Chapter 20: Assessment of the Shark stock complex in the Gulf of Alaska

Cindy A. Tribuzio[1], Katy Echave[1], Cara Rodgveller[1], Peter Hulson[1], and Kenneth J. Goldman[2]

[1]Alaska Fisheries Science Center, Auke Bay Laboratories, National Marine Fisheries Service, Juneau, