combining the BSAI and GOA, data are still extremely limited. 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.

Survey

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 (1984–2017, Table 20.12). 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 2001surveys did not sample deeper than 500 m; the 2003, 2011, 2013 and 2017 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 and 2017 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, 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 Gulf of Alaska. In addition, much of the survey effort in 1984 and 1987 was by Japanese vessels that used a very different net design than what has been the standard used by U.S. vessels throughout the surveys, introducing an element of uncertainty as to 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 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 with no obvious trend in biomass estimates (Figure 20.11). 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 20.12, Figure 20.11). 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. The 2015 biomass estimate (70,933 t, CV = 0.57) is the highest in the time series followed by the lowest since 1990, 6,561 t (CV = 1, Table 20.12, Figure 20.11). Salmon shark catch is rare, often with biomass estimates with confidence intervals overlapping zero (Figure 20.11 and Table 20.12).

ADF&G Trawl Surveys

Data from three large mesh trawl surveys were provided by ADF&G Southcentral Region: Kachemack Bay (1998–2018), Kamishak Bay (1998–2012) and Prince William Sound (1998–2018). Of the three surveys, only the Kamishak Bay survey regularly caught spiny dogfish. Pacific sleeper sharks and salmon sharks are rare. The spiny dogfish CPUE from Kamishak Bay suggests an increasing trend in catch, with the exception of 2008, which only reported catching 1 shark (Figure 20.12). This survey was discontinued in 2012, thus limiting its usefulness for a spiny dogfish assessment.

Longline Surveys

International Pacific Halibut Commission Annual Longline Survey

The IPHC conducts a longline survey each year to assess Pacific halibut. This is a fixed station survey that samples down to 500 m in the Aleutian Islands, Eastern Bering Sea, and the GOA in inside and outside waters, as well as areas south of Alaska. More information on this survey can be found in Soderlund et al. (2009). Total catch of sharks in the IPHC survey in weight and numbers is presented in Table 20.13. Weight is derived from a length-weight relationship in 2010–2014. Only numbers are available from 1998–2009 because no lengths were taken.

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

Spiny dogfish IPHC RPNs have been increasing from the historic low in 2013 (Figure 20.12). Pacific sleeper shark RPNs declined steeply from 2001 through 2013 and have increased steadily over the last four surveys (Figure 20.13). 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 coastwide, from the Bering Sea through the west coast of the U.S., which can be examined to determine if trends occurring in the GOA are mirrored elsewhere (i.e., BSAI, Canada = CAN, and the west coast of the U.S. = WC). The CPUE index for spiny dogfish in the BSAI has been declining since 2013, while it has been increasing in the GOA (Figure 20.14). The index in Canadian waters 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 been declining from a high in 2000 and 2003, respectively (Figure 20.14), 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 on 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 and covers more years than the available IPHC survey data. 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 20.12). The 2014 and 2017 spiny dogfish RPNs were well above average and the highest since 2006. The 2015 and 2016 RPNs were substantially lower than both 2014 and 2017, and were below average. Pacific sleeper sharks are caught more rarely on the AFSC longline survey and so those data are not presented.

ADF&G Longline Surveys

Staff from the ADF&G Southcentral and Southeast regions provided data from three longline surveys: Prince William Sound (1997–2006), Chatham Strait (1998–present) and Clarence Strait (1998–present). 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 been trending downwards since 2009, and the Prince William Sound survey is highly variable (Figure 20.12).

With the exception of 1998, the Pacific sleeper shark index in the Prince William Sound survey appears stable, which is different from other survey data sources (Figure 20.13). However, this survey ended in 2006. The SEAK longline survey trends mirror the long decline in the IPHC survey data. There was also a sharp decline in the 2017 AFSC trawl survey (Figure 20.13).

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. If so, survey catches could be lower 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 CPUE of other species.

Distribution of catch in surveys

Catch of spiny dogfish on the AFSC trawl survey is patchy. In 2015 and 2017 spiny dogfish were caught mostly on the Fairweather grounds in northern Southeast Alaska and in Cook Inlet (Figure 20.15). 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 20.16). 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 20.17). They are often caught at gully stations outside of Prince William Sound, Yakutat Bay and Southeast Alaska. In 2018 there were fewer dogfish caught in the central GOA than in previous years. Spiny dogfish catches on the ADF&G longline survey in inside waters of Southeast Alaska occur primarily in Clarence Strait (Figure 20.18).

The spatial distribution of Pacific sleeper shark catch on the bottom trawl survey is limited to Shelikof Strait and areas southwest of Kodiak Island (Figure 20.19). The IPHC and AFSC longline surveys also catch Pacific sleeper sharks often in Shelikof Strait, as well as scattered stations across the shelf (Figure 20.20 and Figure 20.21). Catch of Pacific sleeper shark by the IPHC occurs 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 20.22).

Analytic Approach

General Model Structure

Sharks in the GOA are managed under Tier 6 (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 for Pacific sleeper shark, salmon shark, and other/unidentified sharks. 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	$OFL = \bar{C}_{1997-2007}$

The ABC/OFL for spiny dogfish are based on a Tier 5 approach, but are still considered Tier 6 due to the unreliability of the trawl survey biomass. Beginning in 2015, the random effects modeled biomass estimates (B_{RFX}) were used for the ABC and OFL calculations (Model 15.1). 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. 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).

The random effects biomass model was fit separately by area (West, Central, and Eastern GOA) and then summed to obtain Gulfwide biomass. 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.

Tier 6* Model	F_{OFL}	Biomass	Equation
15.1	Natural Mortality	Current year random effects biomass	$OFL = M*B_{RFX}$

Description of Alternative Models

Data do not support age or length structured modeling for spiny dogfish at this time, thus alternative methods are used to estimate F_{OFL} for spiny dogfish using demographic modeling approach. The demographic model for spiny dogfish was first presented to the Plan Team in the 2010 SAFE (Tribuzio et al. 2011) and was published in Tribuzio and Kruse 2011. A detailed explanation of the methodology is included in Appendix 20B.

The biomass for spiny dogfish is considered unreliable because it is a minimum biomass estimate. A new model is brought forward in this assessment in an attempt to account for that uncertainty in the biomass estimate by incorporating estimates of availability and susceptibility (i.e., catchability) to the survey gear. Discussion of the model development was presented during the September 2018 GOA Plan Team meeting and is attached in Appendix 20A. To retain consistency with the models presented in September, we continue to use the same model numbers as those presented in September. Both models 15.1 and 15.3A are based on the Tier 5 calculation where $OFL = F_{OFL}$*Biomass, with the differences between the models being how the F_{OFL} and biomass are estimated.

Model	F_{OFL}	Biomass	Equation
15.1	Natural Mortality	Current year random effects biomass	$OFL = M*B_{RFX}$
15.3A	Maximum sustainable F	Current year random effects biomass adjusted by catchability	$OFL = F_{max}*B_a$

The maximum sustainable fishing rate (F_{max}) is derived from the demographic model. Catchability (q) of any gear is a function of the availability of an animal to the survey gear and the selectivity (S) of the gear, or the ability of the gear to catch available animals. Availability can be further broken down into horizontal (a_h) and vertical availability (a_v). Thus the adjusted biomass used in Model 15.3A is $B_a = B_{RFX}/q = B_{RFX}/(S*a_h*a_v)$.

Parameter Estimates

Natural mortality of spiny dogfish (used in Model 15.1) 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 (described in Appendix 20B). This model is not updated for each assessment and thus not considered to be the assessment model. The parameters provided by the demographic analysis are thus estimated outside of the model.

Model 15.3A incorporates catchability based on a_v, a_h, and *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, $q = S*a_h*a_v = 1*1*0.21=0.21$.

Life history parameters, where available, are presented for all the species in the complex in Tables

Table 20.1 and Table 20.2. 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.

Results

Model Evaluation

Model 11.0 assumes that the annual catches for each of the species are normally distributed, and that a mean is representative of catch. Catches are generally either bi-modal or heavy skewed, thus the assumption of normality is violated. A more appropriate metric would be the median or a percentile of the data, or defining a correct distribution for each species prior to computations. We do not recommend these changes for the current assessment because the authors are investigating data-limited methods and plan to bring forward alternative assessment methods in the next full assessment.

The demographic model was evaluated by examining the model's sensitivity to uncertain input parameters (Tribuzio and Kruse 2011). Assuming an unfished stock at the beginning of the simulation, recruitment at age 0, and $r = 0.03$ yr^{-1} (0.012–0.06 yr^{-1}, 95% CI), maximum sustainable *F* was estimated to be $F_{max} = 0.03$ (0.01–0.06, 95% CI). If recruitment were assumed to occur at age 10, then $F_{max} = 0.04$ (0.01–0.08, 95% CI). An ageing study that sampled from commercial trawl and longline gears in the GOA found no spiny dogfish less than 8 years of age. Thus, $F_{max} = 0.04$ is recommended.

The random effects model was fit to the survey biomass estimates (with associated variance) for the Western, Central, and Eastern GOA. The random effects model estimates a process error parameter (constraining the variability of the modeled estimates among years) and random effects parameters for each year modeled. The fit of the random effects model to survey biomass in each area is shown in Figure 20.23. For illustration the 95% confidence intervals are shown for the survey biomass (error bars) and the random effects estimates of survey biomass (shaded area). In general, the random effects model fits the area-specific survey biomass reasonably well. The time series of results from the random effects approach to survey averaging is presented in Table 20.14.

Harvest Recommendations

We recommend continuing with Model 11.0 for Pacific sleeper shark, salmon shark, and other/unidentified sharks. While we acknowledge that this model violates the assumption of normality in the catch data, we recommend delaying making any changes to the model pending results of ongoing explorations of data-limited methods.

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	52
Other/Unidentified Sharks	11.0	188	188	141

We present two alternatives for calculating the spiny dogfish OFL: 1) Status quo (Model 15.1) and 2) Model 15.3A. The results from model 15.3A are recommended and are presented in summary tables throughout the document.

Model	F_{OFL}	B_{RFX} (95% CI)	Ba (95% CI)	OFL (95% CI)	ABC (95% CI)
15.1	0.097	54,301 (22,941–128,532)	NA	5,267 (2,225–12,468)	3,950 (1,669–9,351)
15.3A	0.04	54,301 (22,941–128,532)	258,577 (109,242–612,057)	10,343 (4,370–24,482)	7,757 (3,277–18,362)

Thus the complex totals for each alternative are:

Alternative 1 (Status Quo)		OFL	ABC
Spiny Dogfish	Model 15.1	5,267	3,950
Pacific Sleeper Shark	Model 11.0	312	234
Salmon Shark	Model 11.0	70	52
Other Sharks	Model 11.0	188	141
Shark Complex Total		**5,836**	**4,377**
Alternative 2			
Spiny Dogfish	Model 15.3A	10,343	7,757
Pacific Sleeper Shark	Model 11.0	312	234
Salmon Shark	Model 11.0	70	52
Other Sharks	Model 11.0	188	141
Shark Complex Total		**10,912**	**8,184**

None of these options are likely to constrain the fishery, as current shark catches are generally lower than all of the ABC options presented above. The OFL options have not been exceeded. Exceeding the ABC would trigger the sharks being put on non-retention status, which has little effect on other fisheries because the sharks are already restricted to bycatch only and are rarely retained.

For the 2018 fishery we recommend Alternative 2. The $F_{OFL} = F_{max}$ would be an improvement over the $F_{OFL} = M$, and the authors support using this F rate. Setting $F_{OFL} = F_{max}$ would treat the F_{max} as a limit reference point (as stated by the SSC in the December 2010 minutes) and $F_{ABC} = 0.75*F_{max}$ would be the target reference point. The B_{RFX} is considered a minimum biomass because the species spends a substantial amount of time off-bottom and unavailable to the trawl survey gear, and thus the species is not in Tier 5. Model 15.3A adjusts the biomass to account for the availability and susceptibility to the trawl survey gear, and if accepted, spiny dogfish would be moved to Tier 5.

There are several reasons why F_{max} is more appropriate for spiny dogfish than the status quo method of $F_{OFL} = M$. First, the U.S. west coast spiny dogfish stock has more data (e.g., fishery lengths, longer times series, and more reliable survey estimates) available for the assessment conducted by the Northwest Fisheries Science Center. In that assessment B_{msy} is $B_{79.62\%}$, substantially greater than that for teleost species, for which the Tier system was designed around. Further, the west coast stock is estimated to be at 63% of B_{msy} and recommended $F_{msy} = 0.0053$, a full order of magnitude less than the recommendations in this assessment. For comparison, we calculated B_a back to 2013 and used that to estimate a relative exploitation rate (catch/biomass), resulting in an average rate of 0.0053, which does not include observed catch in inside waters, nor does it include catch from any state managed fisheries (e.g. salmon gillnet fisheries). Thus, fishing could be occurring at a rate greater than what is recommended in neighboring stocks.

Second, deciding which F_{OFL} to use comes down to a decision between a proxy that assumes $F_{OFL} = M$ is sustainable, or a rate based on the best available data ($F_{OFL} = F_{max}$). We recommend the $F_{OFL} = F_{max}$ because the assumption that $F_{OFL} = M$ is sustainable is likely inappropriate for spiny dogfish. Inflection points (B_{MSY}) on population growth curves for sharks tend to occur at biomass values > $B_{50\%}$ (Corte´s 2007; Simpfendorfer *et al.* 2008) and it has been argued that management should strive to maintain biomass of less-productive shark populations, such as spiny dogfish, well above B_{MSY} levels owing to time lags associated with their delayed maturity and high longevity (Musick *et al.* 2000). The demographic analysis, combined with the information from the west coast assessment and the potential for connectivity between stocks suggests that using M as a proxy for F_{OFL} is risky.

Third, there is likely connectivity between the GOA, Canadian U.S. west coast, Bering Sea, Russian and Japanese stocks. Tagging studies have shown that fish tagged in British Columbia, Canada, Washington State and the Gulf of Alaska demonstrate substantial movement between regions (McFarlane and King 2003, Taylor et al. 2009 and Tribuzio unpublished data). Nearly 60% of spiny dogfish tagged with pop-off satellite archival tags (i.e., fishery independent) were recovered in a different jurisdictional area than where they were released (Tribuzio unpublished data). Thus, population level impacts that occur elsewhere, such as the directed fishing that occurred in British Columbia and on the U.S. west coast until recently, likely affects the GOA stock as well. In fact, Taylor et al. (2009) suggested that spiny dogfish in the Northeast Pacific Ocean should be treated as one meta-population, as opposed to separate stocks.

There are two major concerns with regards to management of the Tier 6 shark species; 1) accuracy of catch estimates and 2) the appropriateness of the OFL determination methods. The accuracy of catch is a two-part problem. The first issue is that catch is likely underestimated due to the difficulty in obtaining accurate weight estimates for large sharks on longline vessels. A special project was conducted by the North Pacific Observer Program during the 2018 fishery to estimate size of Pacific sleeper sharks caught on longline vessels. While that project is still ongoing (and will likely continue into 2019), preliminary results indicate that the average weight of sharks per haul that is used for total catch estimates underestimates the true weight of the sharks. The other concern with the accuracy of catch estimates is that not all catches are accounted for. For example, there are substantial state-managed fisheries that may catch significant numbers of sharks, all of which are undocumented. At this time, it is impossible to clarify either issue associated with the accuracy of catch estimates.

The OFL determination for the Tier 6 shark species is based on catch history due to data-limitations. The current Tier 6 method assumes that fishing at the mean or maximum historical catch is sustainable and not at a rate that could cause overfishing. Uncertainty is simply incorporated by assuming that a 25% reduction from the assumed sustainable fishing rate is sufficient. These rates are not informed by biology, nor has there been any examination to verify that these rates are truly sustainable. However, the field of data-limited assessment methods has expanded substantially in recent years in response to MSA and the requirements to set ACLs for all managed stocks. Studies have shown that the simple catch-based metrics used by the NPFMC Tier 6 are the poorest performing of the data-limited methods (DLMs). For long-lived teleost stocks, there is a >90% probability that using these methods will result in overfishing a stock (e.g., Carruthers et al. 2014 and others). While using DLMs to determine an ABC is useful, efforts need to be put into exploring appropriate threshold limits, which are likely a species specific problem. Staff at AFSC have begun evaluating the DLMs and Tier 6 assumptions for the assessed data-limited stocks. The Pacific sleeper shark is the first species in the shark complexes in which we are exploring Tier 6 alternatives and DLMs. We anticipate bringing forward alternative assessment methods for the next full assessment.

Ecosystem Considerations

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

Ecosystem Effects on Stock

Pacific sleeper shark

Pacific sleeper sharks were once thought to be sluggish and benthic because their stomachs commonly contain offal, cephalopods, and bottom dwelling fish such as flounder (*Pleuronectidae*) (e.g., Yang and Page 1999). In contrast, another diet analysis documented prey from different depths in the stomachs of a single shark, such as giant grenadier (*Albatrossia pectoralis*) and pink salmon (*Oncorhynchus gorbuscha*), indicating that they make depth oscillations in search of food (Orlov and Moiseev 1999). Other diet studies have found that Pacific sleeper sharks prey on fast moving fish such as salmon (*O. spp.)* and tuna (*Thunnus spp*.), and marine mammals such as harbor seals (*Phoca vitulina*) that live near the surface (e.g., Bright 1959; Ebert et al. 1987; Crovetto et al. 1992; Sigler et al. 2006), suggesting that these sharks may not be as sluggish and benthic oriented as once thought. Recent research using stable isotope concentrations in both liver and muscle tissue determined that Pacific sleeper sharks likely get a significant portion of their energy from lower trophic prey (i.e. Pacific herring, walleye pollock; Schauffler et al. 2005) and that they also feed on prey from a wide variety of trophic levels (Courtney and Foy 2012). Similar to spiny dogfish, fluctuations in environmental conditions and prey availability may not significantly affect this species because of its wide dietary niche. There are no known predators of Pacific sleeper sharks. Data suggests that most of the Pacific sleeper sharks caught in the BSAI and GOA are immature and there is no information on spawning or mating or gestation, so it is unknown how the fishery affects their recruitment.

Salmon Shark

Salmon sharks are opportunistic feeders, sharing the highest trophic level of the food web in subarctic Pacific waters with marine mammals and seabirds (Brodeur 1988, Nagasawa 1998, Goldman and Human 2004). They feed on a wide variety of prey, from squid and shrimp to salmon (*Oncorhynchus* sp.) and rockfishes (family Sebastes) and even other sharks (Sano 1962, Hart 1973, Compagno 1984, Nagasawa 1998). The species is a significant seasonal predator of returning salmon in some areas (e.g. Prince William Sound), but the species is broadly dispersed across the North Pacific Ocean and likely does not have an overall significant impact on prey species. Salmon sharks are endothermic, which enables them to have a broad thermal tolerance range and inhabit highly varying environments. Because of this ability, they can adapt to changing climate conditions and prey availability. Salmon sharks generally mate in the fall and give birth the following spring. Much of the salmon shark catch in the BSAI occurs in the summer months after spawning.

Spiny dogfish

Previous studies have shown spiny dogfish to be opportunistic feeders that are not wholly dependent on one food source (Alverson and Stansby 1963). Small dogfish are limited to consuming smaller fish and invertebrates, while the larger animals will eat a wide variety of foods (Bonham 1954). In the GOA, preliminary diet studies further suggest that spiny dogfish are highly generalized, opportunistic feeders (Tribuzio, unpublished data). Thus, fluctuations in the environmental conditions and prey availability likely have little effect on the species because of its ability to switch prey, although this also depends on the overall abundance of the prey species. The primary predator on spiny dogfish are other sharks, but data suggest other potential predators could be orcas, lingcod and halibut (Tribuzio, unpublished data). It is not well known if fishing activity occurs when and where sharks spawn. Spiny dogfish have an 18 – 24 month gestation, therefore, fishing activity overlaps with reproduction, regardless of when it occurs.

Fishery Effects on Ecosystem

Because there has been virtually no directed fishing for sharks in Alaska, the reader is referred to the discussion on Fishery Effects in the SAFE reports for the species that generally have the greatest shark catches. 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: Working with AKRO to estimate catch in numbers, and with FMA to investigate if average weights are representative of actual weights.
2. Define the stock structure and movement patterns (i.e. tagging studies, genetics).
    a. Actions: Continued analysis of spiny dogfish pop-off satellite archival tag data; investigating population genetics of Pacific sleeper shark.
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: Set-up pilot study for using eye lens 14C for ageing, developing full project with UAF.

Acknowledgments

We gratefully acknowledge the following individuals for their timely and efficient work in providing survey and catch data for shark species: Wayne Palsson for the Gulf of Alaska trawl survey estimates (AFSC); Claude Dykstra, Eric Soderlund, Aaron Ranta, Anna Henry and Tracee Geernaert (IPHC) provided IPHC longline survey data; the Alaska Regional Office (NMFS) provided estimates of commercial catch; Sarah Gaichas provided catch estimates for 1997–2003; and Bob Ryzner, Rob Ames and Neils Leuthold (AKFIN, Pacific States Marine Fisheries Commission) provided a user friendly portal to access Catch Accounting System data and multiple AFSC survey data sources.

Literature Cited

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

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

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

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

Braccini M, J. Van Rijn, and L. Frick. 2012. High Post-Capture Survival for Sharks, Rays and Chimaeras Discarded in the Main Shark Fishery of Australia? PLoSONE 7(2): e32547. doi:10.1371/journal.pone.0032547

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

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

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

Campana, S.E., W. Joyce, and M.J. Manning. 2009. Bycatch and discard mortaility in commercially caught blue sharks *Prionace glauca* assessed using archival satellite pop-up tags. Marine Ecology Progress Series. 387:241 – 253.

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

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

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

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

Compagno, L.V.J., 1990. Shark exploitation and conservation. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt, Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 391-414. NOAA Technical Report NMFS 90.

Conrath, C.L., C.A. Tribuzio, and K.J. Goldman. 2014. Notes on the reproductive biology of female salmon sharks in the eastern North Pacific Ocean. Transactions of the American Fisheries Society. 143:363-368.

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

Cortes, E. 2007. Chondrichthyan demographic modelling: an essay on its use, abuse and future. *Marine and Freshwater Research* **58**, 4-6.

Cosandey-Godin, A. and A. Morgan. 2011. Fisheries Bycatch of Sharks: Options for Mitigation. Ocean Science Division, Pew Environment Group, Washington, DC. Courtney, D. L. and R. Foy. 2012. Pacific sleeper shark *Somniosus pacificus* trophic ecology in the eastern North Pacific Ocean inferred from nitrogen and carbon stable-isotope ratios and diet. Journal of Fish Biology. 80:1508-1545.

Courtney, D. 2013. A preliminary review of post-release live-discard mortality rate estimates in sharks for use in SEDAR 34. SEDAR34-WP-08. SEDAR, North Charleston, SC. 20 pp.

(http://www.sefsc.noaa.gov/sedar/download/S34_WP_08_Courtney_Discard_Mortality_SEDAR34.pdf?id=DOCUMENT)

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

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

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

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

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

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

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

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

Gaichas, S., L. Fritz, and J. N. Ianelli. 1999. Other species considerations for the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. Appendix D. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Gaichas, S.K., M Ruccio, D. Stevenson and R. Swanson. 2003. Stock assessment and fishery evaluation of skate species (*Rajidae*) in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska for 2004. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

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

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

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

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

Goldman, K.J. and Human B. 2004. Salmon shark, *Lamna ditropis*. *In* Sharks, rays and chimaeras: the status of the chondrichthyan fishes. (eds. Fowler, S.L., M. Camhi, G. Burgess, S. Fordham and J. Musick). IUCN/SSG Shark Specialist Group. IUCN, Gland, Switzerland, and Cambridge, UK.

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

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

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

Heifetz, J., D. M. Clausen, and J. N. Ianelli. 1994. Slope rockfish. In Stock assessment and fishery evaluation report for the 1995 Gulf of Alaska groundfish fishery, p. 5-1 - 5-24. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

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

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

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

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

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

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

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

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

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

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

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

Mandelman, J.W. and M.A. Farrington. 2007. The estimated short-term discard mortality of a trawled elasmobranch, the spiny dogfish (*Squalus acanthias*). Fisheries Research, 83 (2-3): 238-245. DOI: 10.1016/j.fishres.2006.10.001

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

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

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

Musick, J. A., Burgess, G., Cailliet, G., Camhi, M., and Fordham, S. 2000. Management of sharks and their relatives (Elasmobranchii). *Fisheries* **25**, 3:9-13.

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

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

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

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

Rulifson, R. 2007. Spiny dogfish mortality induced by gill-net and trawl capture and tag and release. North American Journal of Fisheries Management. 27:279-285. Doi: 10.1577/M06-071.1

Ruttenberg BI, Hamilton SL, Walsh SM, Donovan MK, Friedlander A, et al. (2011) Predator-Induced Demographic Shifts in Coral Reef Fish Assemblages. PLoS ONE 6(6): e21062. doi:10.1371/journal.pone.0021062

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

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

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

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

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

Simpfendorfer, C., Cortes, E., Heupel, M., Brooks, E., Babcock, *et al.* 2008. An integrated approach to determining the risk of over-exploitation for data-poor pelagic Atlantic sharks. International Commission for the Conservation of Atlantic Tunas SCRS/2008/140. Available at http://www.iccat.int/Documents/Meetings/Docs/SCRS/SCRS-08-140_Simpfendorfer_et_al_REV.pdf [Accessed 26 May 2009].

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

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

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

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

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

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

Taylor, I.G., G.R. Lippert, V.F. Gallucci and G.G. Bargmann. 2009. Movement patterns of spiny dogfish from historical tagging experiments in Washington State. In ' Biology and Management of Dogfish Sharks'. (Eds. V. F. Gallucci, G. A. McFarlane, and G. Bargmann) pp. 67 – 76. (American Fisheries Society: Bethesda, MD)

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

Tribuzio, C.A., K. Echave, C. Rodgveller, P.J. Hulson. 2012. Assessment of the shark stock complex in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands for 2012. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. Pgs. 1771-1848.

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

Tribuzio, C.A., K. Echave, C. Rodgveller, J. Heifetz, K.J. Goldman. 2010a. Assessment of the sharks in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands for 2012. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501. Pgs. 1451-1500.

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

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

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

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

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

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

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

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

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

Tables

Table 20.1. Biological characteristics and depth ranges for shark species in the Gulf of Alaska. Missing information is denoted by "?". Species in bold are the primary species in this assessment.

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

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

Table 20.2. 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 20.3. 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	2,390				N/A	Other Species TAC
1999	14,600	3,858	1,036				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	25	9	749	N/A	Other Species TAC
2004	12,592	1,705	544	3	24	571	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	617	1	5	623	1,792	Other Species TAC
2009	4,500	3,188	1,741	23	78	1,842	777	Other Species TAC
2010	4,500	1,724	691	10	3	704	957	Other Species TAC
2011	6,197	NA	485	4	4	493	6,197	Shark Complex TAC[#]
2012	6,028	NA	662	5	12	679	6,028	Shark Complex TAC
2013	6,028	NA	2,176	59	195	2,430	6,028	Shark Complex TAC
2014	5,989	NA	1,554	52	127	1,733	5,989	Shark Complex TAC
2015	5,989	NA	1,416	85	69	1,570	5,989	Shark Complex TAC
2016	4,514	NA	2,015	71	152	2,238	4,514	Shark Complex TAC
2017	4,514	NA	1,632	476	243	2,351	4,514	Shark Complex TAC
2018	4,514	NA	2,141	27	67	2,235	4,514	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 2003-2015 from AKRO Catch Accounting System (CAS, queried through AKFIN on Oct. 9, 2018).

Table 20.4. 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 of retained (with coefficient of variation) and discarded sharks are derived from the Statewide Harvest Survey. Estimates of retained salmon shark are derived from recreational charter logbooks and only reflect catch in the charter fleet. Recreational catch of sharks does not count against the total allowable catch (TAC). Source: Scott Meyer, ADF&G. Note that these numbers have not been updated for this assessment.

All Sharks Combined

	Western			Central			Eastern			
Year	**Retained**	**CV**	**Discarded**	**Retained**	**CV**	**Discarded**	**Retained**	**CV**	**Discarded**	**Total Est Catch**
1998	0	--	0	595	0.14	10,151	168	0.30	4,650	15,564
1999	0	--	0	471	0.23	5,189	202	0.42	13,108	18,970
2000	0	--	0	403	0.25	9,301	351	0.46	15,543	25,598
2001	17	0.94	20	392	0.20	18,224	550	0.30	14,518	33,721
2002	0	--	0	347	0.27	7,242	239	0.41	4,234	12,062
2003	0	--	30	755	0.20	24,453	444	0.28	11,273	36,955
2004	0	--	37	399	0.22	16,351	346	0.33	9,193	26,326
2005	0	--	108	950	0.17	45,209	633	0.30	23,041	69,941
2006	0	--	0	554	0.22	38,868	313	0.24	19,235	58,970
2007	0	--	0	555	0.20	44,458	567	0.32	30,161	75,741
2008	0	--	410	559	0.22	22,750	358	0.39	28,923	53,000
2009	0	--	0	213	0.31	19,446	183	0.48	13,255	33,097
2010	0	--	13	286	0.31	19,080	46	0.74	10,348	29,773
2011	0	--	9	469	0.41	8,830	62	0.53	4,781	14,151
2012	0	--	7	126	0.49	6,531	75	0.49	6,517	13,256
2013	0	--	16	538	0.41	6,109	173	0.44	4,925	11,761
2014	0	--	0	1,353	0.44	14,100	748	0.57	13,909	30,110

	Salmon Shark Retained Estimates			
Year	**Western**	**Central**	**Eastern**	**Total**
1998	0	122	84	206
1999	no data	no data	no data	
2000	0	76	99	175
2001	1	98	85	184
2002	0	110	90	200
2003	0	86	97	183
2004	1	103	56	160
2005	3	202	38	243
2006	1	246	37	284
2007	0	207	37	244
2008	0	81	13	94
2009	0	50	13	63
2010	0	20	7	27
2011	0	1	7	8
2012	0	11	10	21
2013	0	3	4	7
2014	0	17	5	22

Table 20.5. 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 9, 2018

Year	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/Unidentified shark
1999	80%	100%	46%	
2000	64%	100%	0%	
2001	78%	78%	0%	
2002	15%	98%	86%	82%
2003	98%	100%	100%	93%
2004	96%	100%	100%	91%
2005	98%	99%	98%	69%
2006	96%	99%	97%	78%
2007	96%	100%	100%	90%
2008	93%	98%	94%	59%
2009	98%	98%	99%	7%
2010	95%	95%	98%	27%
2011	98%	95%	98%	37%
2012	97%	100%	99%	56%
2013	99%	100%	100%	69%
2014	99%	99%	100%	71%
2015	99%	100%	100%	65%
2016	99%	100%	99%	96%
2017	98%	100%	97%	98%
2018	100%	100%	98%	97%
Average	90%	98%	85%	70%

Table 20.6. Estimated incidental catch (t) of sharks in the Gulf of Alaska (GOA) by species as of October 9, 2018. 1990-1998 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999); 1997 – 2002 from the pseudo-blend catch estimation procedure (Gaichas 2001, 2002); 2003 – 2018 from the Alaska Regional Office Catch Accounting System. Breaks in the table represent different catch estimation periods. Also presented are the 1997 – 2007 average catches which are used to estimate Tier 6 OFL for Pacific sleeper shark, salmon shark and other/unidentified sharks, and other catch history metrics.

Year	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/ Unident shark	Total sharks
1990	171	20	53	30	274
1991	141	49	42	108	340
1992	321	38	142	17	518
1993	383	215	89	340	1027
1994	160	120	25	56	3610
1995	141	63	55	49	308
1996	337	66	28	53	484
1997	233	118	25	59	435
1998	298	161	79	132	670
-	-	-	-	-	-
1997	657	136	124	123	1,040
1998	865	74	71	1,380	2,390
1999	314	558	132	33	1,037
2000	398	608	38	74	1,118
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	404	171	107	9	691
2011	447	26	7	5	485
2012	459	142	50	10	661
2013	2,072	95	3	6	2,176
2014	1,330	72	145	6	1,553
2015	957	71	371	17	1,416
2016	1,849	78	80	7	2,014
2017	1,480	130	13	10	1,633
2018	1,885	232	5	18	2,140
1997 – 2007					
Mean	528	312	70	188	1,097
(95% CI of Mean)	(0 – 1,556)	(0 – 641)	(0 – 152)	(0 – 965)	(40 – 2,155)
Median	443	270	58	74	845*
95th Percentile	865	558	132	123	1,678*
99th Percentile	1,155	603	140	1,254	3,152*
Maximum	1,188	608	141	1,380	3,316*

*Total complex value is the sum of the individual species values

Table 20.7. Estimated catch (t) of spiny dogfish in the Gulf of Alaska by target fishery. 1990 – 1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999); 1997 – 2001 catch estimated with improved pseudo-blend (Gaichas 2002); and 2003 – present from the Alaska Regional Office Catch Accounting System (queried through AKFIN on Oct 9, 2018). Prior to 2003 the catch by fishery were estimated by a different procedure and do not sum to the total catch of spiny dogfish in Table 20.6. These values may be used to infer relative magnitude, but are not comparable to estimates beginning in 2003. Data do not include catch from Federal fisheries operating in inside waters of Prince William Sound or Southeast Alaska.

	Atka Mackerel	**Flatfish**	**Halibut**	**Other**	**Pollock**	**Pacific Cod**	**Rockfish**	**Sablefish**	**Total**
1990		13.5			36.0	57.6	1.8	59.0	167.9
1991		16.2			52.6	29.3	16.4	26.2	140.7
1992		116.0			50.5	84.4	22.4	40.7	314.0
1993		138.5			10.1	137.0	2.4	95.3	383.3
1994		83.4			16.9	22.0	2.5	35.4	160.2
1995		24.1			28.1	2.8	18.4	50.7	124.1
1996		182.6			15.3	2.9	19.8	79.5	300.1
1997		137.2			57.6	2.8	326.2	133.7	657.5
1998		69.0			727.2	4.9	3.1	59.6	863.8
1999		56.6			160.2	8.6	4.8	83.4	313.6
2000		66.3			29.4	18.7	146.6	136.6	397.6
2001		162.5			172.8	11.6	25.1	122.1	494.1
2002		1.3	0.0		0.7	12.2	0.4	0.3	13.7
2003	0	166.0	6.6	82.46	43.6	6.1	35.5	17.3	357.5
2004	0	15.5	13.4	1.32	19.6	9.2	2.3	121.7	182.9
2005	0	50.1	17.3	0.6	27.9	15.2	2.8	329.3	443.2
2006	0	122.9	725.9	23.61	113.2	49.3	2.0	150.6	1,187.6
2007	0	151.4	157.7	0	250.9	47.6	6.2	180.6	794.4
2008	0	86.1	0.2	0	289.6	59.6	4.8	91.1	531.4
2009	0	204.8	1,022.1	0	319.0	17.6	7.0	82.1	1,652.7
2010	0	161.8	25.1	0	120.6	19.8	3.5	73.3	404.2
2011	0	97.4	3.8	0	80.8	16.3	1.6	247.1	447.0
2012	0	97.5	32.9	0	19.0	19.1	4.1	286.8	459.5
2013	0.1	194.6	611.8	0	45.0	11.4	90.0	1,119.6	2,072.4
2014	0	133.6	564.6	0	374.8	13.4	2.2	241.8	1,330.4
2015	0	131.5	513.4	0.1	111.3	35.4	2.3	163.0	956.9
2016	0	516.7	418.2	0	341.6	49.2	3.4	519.9	1,848.9
2017	0	206.5	531.3	<0.1	316.6	49.0	26.2	350.1	1,479.7
2018	0	19.3	1,423.1	0	27.3	19.1	9.6	387.0	1,885.5

Table 20.8. Estimated catch of Pacific sleeper shark and spiny dogfish in the inside waters of Prince William Sound (NMFS area 649) and Southeast Alaska (NMFS area 659) by target fishery. These catch estimates do not count against the total allowable catch (TAC). Empty spaces are where no data is available. Greyed out boxes denote year and target fishery combinations where confidentiality restrictions preclude reporting catch. 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 9, 2018).

Species	Year	Halibut	Pacific Cod	Pollock	Rockfish	Sablefish	Total
Pacific Sleeper Shark	2003	1.1	▨	22.5		3.9	▨
	2004	0.5	0.1	1.4		2.5	4.6
	2005	<0.1		3.3		1.3	4.6
	2006		0.1	▨		2.3	▨
	2007	0.3				2.2	2.5
	2008			▨		1.9	▨
	2009		0.5	1.0			1.5
	2010		1.9	6.1		3.5	11.5
	2011		0.6			▨	▨
	2012			0.2		2.9	3.0
	2013	150.6	1.2	▨		0.9	153.2
	2014	37.3	0.1			2.6	39.9
	2015	26.7	20.8	0.1		▨	▨
	2016	11.2	36.5	0.2		<0.1	47.8
	2017	424.6	7.9				432.5
	2018	9.0	1.0	0.4		12.9	23.3
Spiny Dogfish	2003	0.7		0.7		2.7	4.1
	2004	1.6	<0.1			19.4	21.0
	2005	0.7		▨		40.6	▨
	2006	65.7	0.0			26.2	92.0
	2007	18.3	1.4			6.0	25.7
	2008		0.6			3.1	3.7
	2009	86.6	10.2	0.2		2.8	99.8
	2010	1.5	3.9	▨	<0.1	0.5	5.9
	2011	<0.1	3.4	<0.1	▨	2.1	▨
	2012	2.1	0.1	0.2	<0.1	10.8	13.2
	2013	60.6	5.7	0.1	▨	51.6	▨
	2014	100.3	24.9	0.2	<0.1	10.4	135.9
	2015	40.4	57.3	0.3		5.8	103.7
	2016	84.6	37.4	1.1		11.6	134.6
	2017	223.7	39.7	0.1		22.1	285.6
	2018	56.9	4.0	0.2		9.3	70.4

Table 20.9. Estimated catch (t) of Pacific sleeper shark in the Gulf of Alaska by target fishery. 1990 – 1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999); 1997 – 2001 catch estimated with improved pseudo-blend (Gaichas 2002); and 2003 – present from the Alaska Regional Office Catch Accounting System (queried through AKFIN on Oct 9, 2018). Prior to 2003 the catch by fishery were estimated by a different procedure and do not sum to the total catch of Pacific sleeper shark in Table 20.6. These values may be used to infer relative magnitude, but are not comparable to estimates beginning in 2003. Data do not include catch from Federal fisheries operating in inside waters of Prince William Sound or Southeast Alaska.

	Atka Mackerel	**Flatfish**	**Halibut**	**Other**	**Pollock**	**Pacific Cod**	**Rockfish**	**Sablefish**
1990	0	0.4			2.9	9.9	4.3	2.2
1991	0	3.1			27.2	2.8	0.0	16.2
1992	0	2.7			1.1	27.4	0.0	6.4
1993	0	1.0			156.5	21.8	0.0	35.5
1994	0	0.8			79.6	16.6	1.3	21.2
1995	0	20.7			16.9	13.7	0.1	11.6
1996	0	12.1			14.5	11.9	0.0	26.4
1997	0	46.0			22.3	59.3	0.9	7.5
1998	0	10.1			32.4	19.6	0.2	11.3
1999	0	6.0			34.1	505.8	3.0	8.7
2000	0	35.9			178.4	376.8	0.3	16.7
2001	0	6.3			145.9	65.8	0.7	30.3
2002	0	41.7	0.0		0.8	5.6	0.0	0.0
2003	0	93.0	59.1	1.6	50.3	56.3	0.3	9.2
2004	0	73.7	8.4	0.5	168.9	25.5	0.8	4.1
2005	0	129.6	2.2	0.907	196.0	133.8	0.2	18.9
2006	0	60.4	0.8	0	153.3	13.5	0.4	23.2
2007	0	222.7	3.9	0	59.0	9.1	0.0	0.7
2008	0	2.1	0.0	0	47.5	13.2	1.1	2.0
2009	0	14.5	0.2	0	30.2	10.4	0.3	0.2
2010	0	8.0	0.0	0	150.1	12.1	0.0	0.5
2011	0	9.9	0.0	0	3.6	6.3	2.1	4.3
2012	0	131.8	0.0	0	3.8	0.2	0.0	6.7
2013	0	2.6	63.0	0	14.6	14.2	0.5	0.4
2014	1.0	39.2	23.0	0	6.3	2.0	0.0	1.7
2015	2.0	18.7	20.3	0	12.0	18.0	1.6	0.0
2016	3	15.9	6.9	0	37.4	8.9	7.6	1.6
2017	4.0	106.4	12.6	0	0.6	0.1	9.6	0.9
2018	5.0	191.1	27.9	0	7.3	1.5	3.2	1.5

Table 20.10. Estimated catch (t) of salmon shark in the Gulf of Alaska by target fishery. 1990 – 1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999); 1997 – 2001 catch estimated with improved pseudo-blend (Gaichas 2002); and 2003 – present from the Alaska Regional Office Catch Accounting System (queried through AKFIN on Oct 9, 2018). Prior to 2003 the catch by fishery were estimated by a different procedure and do not sum to the total catch of salmon shark in Table 20.6. These values may be used to infer relative magnitude, but are not comparable to estimates beginning in 2003. Data do not include catch from Federal fisheries operating in inside waters of Prince William Sound or Southeast Alaska.

	Atka Mackerel	**Flatfish**	**Halibut**	**Other**	**Pollock**	**Pacific Cod**	**Rockfish**	**Sablefish**	**Total**
1990	0	0.2		0	45.3	3.2	0.7	2.1	51.5
1991	0	0		0	36.2	0	0	5.3	41.5
1992	0	0.2		0	123.1	16.5	0.0	2.1	141.9
1993	0	2.5		0	86.7	0	0	0	89.2
1994	0	0		0	24.2	0	0	0	24.2
1995	0	3.2		0	25.9	21.6	0.2	3.1	54.0
1996	0	0.0		0	26.9	0	0	0.2	27.1
1997	0	0		0	19.8	0.1	0	0	19.9
1998	0	0.8		0	69.7	0	0.4	0	70.9
1999	0	0.7		0	111.8	0.7	0	18.4	131.6
2000	0	3.7		0	32.7	0	0.8	0.6	37.8
2001	0	1.5		0	29.5	0	1.8	0	32.8
2002	0	0.3		0	0	0	0	0	0.3
2003	0	0.3	0	0.3	34.6	0	0	0.1	35.2
2004	0	5.4	0	0	33.1	1.7	0.1	0.4	40.7
2005	0	15.7	0	0	43.1	0.8	0.5	0	60.1
2006	0	1.6	0	0	31.4	0.6	0.6	0	34.3
2007	0	9.0	0.1	0	130.9	0	0.5	0	140.6
2008	0	0.1	0	0	6.4	0	0.7	0	7.2
2009	0	2.0	0	0	6.9	0	0.4	0	9.2
2010	0	1.0	0.1	0	103.8	0	2.4	0	107.3
2011	0	0.9	0	0	5.6	0	0.2	0	6.6
2012	0	0.1	0	0	49.6	0	0.4	0	50.1
2013	0	0.1	0	0	2.8	0	0	0	2.9
2014	0	0.6	0.1	0	144.0	0	0	0.2	144.9
2015	0	0	0	0	369.0	0	2.2	0	371.2
2016	0	0.5	0	0	79.3	0	0	0	80.2
2017	0	1.5	0.0	0	10.3	0	1	0.0	12.5
2018	0	0	0	0	3.2	0	1.1	0	4.7

Table 20.11. Estimated catch (t) of other/unidentified sharks in the Gulf of Alaska by target fishery. 1990 – 1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999); 1997 – 2001 catch estimated with improved pseudo-blend (Gaichas 2002); and 2003 – present from the Alaska Regional Office Catch Accounting System (queried through AKFIN on Oct 9, 2018). Prior to 2003 the catch by fishery were estimated by a different procedure and do not sum to the total catch of other/unidentified sharks in Table 20.6. These values may be used to infer relative magnitude, but are not comparable to estimates beginning in 2003. Data do not include catch from Federal fisheries operating in inside waters of Prince William Sound or Southeast Alaska.

	Atka Mackerel	Flatfish	Halibut	Other	Pollock	Pacific Cod	Rockfish	Sablefish	Total
1990		0.8			4.1	21.3	1.4	2.9	30.5
1991		35.5			17.8	36.7	4.4	13.7	108.1
1992		3.5			3.3	8.4	0.1	1.5	16.8
1993		3.7			138.3	38.1	0	159.3	339.4
1994		3.0			41.6	2.3	0	8.9	55.8
1995		10.6			4.0	3.4	9.7	14.3	42.0
1996		17.8			14.2	3.1	1.9	16.0	53.0
1997		9.0			8.9	13.4	47.5	43.9	122.7
1998		17.9			24.2	10.2	2.3	1,325.2	1,379.8
1999		8.1			6.1	12.3	0.1	6.4	33.0
2000		34.0			12.3	3.5	4.8	18.7	73.3
2001		1.5			35.0	1.4	1.4	37.7	77.0
2002		4.6	0		2.8	8.9	0.1	0.4	16.8
2003		18.2	17.5	0.2	7.6	6.4	0.2	3.1	53.2
2004		18.8	2.6	0	11.1	2.7	0.2	3.3	38.7
2005		21.5	0.2	0	34.7	1.2	0.2	11.0	68.8
2006		24.4	0	0	40.9	11.9	1.6	4.4	83.2
2007		49.6	0	0	13.8	38.3	0.4	4.9	107.0
2008		2.4	0	0	4.3	2.4	0	2.9	12.0
2009		10.6	0	0	10.4	2.7	0	0	23.7
2010		4.0	0.2	0	3.7	0.2	1.2	0	9.3
2011		2.3	0	0	1.1	0.2	0.9	0.1	4.6
2012		1.9	0	0	3.7	0.1	0.1	4.6	10.4
2013		0.2	1.1	0	1.0	0.2	2.7	0.4	5.6
2014		0.3	0	0	2.2	0.2	0.1	3.4	6.2
2015		0.2	5.3	0	6.0	0	0	5.5	17.0
2016		0.8	0.8	0	0.6	0	0.9	4.3	7.4
2017		0	0	0	3.6	0	3.3	3.0	9.9
2018		0	0.2	0	0.2	0	1.3	16.5	18.2

Table 20.12. 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, 2018 (RACEBASE, queried through AKFIN).

		Spiny Dogfish			Sleeper Shark			Salmon Shark			
Year	Survey Hauls	Haul w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV	Hauls w/catch	Biomass Est.	CV	Total Shark Biomass
1984	929	125	10,143.0	0.206	1	163.2	1.000	5	7,848.8	0.522	18,155.0
1987	783	122	10,106.8	0.269	8	1,319.2	0.434	15	12,622.5	0.562	24,048.5
1990[#]	708	114	18,947.6	0.378	3	1,651.4	0.660	13	12,462.0	0.297	33,061.0
1993[#]	775	166	33,645.1	0.204	13	8,656.8	0.500	9	7,728.6	0.356	50,030.5
1996[#]	807	99	28,477.9	0.736	11	21,100.9	0.358	1	3,302.0	1.000	52,880.8
1999	764	168	31,742.9	0.138	13	19,362.0	0.399	0	0	NA	51,104.9
2001[*,#]	489	75	31,774.3	0.450	15	37,694.7	0.362	0	0	NA	69,469.0
2003[$]	809	204	98,743.8	0.219	28	52,115.6	0.247	2	3,612.8	0.707	154,472.2
2005	839	156	47,938.8	0.170	25	57,022.0	0.263	1	2,455.3	1.000	107,416.1
2007	820	161	162,759.4	0.349	15	41,848.9	0.406	2	12,339.7	0.752	216,948.0
2009	884	176	27,879.9	0.120	8	39,687.7	0.446	0	0	NA	67,567.6
2011[$]	670	97	41,093.0	0.218	5	29,496.1	0.540	1	3,765.9	1.000	74,355.0
2013[$]	548	58	160,384.3	0.404	6	40,848.1	0.457	1	3,978.5	1.000	205,210.9
2015	772	81	51,916.4	0.254	6	70,932.6	0.570	2	5,930.9	0.875	128,779.9
2017[$]	536	112	53,978.6	0.189	1	6,561.4	1.000	0	0.0	NA	60,540.0

[#] Survey maximum depth was 500m

[$] Survey maximum depth was 700m

[*] Survey did not sample the Eastern Gulf of Alaska

Table 20.13. Research survey catch of sharks 1977 - 2017 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 estimated catch (t) is directly from the survey. Beginning in 2010 all research and other non-commercial catch is provided by the Alaska Regional Office.

Year	Source	AFSC Trawl Surveys (t)	AFSC LL Survey (#s)	AFSC LL Survey (t)	IPHC LL Survey (#s)	IPHC LL Survey (t)	ADF&G (t) (includes sport and research)
1977	Assessment of the sharks in the Gulf of Alaska (Tribuzio et al. 2010)	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	NA			
1990		3.52	583	NA			
1991		0.15	2,039	NA			
1992		0.12	3,881	NA			
1993		5.03	2,557	NA			
1994		0.43	2,323	NA			
1995		0.57	3,882	NA			
1996		3.48	2,206	NA			
1997		0.52	2,822	NA			
1998		0.58	7,701	NA	42,361	NA	
1999		NA	1,185	NA	21,705	NA	
2000		NA	1,212	NA	29,257	NA	
2001		0.45	1,726	NA	34,227	NA	
2002		NA	1,576	NA	22,028	NA	
2003		7.36	2,372	NA	68,940	NA	
2004		NA	1,964	NA	48,850	NA	
2005		7.13	3,775	NA	44,082	NA	
2006		0	6,593	NA	41,355	NA	
2007		14.06	3,552	NA	34,023	NA	
2008		0.73	3,606	NA	24,655	NA	
2009		4.03	4,709	NA	29,299	NA	
2010	AKRO	0.50	2,622	6.26	NA	399.86	9.66
2011		2.76	2,108	4.39	NA	150.95	5.70
2012		3.01	1,835	5.45	NA	188.92	6.17
2013		8.54	1,017	2.74	NA	293.22	5.32
2014		1.95	2,844	8.09	NA	153.85	14.70
2015		4.71	2388	5.20	NA	232.63	9.43
2016		0.17	2259	4.87	NA	324.16	4.64
2017		2.31	3131	8.48	NA	173.82	2.95

Table 20.14. Biomass of spiny dogfish estimated by the random effects model with 95% confidence intervals (CI).

	Est. Biomass	Lower 95% CI	Upper 95% CI
1984	10,119.9	14,886.6	6,879.5
1985	9,972.5	21,702.0	4,582.6
1986	9,894.2	21,648.4	4,522.0
1987	9,948.2	15,666.6	6,317.0
1988	9,838.0	19,907.7	4,861.8
1989	11,041.8	22,641.9	5,384.8
1990	14,181.0	24,914.5	8,071.6
1991	16,179.4	33,258.4	7,870.9
1992	20,849.5	41,676.5	10,430.4
1993	30,309.2	43,923.1	20,914.9
1994	28,518.8	64,929.7	12,526.2
1995	27,020.1	69,776.3	10,463.2
1996	25,756.8	60,470.8	10,970.8
1997	26,123.5	64,149.5	10,638.3
1998	28,105.0	58,378.2	13,530.6
1999	32,563.7	42,435.6	24,988.3
2000	42,190.0	81,743.0	21,775.5
2001	54,821.5	105,784.0	28,410.8
2002	68,064.0	133,453.0	34,714.2
2003	84,563.4	121,535.0	58,838.9
2004	65,918.2	119,750.0	36,285.6
2005	53,347.6	72,547.6	39,229.0
2006	72,705.2	139,647.0	37,852.9
2007	100,361.0	168,866.0	59,647.2
2008	54,154.2	102,280.0	28,673.1
2009	29,905.7	37,508.1	23,844.2
2010	35,944.9	65,600.1	19,695.7
2011	43,271.0	63,044.5	29,699.3
2012	63,750.4	128,328.0	31,669.8
2013	97,368.9	176,753.0	53,638.3
2014	72,612.8	147,666.0	35,706.5
2015	56,071.6	85,590.4	36,733.4
2016	54,663.2	101,965.0	29,304.7
2017	54,301.2	77,025.9	38,280.9
2018	54,301.2	128,532.0	22,940.8
2019	54,301.2	180,557.0	16,330.7
2020	54,301.2	240,962.0	12,236.9

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

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

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

Figures

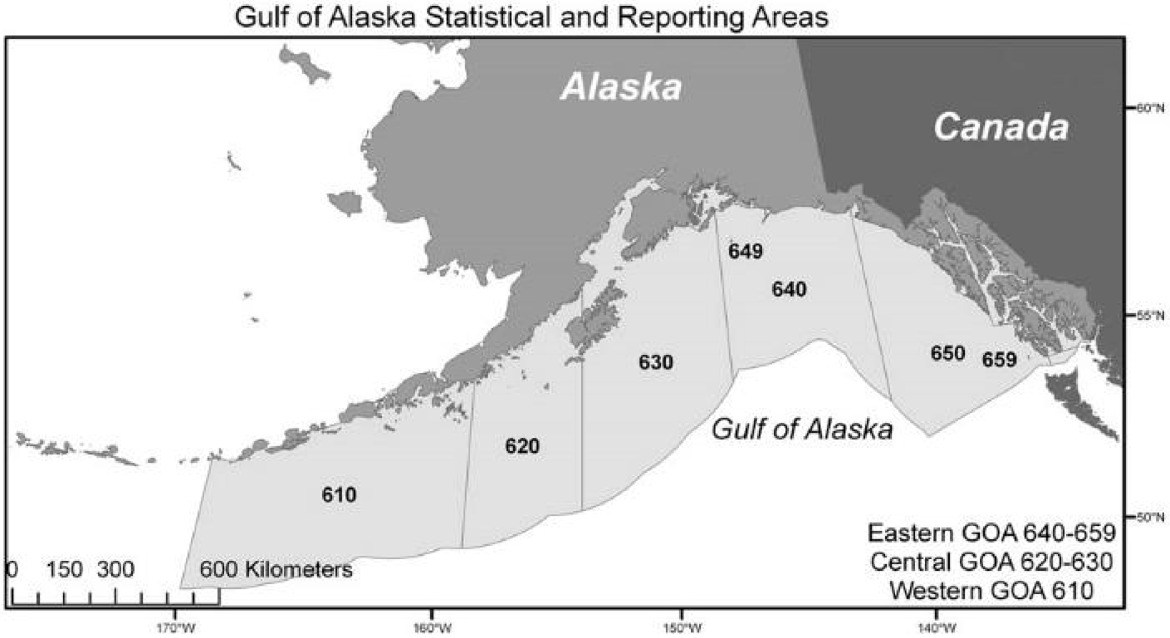

Figure 20.1. NMFS statistical and regulatory areas in the Gulf of Alaska.

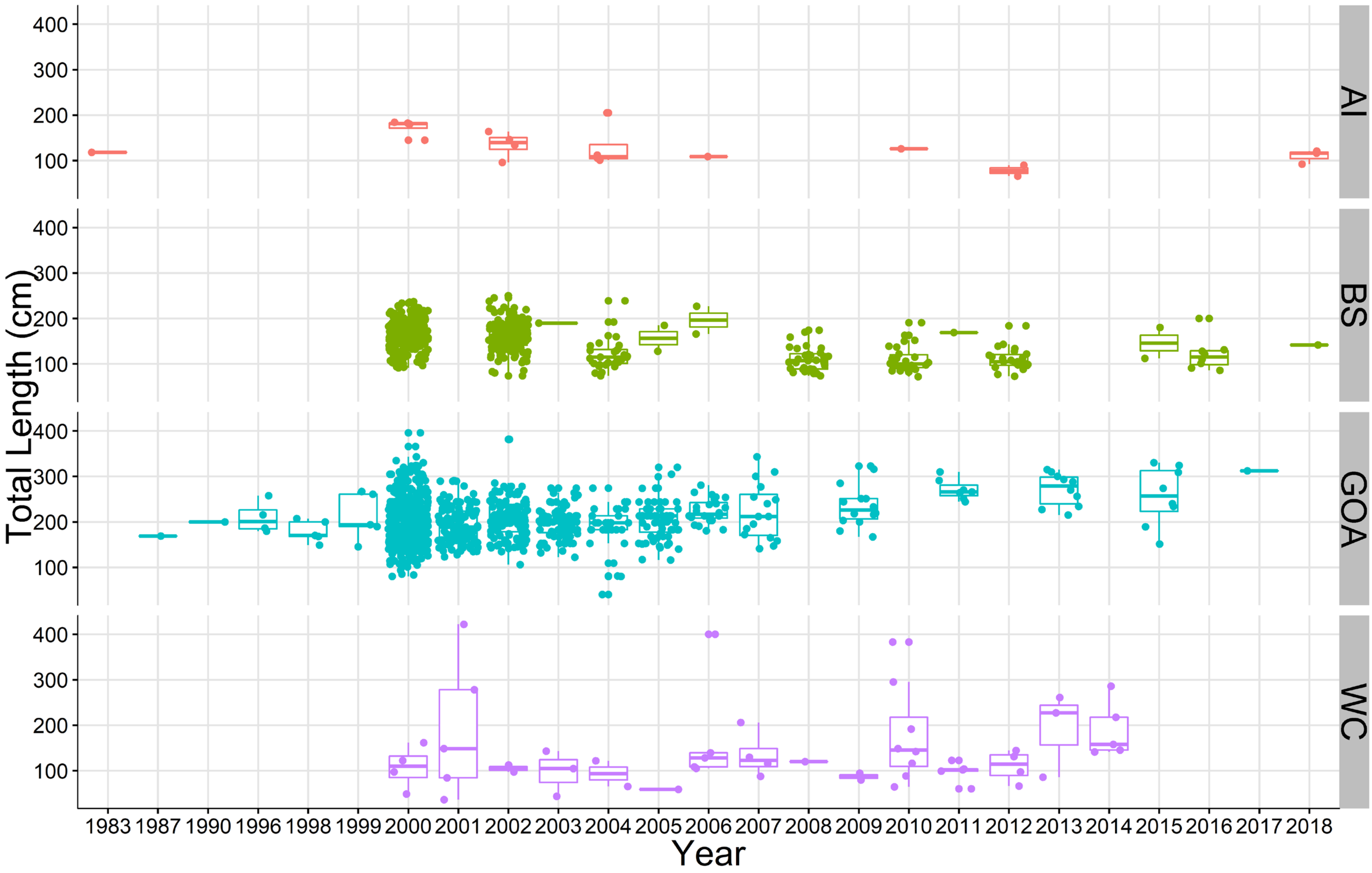

Figure 20.2. Size distribution of Pacific sleeper shark collected in the Aleutian Islands (AI), Bering Sea (BS), Gulf of Alaska (GOA) and the U.S. West Coast (WC). Data are compiled from standard NMFS groundfish trawl surveys, non-standard NMFS surveys (i.e., opportunistic sample collection), directed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

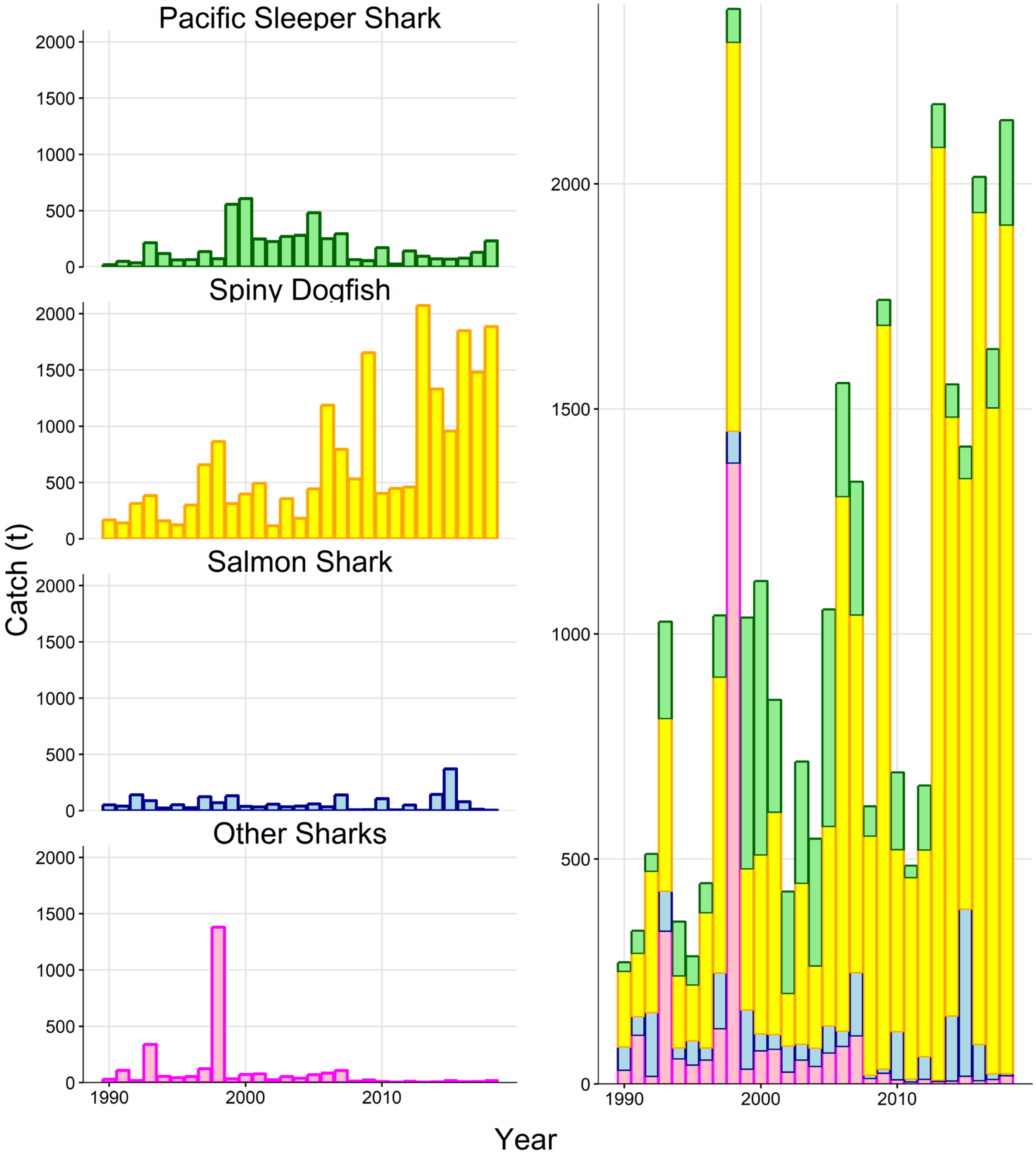

Figure 20.3. Estimated incidental catch (t) of sharks in the Gulf of Alaska (GOA) by species. 1990–1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999); 1997–2001 catch estimated with improved pseudo-blend (Gaichas 2002); and 2003–present from the Alaska Regional Office Catch Accounting System (queried through AKFIN on October 15, 2015).

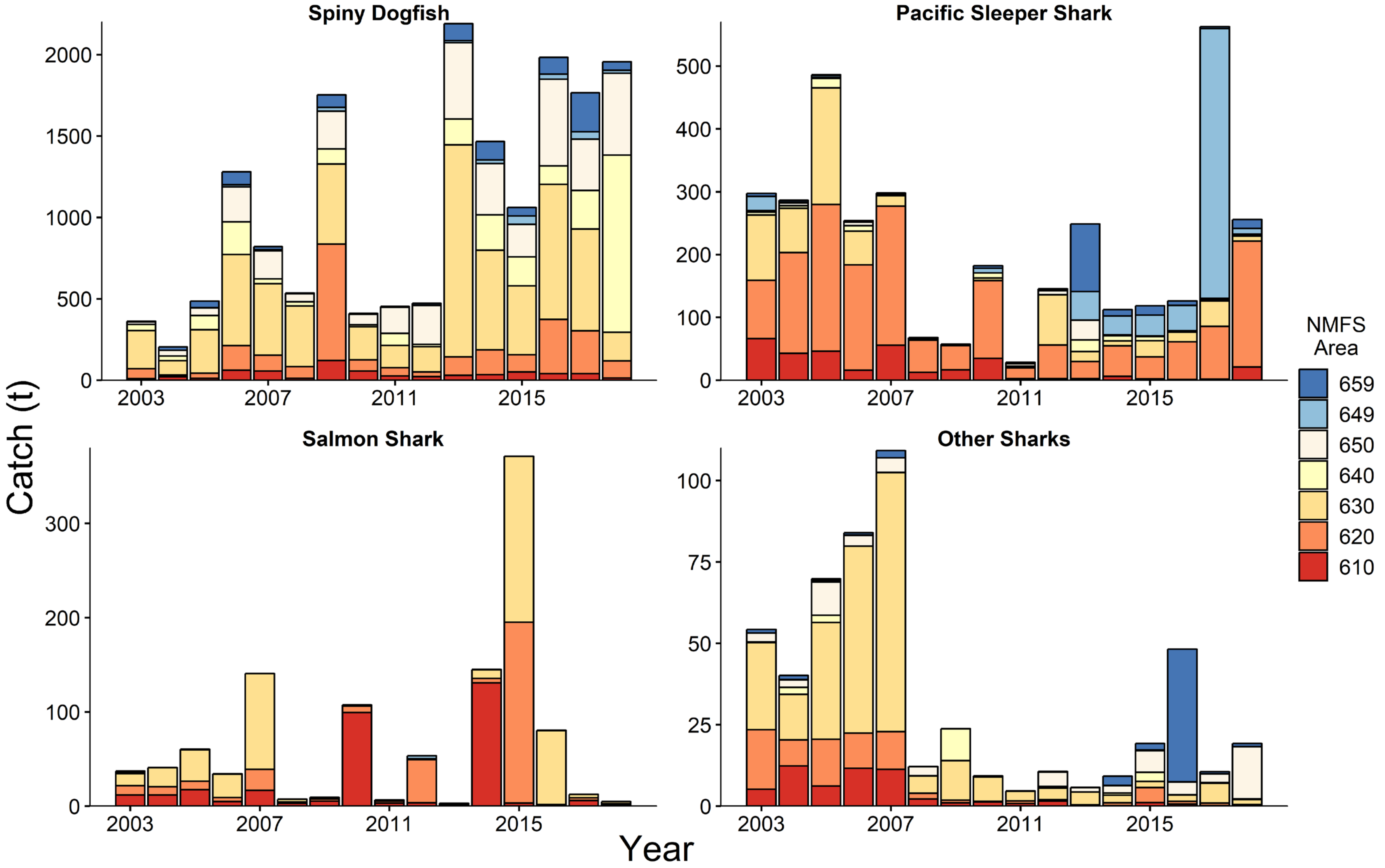

Figure 20.4. Estimated catch of sharks by NMFS area in the Gulf of Alaska. Only data from 2003–present, Alaska Regional Office Catch Accounting System queried through AKFIN on October 9, 2018. Catch occurring in NMFS areas 649 (Prince William Sound) and 659 (Southeast Alaska inside waters), those areas 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.

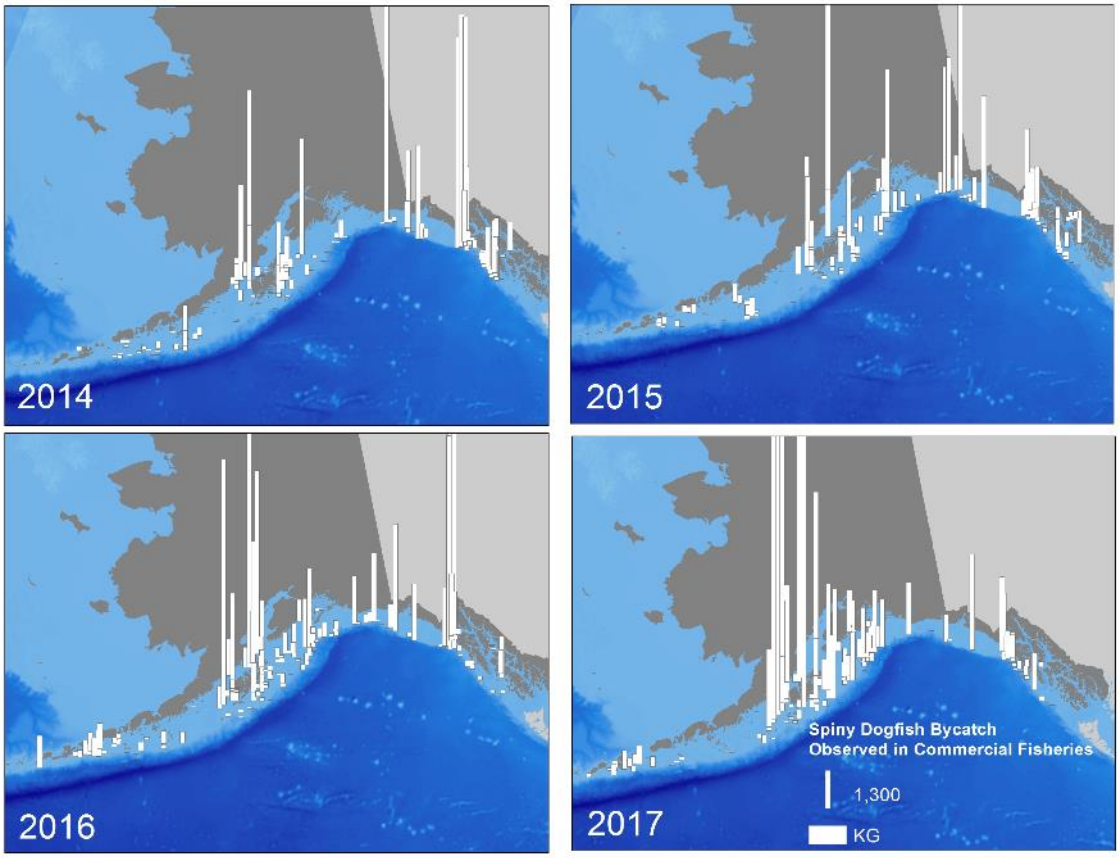

Figure 20.5. Spatial distribution of observed spiny dogfish catch in the Gulf of Alaska from 2014–2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400 km^2 grids. Grid blocks with zero catch were not included for clarity. Data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

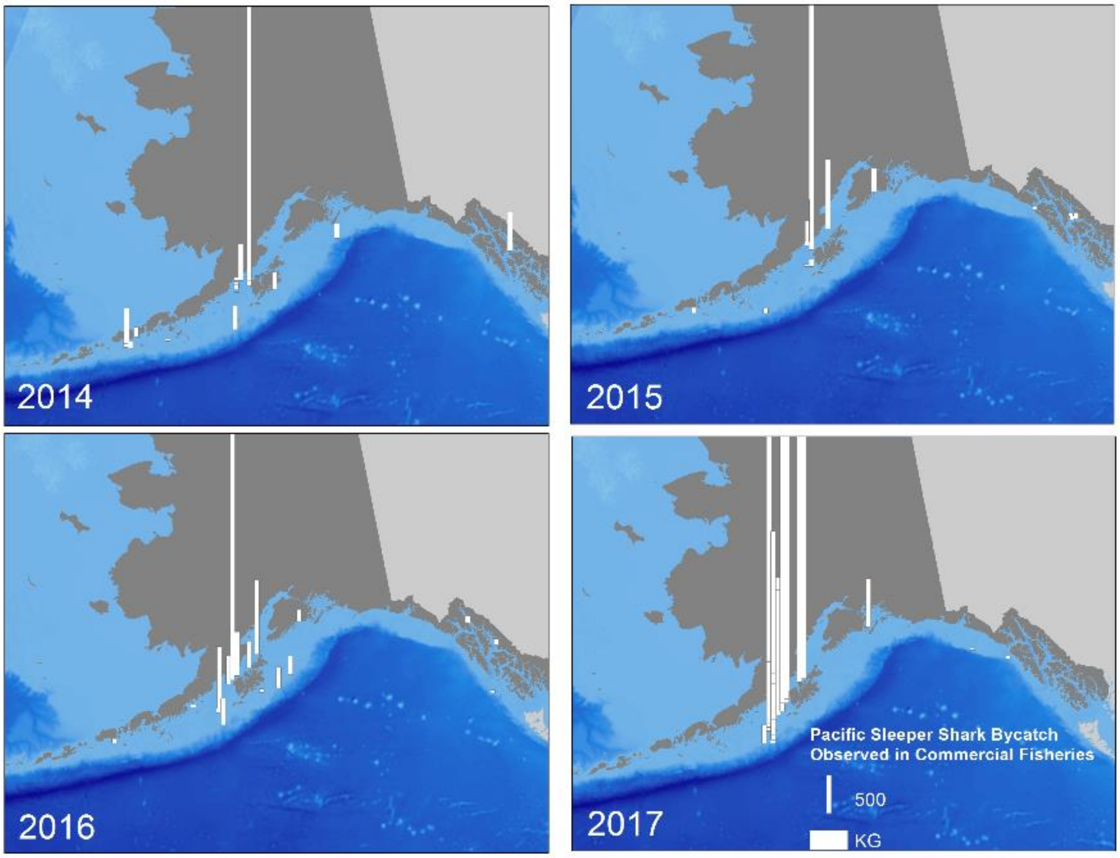

Figure 20.6. Spatial distribution of observed Pacific sleeper shark catch in the Gulf of Alaska from 2014–2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400 km^2 grids. Grid blocks with zero catch were not included for clarity.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

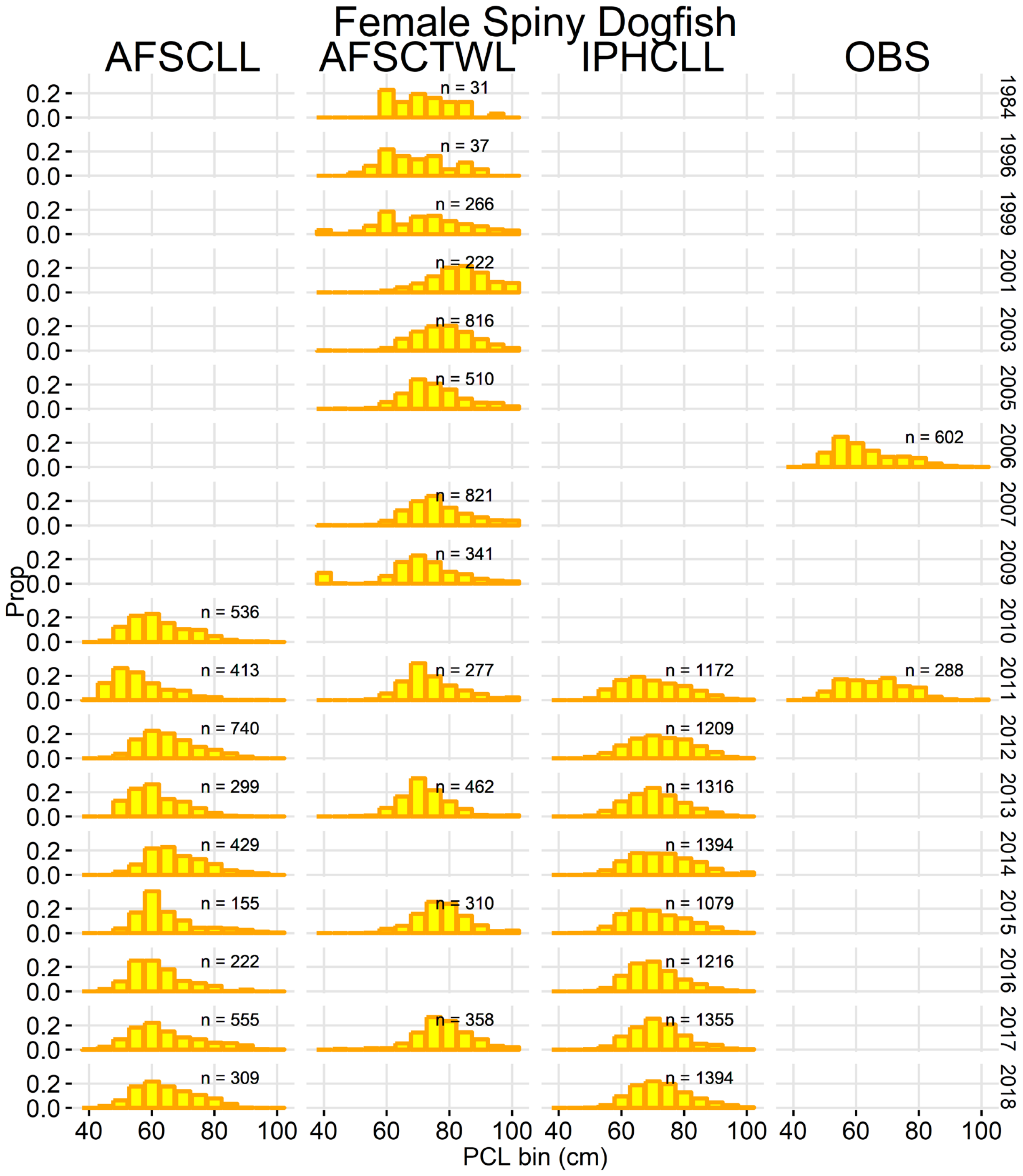

Figure 20.7. Observed length frequencies and sample sizes for female spiny dogfish in the Gulf of Alaska. The Alaska Fisheries Science Center longline survey data (AFSCLL) and International Pacific Halibut Commission longline survey data (IPHCLL) are from the annual surveys operated by the AFSC and the IPHC. The AFSC trawl survey data (AFSCTWL) are from the biennial trawl survey. The observer program data (OBS) are from a special project conducted by the Observer Program in 2006 and 2011.

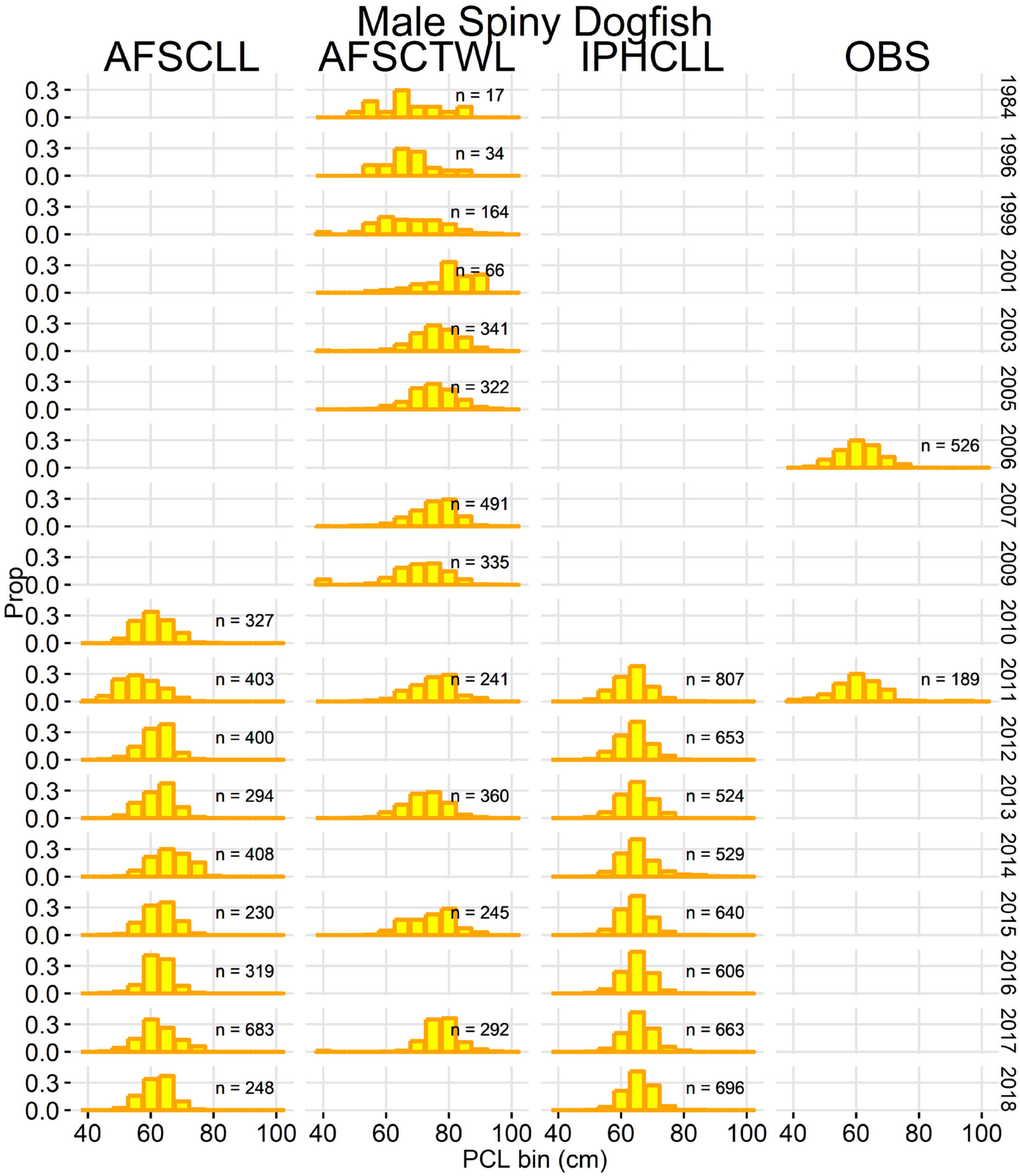

Figure 20.8. Observed length frequencies and sample sizes for male spiny dogfish in the Gulf of Alaska. The Alaska Fisheries Science Center longline survey data (AFSCLL) and International Pacific Halibut Commission longline survey data (IPHCLL) are from the annual surveys operated by the AFSC and the IPHC. The AFSC trawl survey data (AFSCTWL) are from the biennial trawl survey. The observer program data (OBS) are from a special project conducted by the Observer Program in 2006 and 2011.

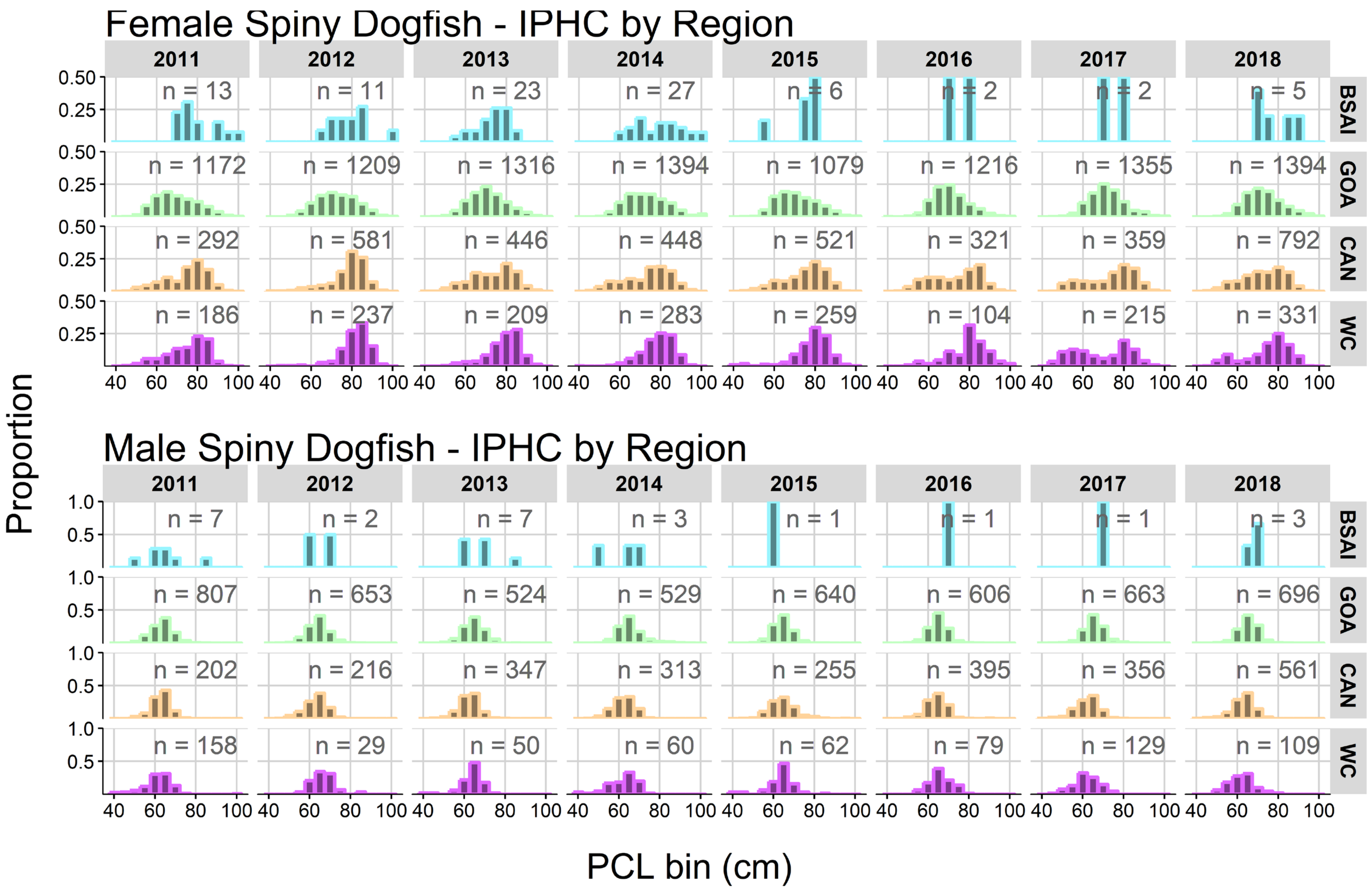

Figure 20.9. Observed length frequencies and sample sizes for male and female spiny dogfish sampled in the International Pacific Halibut Commission longline survey by region of capture. BSAI = Bering Sea and Aleutian Islands, GOA = Gulf of Alaska, CAN = Canadian west coast and WC = U.S. west coast.

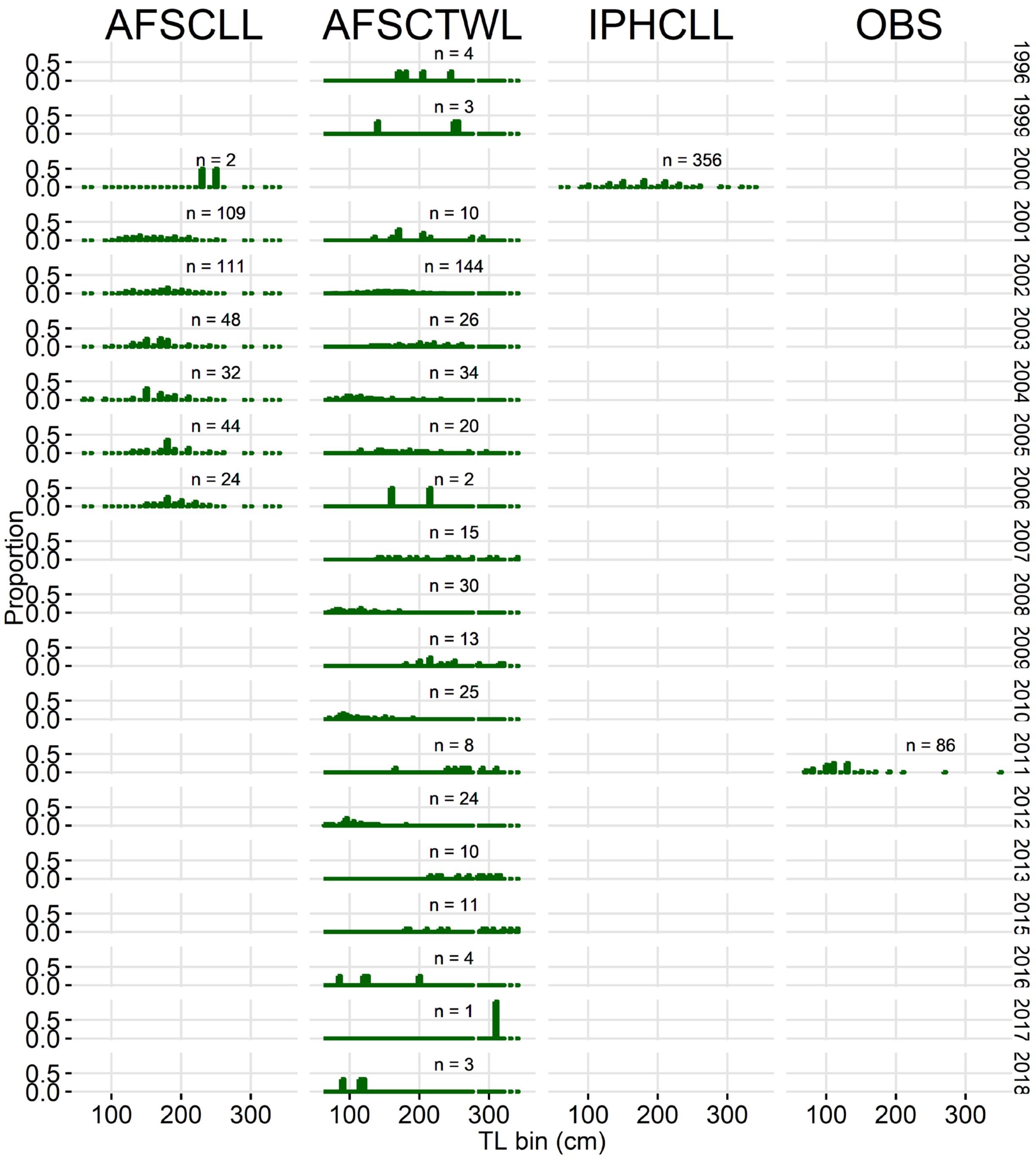

Figure 20.10. Observed length frequencies and sample sizes for Pacific sleeper shark. The Alaska Fisheries Science Center longline survey data (AFSCLL) and International Pacific Halibut Commission longline survey data (IPHCLL) are from the annual surveys operated by the AFSC and the IPHC. The AFSC trawl survey data (AFSCTWL) are from the biennial trawl survey. The observer program data (OBS) are from a special project conducted by the Observer Program in 2006 and 2011.

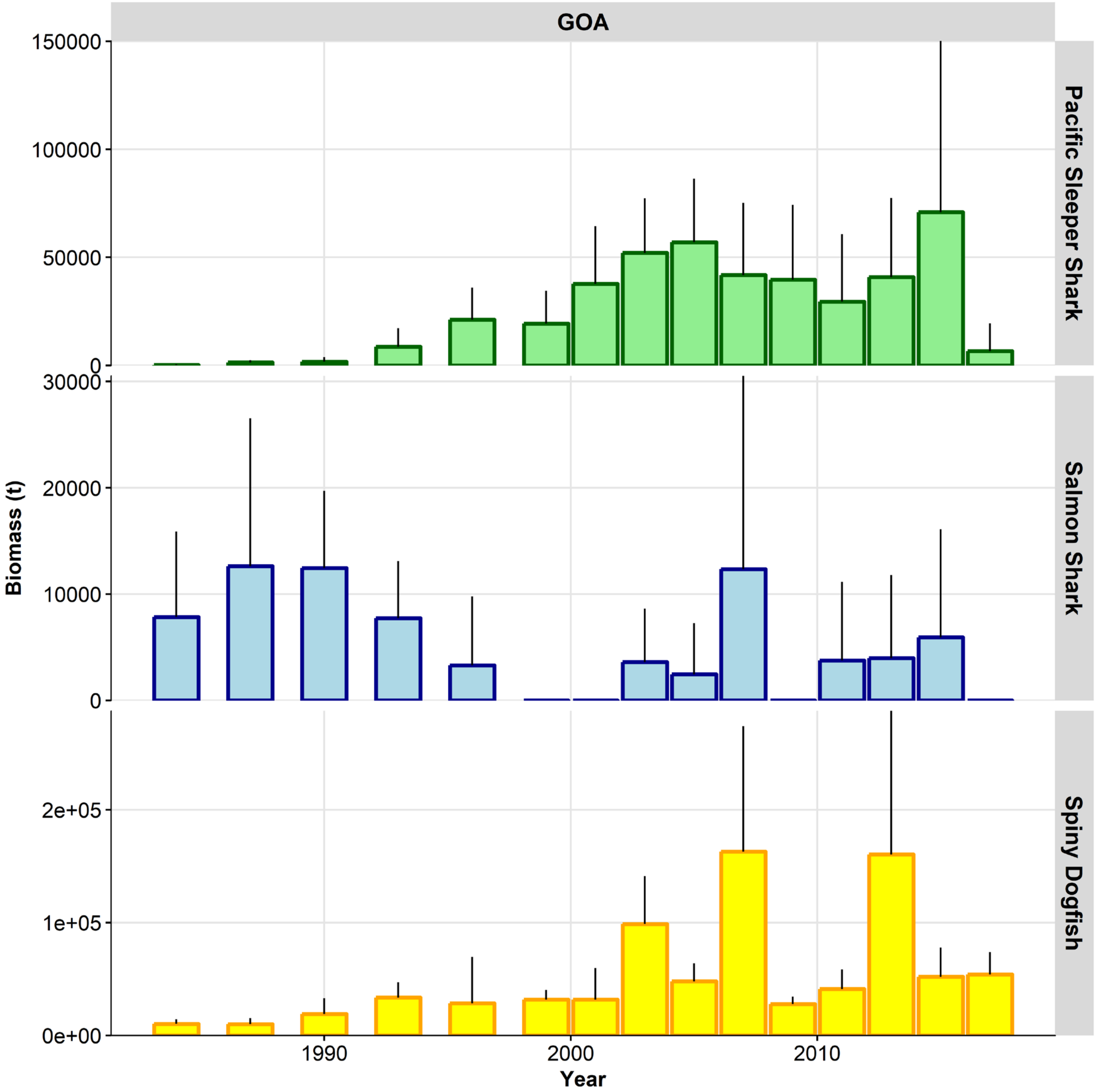

Figure 20.11. Time series of individual species biomass estimates (t) of sharks in the Alaska Fisheries Science Center Gulf of Alaska (GOA) bottom trawl survey. Error bars are 95% confidence intervals. Source: RACEBASE, queried through AKFIN on October 9, 2018.

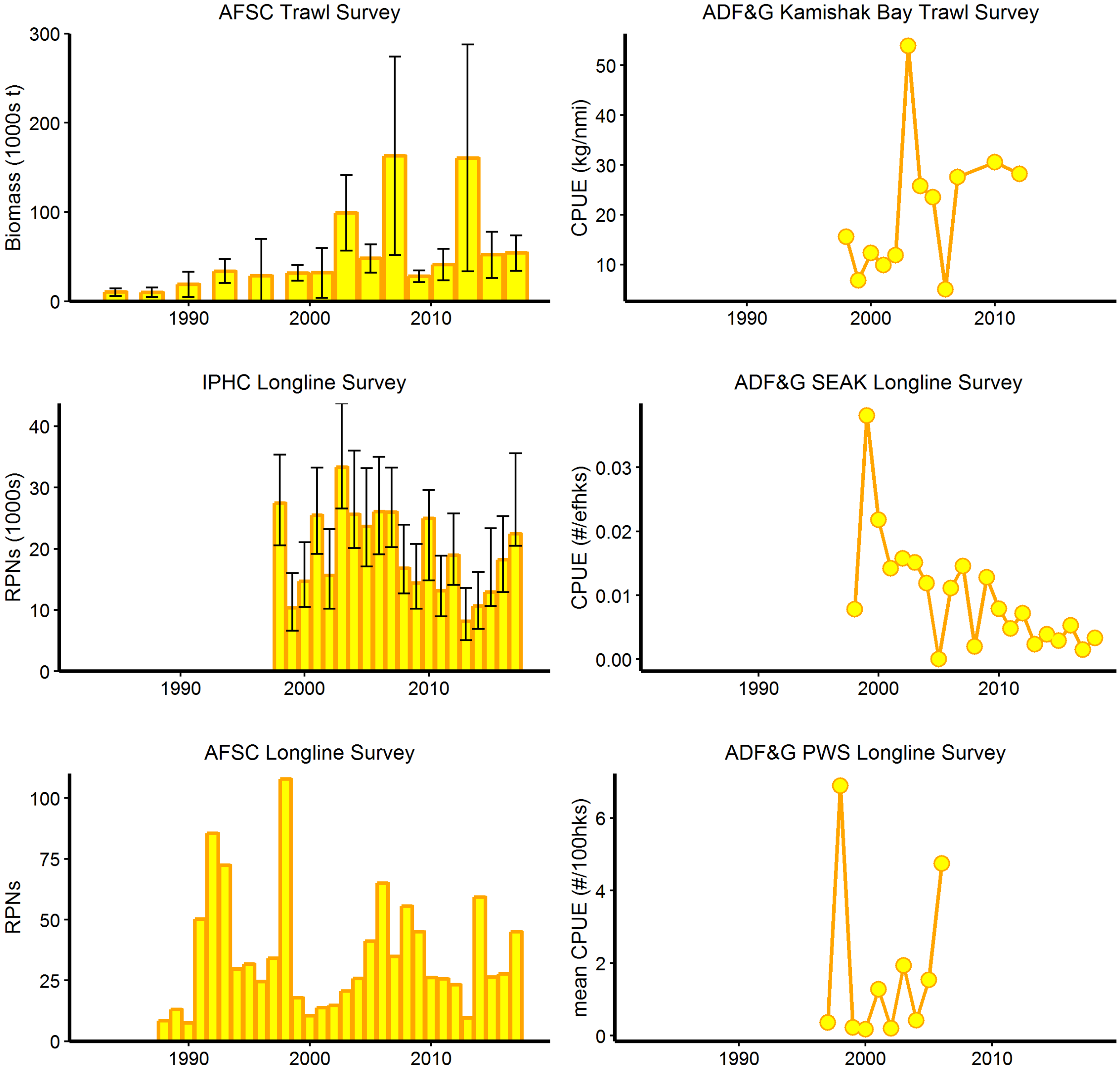

Figure 20.12. Survey indices available for spiny dogfish in the Gulf of Alaska. Catch per unit of effort (CPUE) is available for Alaska Department of Fish and Game (ADF&G) surveys in Prince William Sound, Kamishak Bay and Southeast Alaska. The Alaska Fisheries Science Center (AFSC) trawl survey provides an index of biomass. The AFSC and International Pacific Halibut Commission (IPHC) longline surveys provide relative population numbers (RPNs).

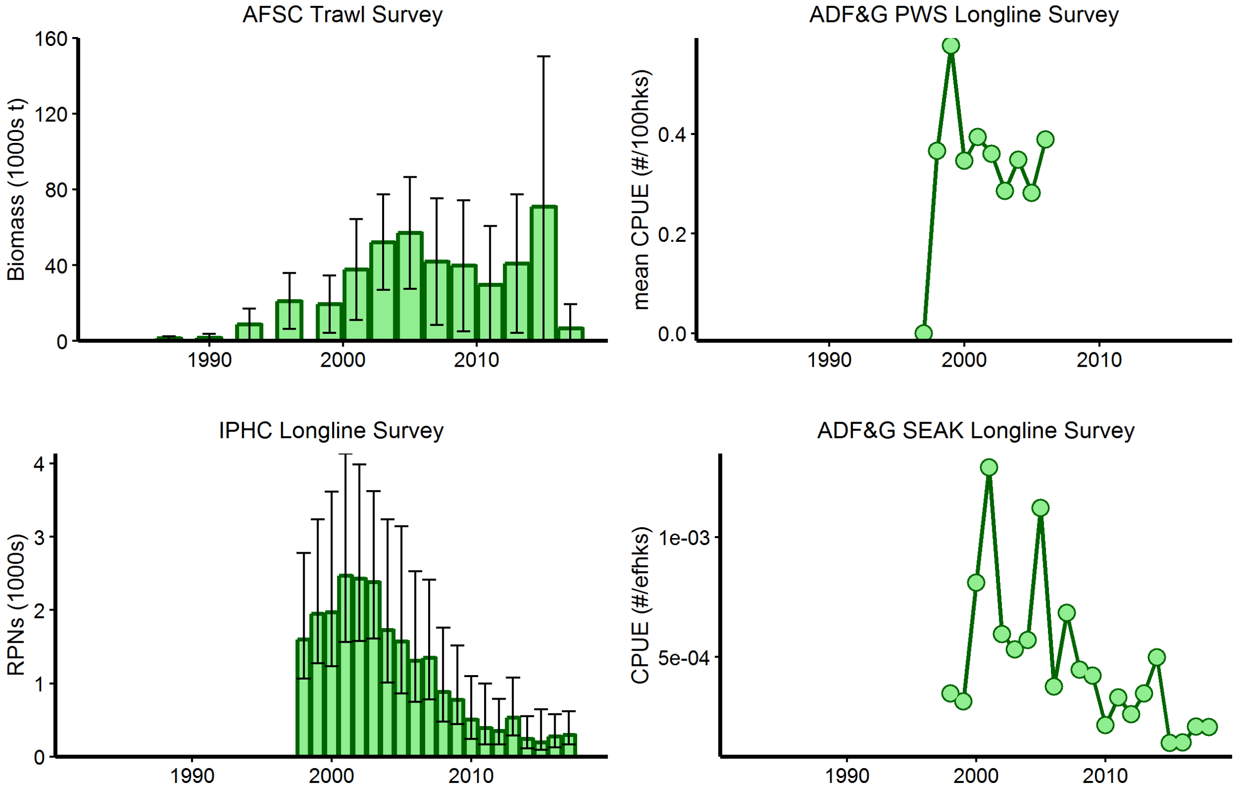

Figure 20.13. Survey indices available for Pacific sleeper shark in the Gulf of Alaska. Catch per unit of effort (CPUE) is available for Alaska Department of Fish and Game (ADF&G) surveys in Prince William Sound and Southeast Alaska. The Alaska Fisheries Science Center (AFSC) trawl survey provides an index of biomass. The International Pacific Halibut Commission (IPHC) longline survey provides relative population numbers (RPNs).

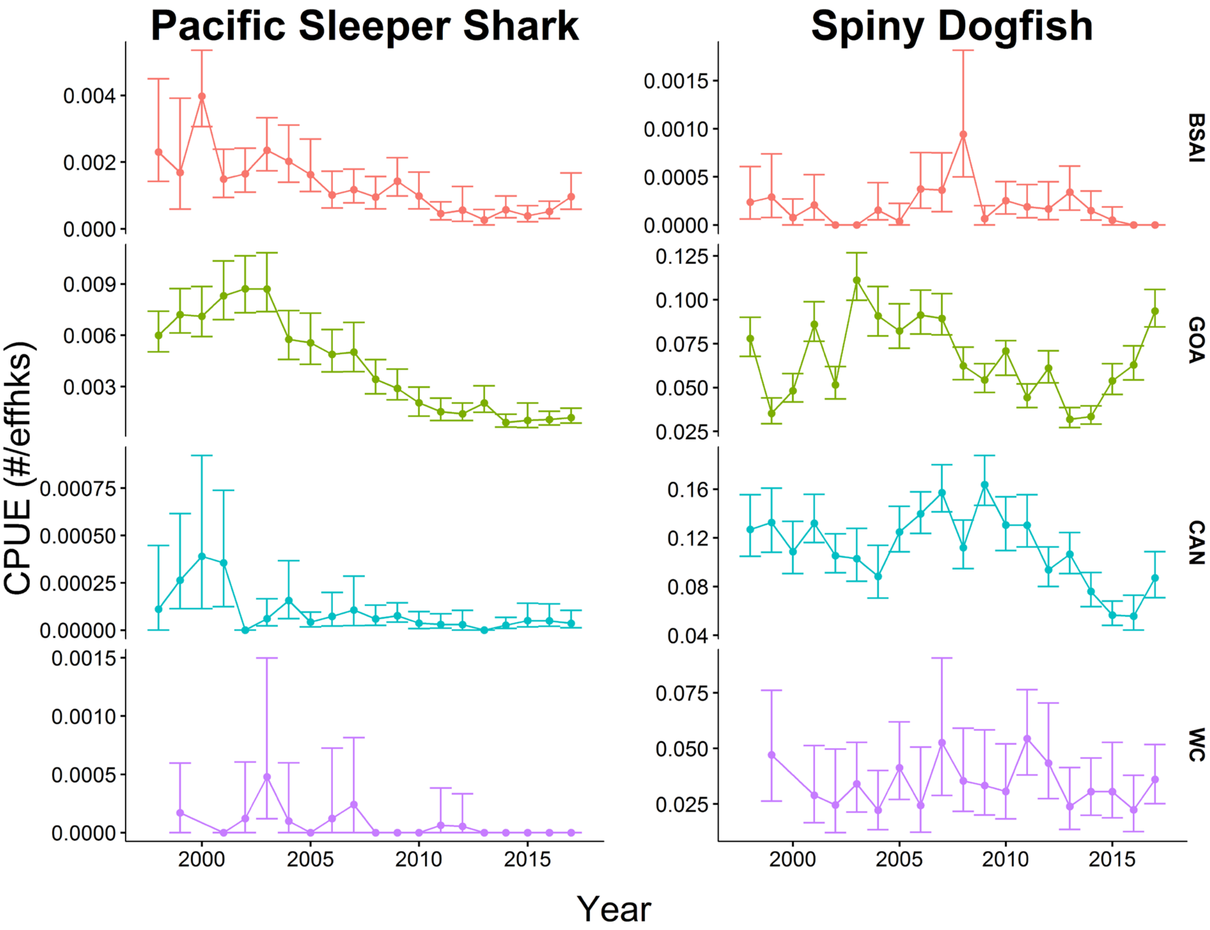

Figure 20.14. Catch per unit of effort (CPUE) with bootstrapped 95% confidence intervals for each region of the International Pacific Halibut Commission annual longline survey. BSAI = Bering Sea and Aleutian Islands, GOA = Gulf of Alaska, CAN = Canada, and WC = the west coast of the United States

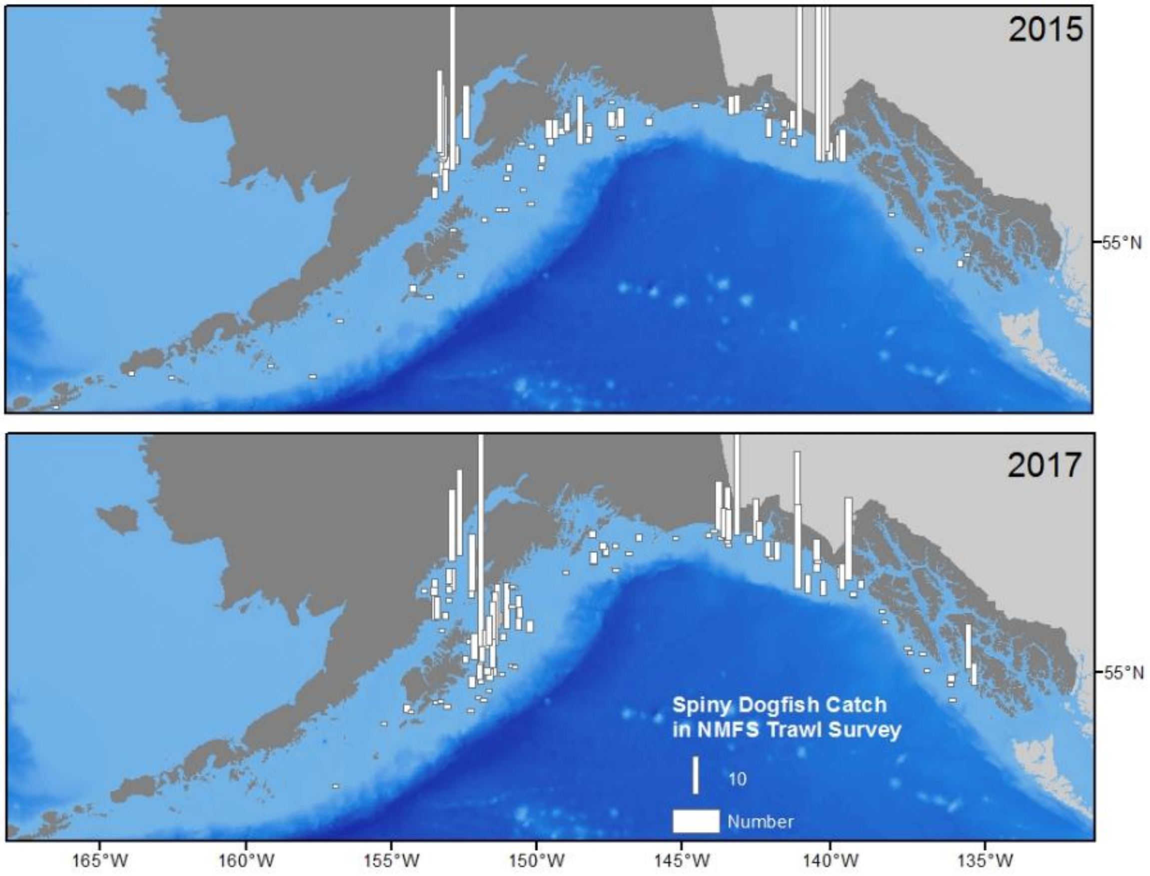

Figure 20.15. Spatial distribution of the catch of spiny dogfish during the 2015 and 2017 Alaska Fisheries Science Center biennial trawl survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

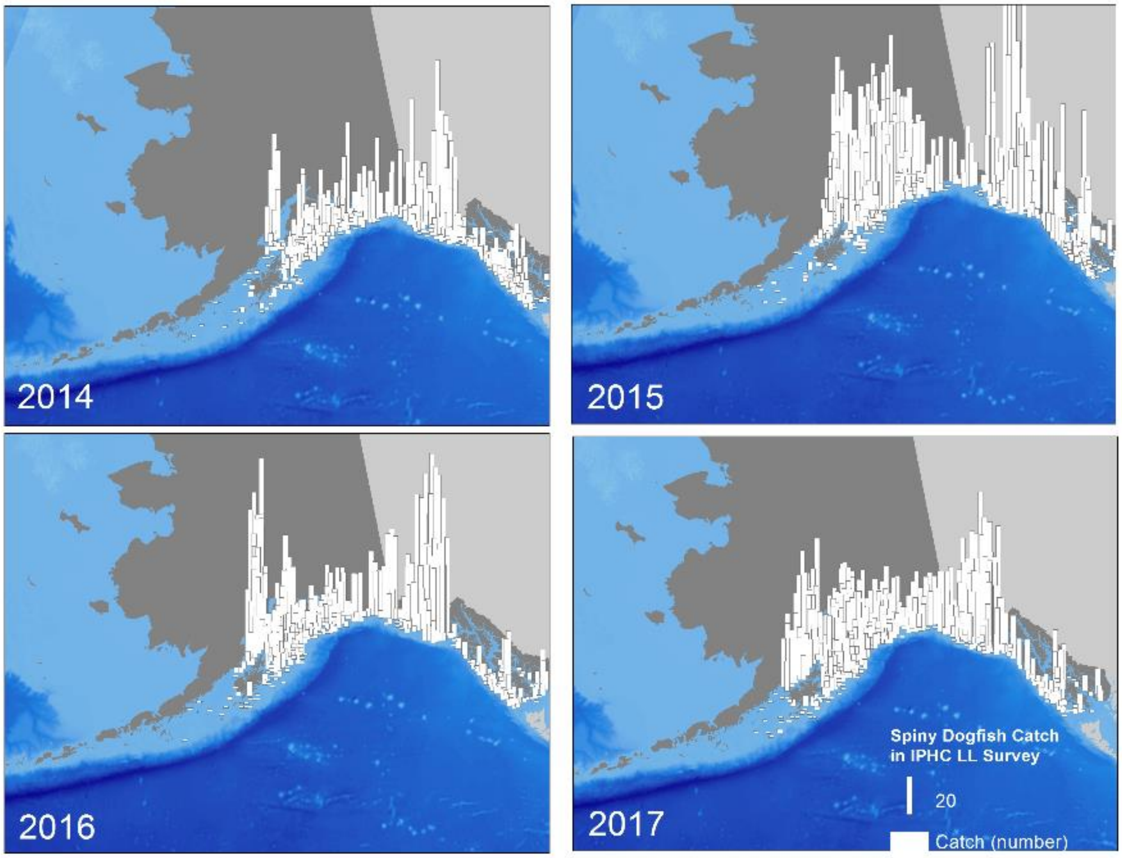

Figure 20.16. Spatial distribution of the catch of spiny dogfish during 2014–2017 International Pacific Halibut Commission (IPHC) longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

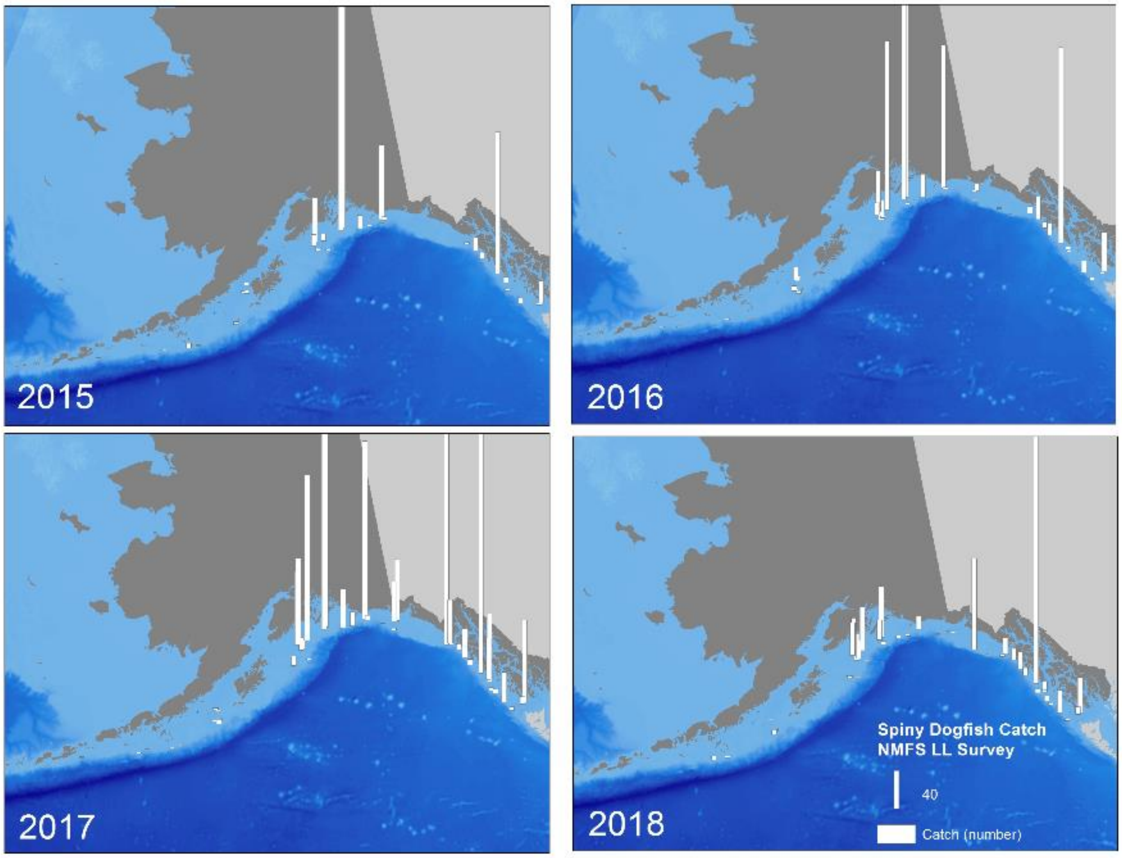

Figure 20.17. Spatial distribution of the catch of spiny dogfish during 2015–2018 Alaska Fisheries Science Center longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

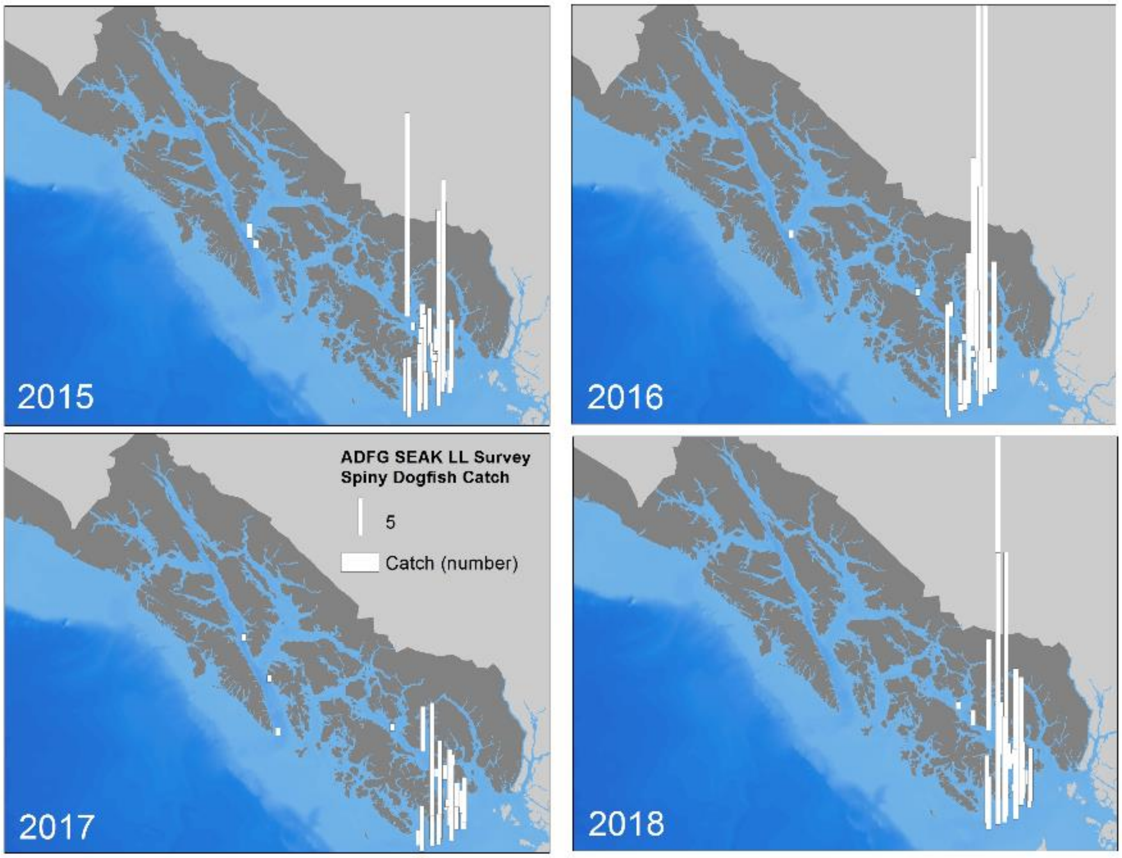

Figure 20.18. Spatial distribution of the catch of spiny dogfish during the 2015–2018 Alaska Department of Fish and Game (ADFG) longline surveys in Southeast Alaska. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

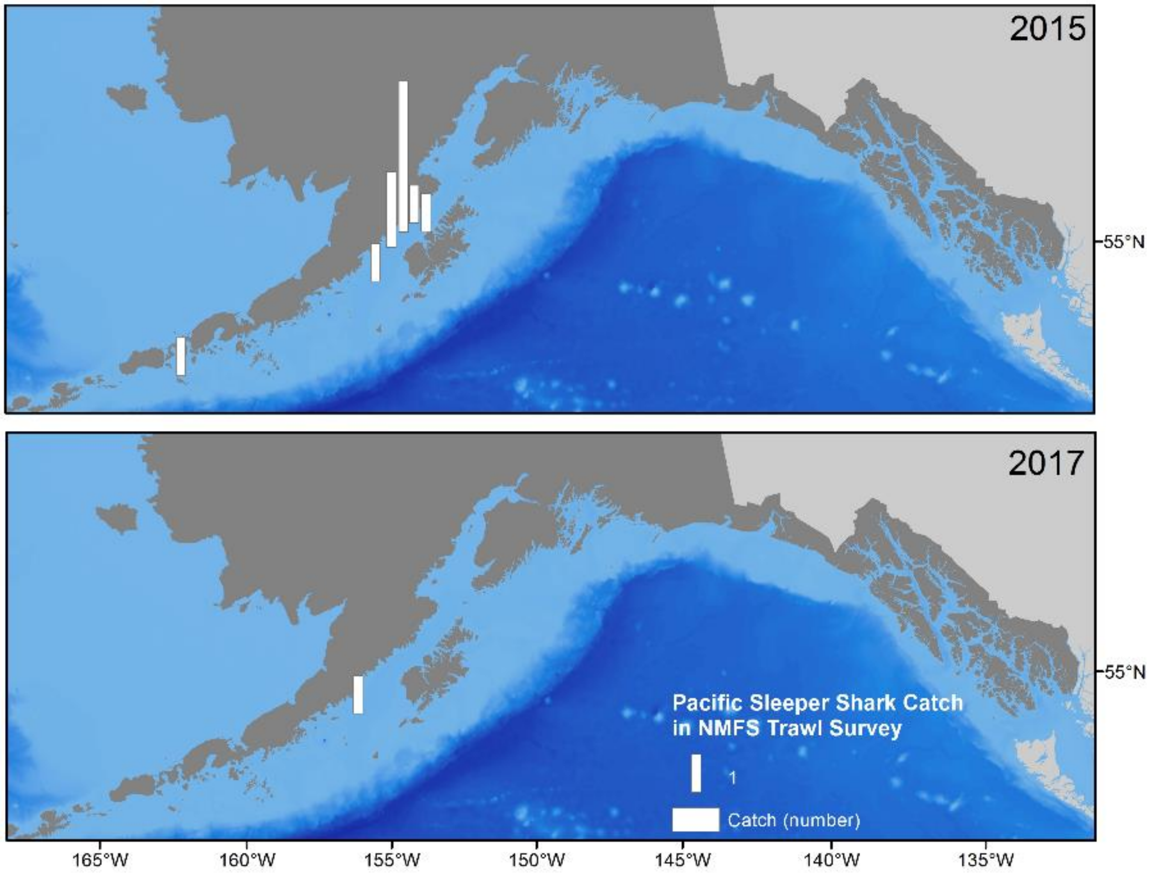

Figure 20.19. Spatial distribution of the catch of Pacific sleeper shark during 2015 and 2017 Alaska Fisheries Science Center biennial trawl surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

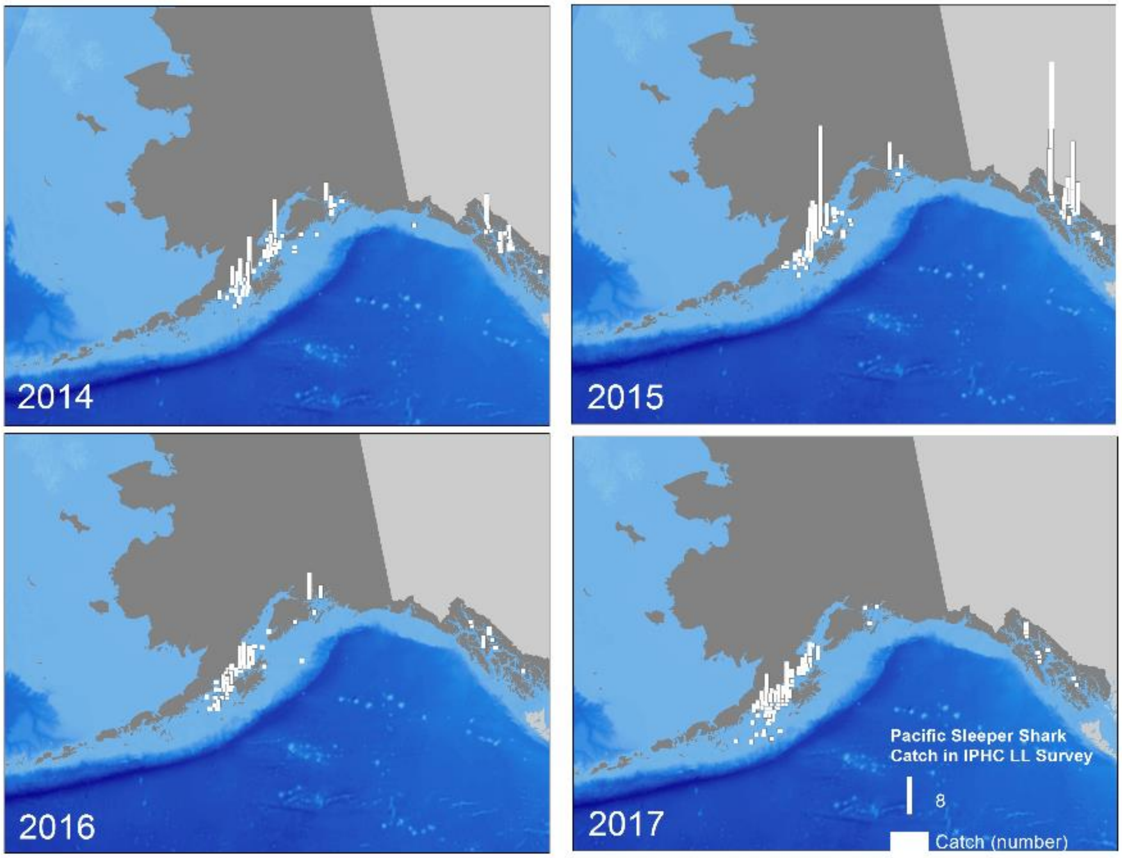

Figure 20.20. Spatial distribution of the catch of Pacific sleeper shark during the 2014–2017 International Pacific Halibut Commission (IPHC) longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

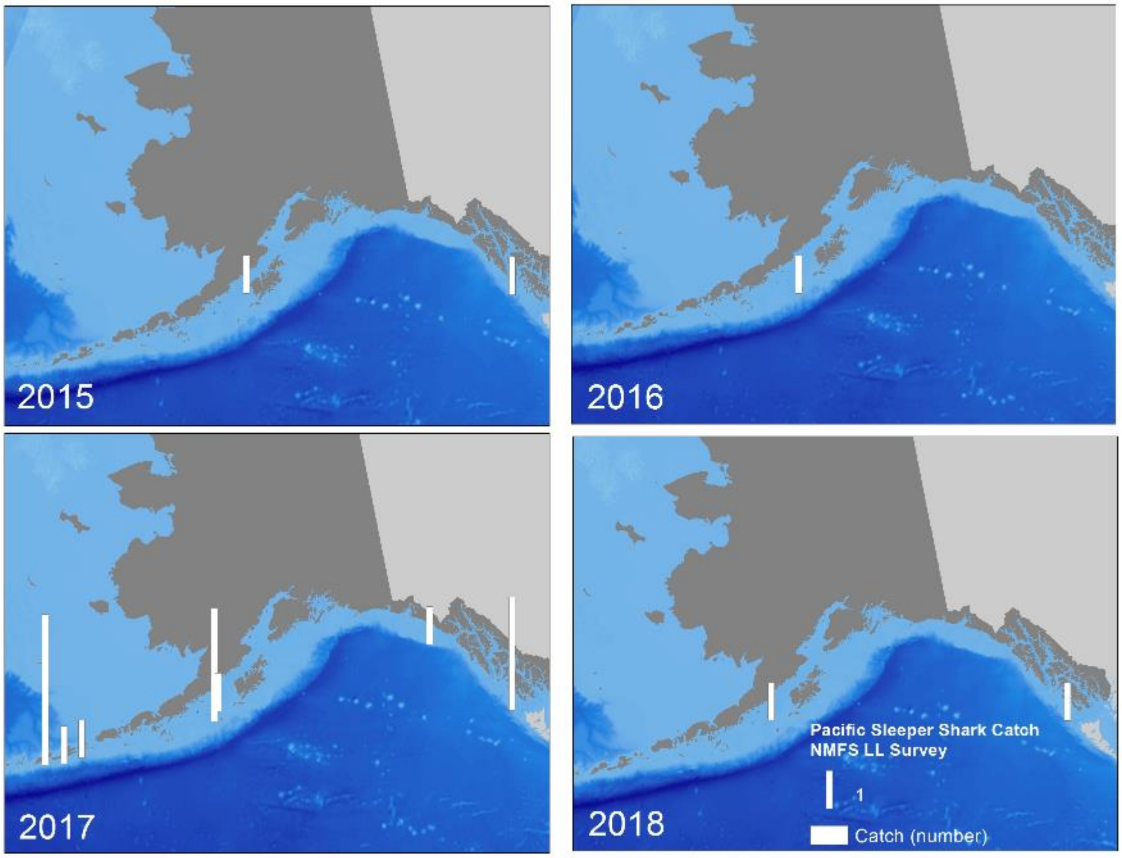

Figure 20.21. Spatial distribution of the catch of Pacific sleeper shark during the 2015–2018 Alaska Fisheries Science Center longline surveys. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

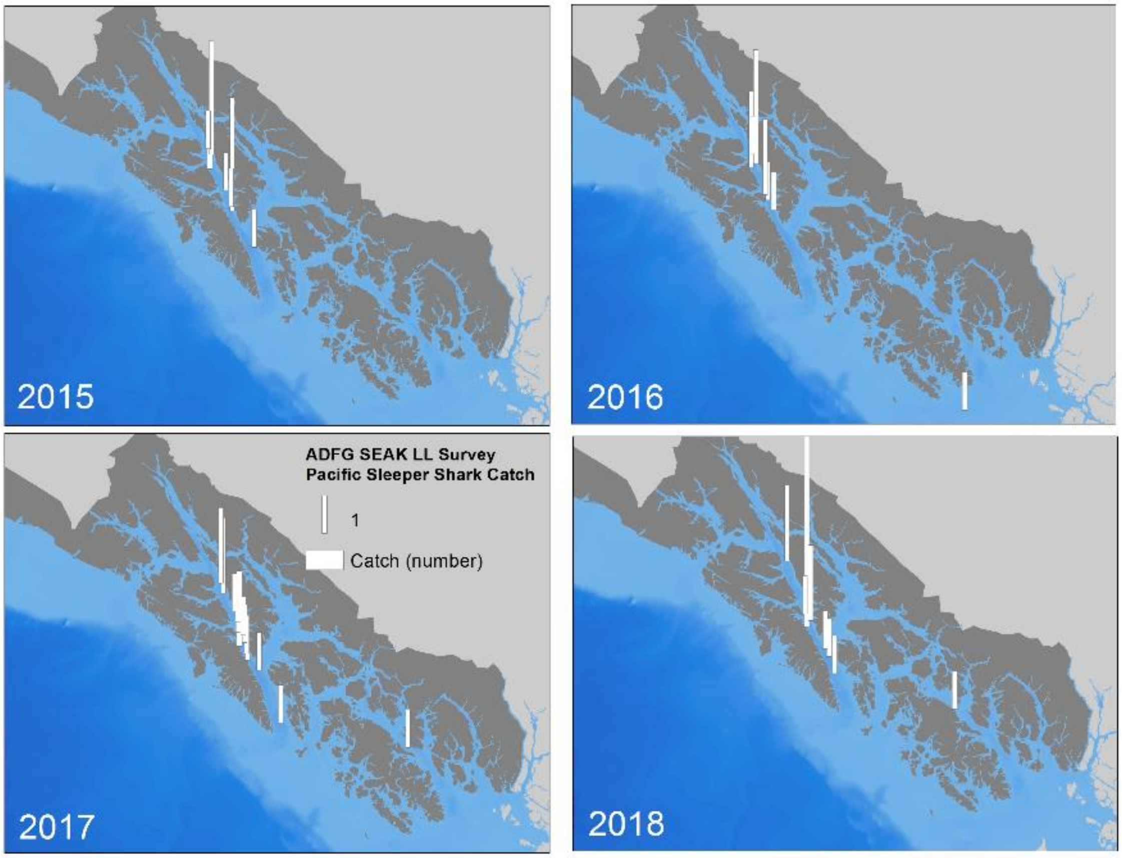

Figure 20.22. Spatial distribution of the catch of Pacific sleeper shark during 2015–2018 Alaska Department of Fish and Game (ADFG) longline surveys in Southeast Alaska. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

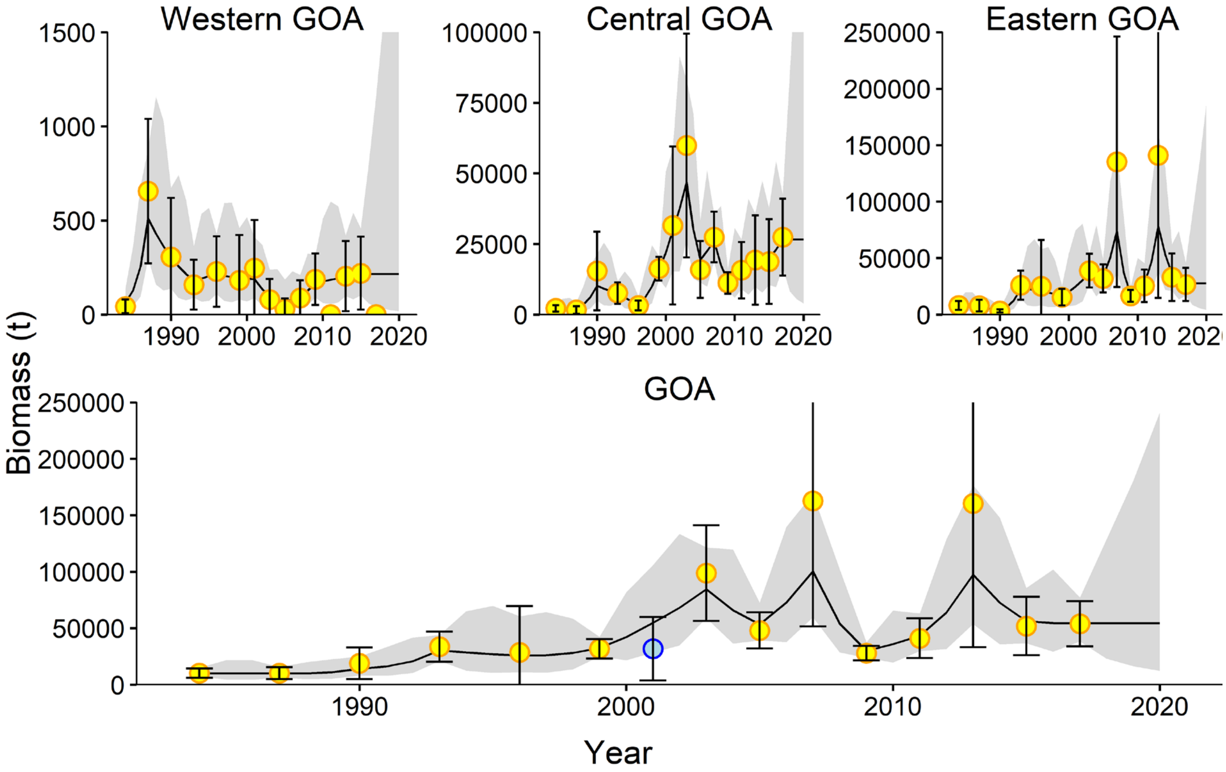

Figure 20.23. Fit of the random effects survey averaging to the Alaska Fisheries Science Center Gulf of Alaska (GOA) trawl survey biomass estimates by regulatory area (Western GOA, Central GOA, and Eastern GOA) for spiny dogfish. The yellow points are the survey biomass with 95% confidence intervals, black line is the random effects estimated biomass and the shaded areas are the confidence intervals from the model. The blue point is the year in which the survey did not sample the Eastern GOA.

Appendix 20A. Improving the Stock Assessments for the Shark Stock Complexes in the BSAI and GOA

September 2018

Executive Summary

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

SSC and Plan Team Comments Addressed in This Document

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

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

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

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

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

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

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

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

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

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

"*In response, the Plan Team recommended:*

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

A research update addressing #'s 1, 3 & 4 is provided in the GOA/BSAI Pacific sleeper shark research update section, and #'s 2 & 5 are discussed in the accuracy of catch estimates section.

GOA Spiny Dogfish

Trawl Survey Catchability

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

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

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

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

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

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

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

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

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

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

GOA/BSAI Pacific Sleeper Shark

Research Update

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

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

Accuracy of Catch Estimates

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

The AKRO have provided total catch estimates in numbers and in weight for PSS from 2011 – 2017. Preliminary investigations into total catch estimates of PSS by size suggest that much of the catch is composed of small PSS, especially in the BSAI, on both trawl and longline gears (Figure A.1). While the reported small weight on longline gear is likely biased by the difficulty of obtaining weights of large animals, it is unlikely that the trawl size estimates are biased because accurate measurements are more easily obtained on trawl vessels (either length converted to weight, or weight directly). Because the size of PSS are likely biased in longline gear fisheries, we are examining catch estimates in number. Efforts are underway to extend that time series back to 2003, however the structure of CAS is different prior to 2011 and estimating catch numbers prior to 2011 will require creating a separate estimation program, which is labor/time intensive and a low priority for the AKRO. Therefore, catch estimates in numbers may not be possible prior to 2011. In future work we plan to investigate; 1) how mean weight is utilized within NORPAC and CAS, 2) if there are improved options for estimating mean weight on longline vessels (such as utilizing size bins), 3) if utilizing catch by numbers in the assessment would be informative, and 4) the biological impacts of catching large numbers of small animals as opposed to smaller numbers of large animals.

Acknowledgements

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

Literature Cited

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

Hulson, P-J. F., C. A. Tribuzio, K. Coutré. 2016. The use of satellite tags to inform the stock assessment of a data-poor species: estimating vertical availability of spiny dogfish in the Gulf of Alaska. In: T. J. Quinn II, J. L. Armstrong, M. R. Baker, J. Heifetz, and D. Witherell (eds.) Assessing and Managing Data-limited Fish Stocks. Alaska Sea Grant, University of Alaska Fiarbanks. 129-149.

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

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

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

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

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

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

Tables and Figures

Table 20A.1. Summary of Pacific sleeper shark (PSS) size data observed to date in the 2018 longline fishery. Each shark_ID is an individual animal. In all but one case, the sampled shark(s) were a complete census of the PSS caught on the haul. The Obs_size is the observer estimated size class, Obs_wt is the weight range associated with that size class and the NORPAC_meanwt is the mean weight of sharks used to estimate total catch.

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

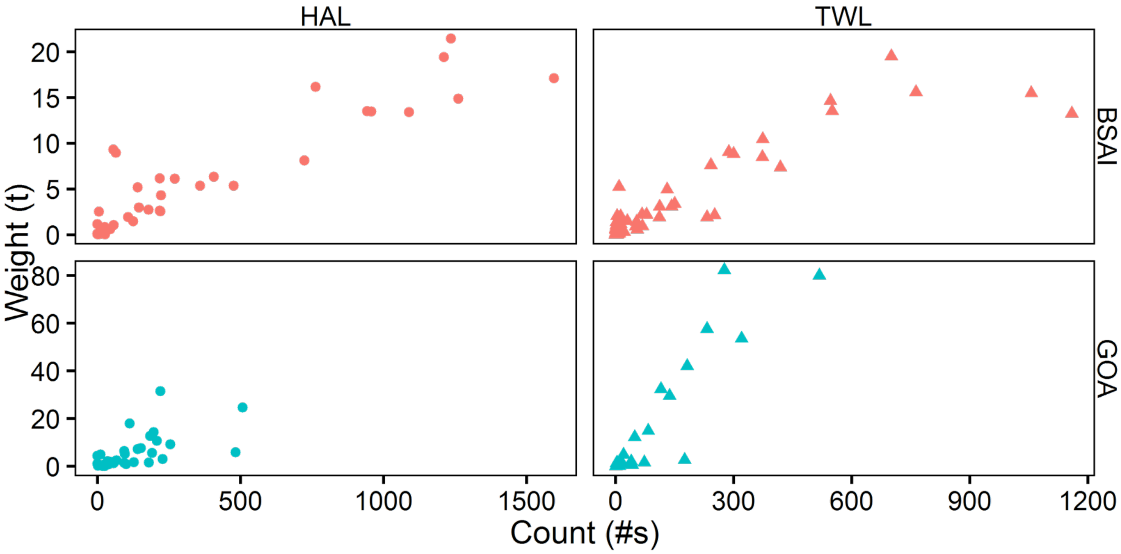

Figure 20A.1. Total estimated catch of Pacific sleeper sharks (PSS) in tons and numbers for trawl (TWL) and longline (HAL) fisheries. Each dot is a NMFS area and year.

Appendix 20B. Demographic Methods Used in the Tier 5 Spiny Dogfish Assessment

Executive Summary

The spiny dogfish assessment model (15.3A) utilizes a maximum sustainable fishing mortality rate (F_{max}), which is estimated from a demographic model. The demographic model used in this assessment was published by Tribuzio and Kruse (2011), where model evaluation, sensitivities, and risk analyses were also examined. The purpose of this appendix is to provide reviewers with a succinct overview of the methods. Tribuzio and Kruse (2011) examined stage- and age-based models, both of which returned similar point estimates, however the stage-based model tended to result in point estimates for the intrinsic rate of increase (r) that were not significantly different from zero and F_{max} was lower. We recommend the age-based model for use in the spiny dogfish assessment, as described below.

Methods

Model structure

An age-structured demographic model was used to investigate the population dynamics of GOA spiny dogfish. These types of models are convenient and easily implemented because they only require basic life history information (Brewster-Geisz and Miller 2000, Caswell 2001, Frisk et al. 2002, Simpfendorfer 2005). This is a female only model: males are not considered in the context of the population demographics. The basic formulation is:

$$N_{t+1} = \mathbf{M} N_t ,$$

where N_t is the vector of numbers of animals at each age class at time t and **M** is the transition or projection matrix composed of survival and fecundity for each age (Caswell 2001; Simpfendorfer 2005). It should be noted that the models in our study ignore the possible impact of density-dependence on parameters such as survival, fecundity and growth. Because knowledge of the mechanisms of density dependent compensation is largely theoretical for spiny dogfish, we assumed density independence (Walker 1998).

The projection matrix for the age-based model, **M**, is a Leslie matrix of the form (Caswell 2001, Aires-da-Silva and Gallucci 2007):

$$M = \begin{bmatrix} f_0 & f_1 & \cdots & f_{i-1} & f_i \\ l_0 & 0 & \cdots & 0 & 0 \\ 0 & l_1 & \cdots & 0 & 0 \\ 0 & 0 & \cdots & l_{i-1} & 0 \end{bmatrix},$$

Where i is the age class, l is the age-specific survival and f is age-specific per-capita fecundity rate (fertility). We assumed a birth pulse, post-breeding census, where birth occurs at the end of the year and fertility is given by:

$$f_i = l_i m_i ,$$

where m_i is the age-specific female fecundity (the number of female pups produced by each female each year). Spiny dogfish have been aged to at least 100 years in the northeastern Pacific Ocean (G. A.

McFarlane, Department of Fisheries and Oceans Canada, pers. comm.), so we included a maximum of 120 age classes depending on the random distribution for longevity (described later).

The above matrices can be used to solve the Euler-Lotka equation (Caughly 1977) for the instantaneous rate of increase (r), population growth rate ($\lambda = e^r$), net reproductive rate or the total number of female offspring produced per individual in a single cohort (R_0), generation time or the time for the population to increase by R_0 ($T = lnR_0/ln\lambda$), the mean age of the parents of a cohort ($\mu 1$), and the population doubling time ($t_{x2} = ln(2)/r$). The right eigenvector, **w**, represents the stable age distributions (SAD) and the left eigenvector, **v**, the reproductive values (RV) which are the proportions at age and the contribution of offspring by each age class to future classes for a stable population ($r = 0$), respectively. See Caswell (2001) for a detailed explanation of the matrix algebra and solving for r, R_0, *mu1 SAD*/*SSD* and *RV*. Elasticities (e_{ij}) were also estimated to examine how the population growth rate is affected by changes in individual age/stage survival and fecundity using the equation (Heppell *et al.* 1999; Caswell 2001):

$$e_{kj} = \frac{a_{kj}}{\lambda} \frac{v_k w_k}{\langle \mathbf{w}, \mathbf{v} \rangle},$$

where a_{kj} are the elements of **M**, **v** and **w** are the left and right eigenvectors of **M** and <**w,v**> is the scalar product of **v** and **w**. Elasticities are additive and all the elasticities for a population (the sum of the elasticities over all k and j) must sum to 1.

Stochasticity and Input parameters

While many studies of spiny dogfish age, growth, life history, and movement have been conducted, there remains a great deal of uncertainty in the parameter estimates. Statistical distributions (probability density functions, pdfs, or probability mass functions, pmfs) were defined for the input parameters to account for this uncertainty or natural variability and both models were run using a simulation approach (Cortes 2002). The Monte Carlo simulations involved randomly drawing each parameter from the defined distributions and recording the output parameters (described above) for that "population". The average of 10,000 replications was taken as the parameter value with 95% confidence intervals being the 2.5th and 97.5th percentile.

Growth model parameters for GOA female spiny dogfish (Tribuzio *et al.* 2010b) were used to estimate the instantaneous natural mortality (M) using a set of indirect techniques (Cortes 2002; Simpfendorfer *et al.* 2005; Tribuzio and Kruse 2012). Eight models using either the growth coefficient (k), size at 50% maturity, longevity, gonad somatic index, or size at age-0 (t_0), or a combination, were used to estimate M (Alverson and Carney 1975; Pauly 1980; Hoenig 1983; Gunderson and Dygert 1988; Chen and Watanabe 1989; Jenson 1996). A triangular pdf was used to incorporate uncertainty around the M estimate in the models with the median M estimate (0.054) as the most likely value and the minimum (0.011) and maximum (0.101) estimates (Tribuzio and Kruse 2012) forming the range . Then, the estimates of M were converted to survivorship ($S = e^{-Z}$, where $Z = F+M$) and incorporated into the model. Longevity was based on the estimates of M (*longevity* = $-\ln(0.01)/M$, Hewitt and Hoenig 2005), and a similar triangular pmf was used with the minimum, median and maximum longevity estimates.

Age at first capture was either fixed at 4 years (the youngest age encountered in GOA dogfish sampling), or allowed to vary uniformly between zero and 60 years or between zero and the age at 50% maturity, depending on the analysis. The pmf for age at 50% maturity was a normal distribution with a mean of 34 years and standard deviation of 7 years (Tribuzio and Kruse 2012).

Female fecundity (m_x) used in the models was the number of female pups per adult female per year, using a 1:1 sex ratio of pups, and a 2 year reproductive cycle (Tribuzio *et al.* 2009). Female fecundity was a function of length at age (no. female pups = $0.25TL_{ext}$-18.2, Tribuzio and Kruse 2012). To include uncertainty around the age-specific fecundity we estimated the standard deviation for each average female fecundity at age and created a random normal distribution pdf for each age class.

Fishing effects

The model was run without fishing to determine the parameters of an assumed virgin population (i.e. $Z = M$), then fishing mortality (F) was included to examine the effects of different fixed harvest rates on the population ($Z = F+M$). Instantaneous fishing mortality ranged between 0 and 1. Fishing mortality was applied uniformly across the age classes that were susceptible to fishing (i.e. knife edge selectivity).

Literature Cited

Aires-da-Silva, A. M., and Gallucci, V. F. (2007). Demographic and risk analyses applied to management and conservation of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. *Marine and Freshwater Research* **58**, 570-580.

Alverson, D. L., and Carney, M. J. (1975). A graphic review of the growth and decay of population cohorts. *ICES Journal of Marine Science* **36**,133-143.

Brewster-Geisz, K. K., and Miller, T. J. (2000). Management of the sandbar shark, *Carcharhinus plumbeus*: implications of a stage-based model. *Fishery Bulletin* **98**, 236-249.

Caswell, H. (2001). ‘Matrix Population Models: Construction, Analysis and Interpretation.’ 2nd edn. (Sinaur Associates: Sunderland, Massachusetts.)

Caughly, G. (1977). ‘Analysis of Vertebrate Populations.’ (Wiley: London.)

Chen, S., and Watanabe, S. (1989). Age dependence of natural mortality coefficient in fish population dynamics. *Nippon Suisan Gakkaishi* **55**, 205-208.

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

Frisk, M. G., Miller, T. J., and Fogarty, M. J. (2002). Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. *Canadian Journal of Fisheries and Aquatic Sciences* **58**, 969-981.

Gunderson, D. R., and Dygert, P. H. (1988). Reproductive effort as a predictor of natural mortality rate. *ICES Journal of Marine Science* **44**, 200-209.

Heppell, S., Crowder, L. B., and Menzel, T. R. (1999). Life table analysis of long-lived marine species with implications for conservation and management. In 'Life in the Slow Lane: Ecology and Conservation of Long-Lived Marine Animals'. (Ed. J. A. Musick) pp. 137-148. (American Fisheries Society Symposium **23**: Bethesda, MD)

Hewitt, D. A., and Hoenig, J. M. (2005). Comparison of two approaches for estimating natural mortality based on longevity. *Fishery Bulletin* **103**, 433-437.

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

Jenson, A. L. (1996). Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences* **53**, 820-822.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science* **39**, 175-192.

Simpfendorfer, C. A. (2005). Demographic models: life tables, matrix models and rebound potential. In 'Management Techniques for Elasmobranch Fisheries'. (Eds. J. A. Musick, R. Bonfil). pp. 143-144. Fisheries Technical Paper **479** (FAO, Rome).

Simpfendorfer, C. A., Bonfil, R., and Latour, R. J. (2005). Mortality estimation. In 'Management Techniques for Elasmobranch Fisheries'. (Eds. J. A. Musick, R. Bonfil). pp. 165-185. Fisheries Technical Paper **479** (FAO, Rome).

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

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

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

Walker, T. I. (1998) Can shark resources be harvested sustainably? A question revisited with a review of shark fisheries. *Marine and Freshwater Research* **49**, 553-572.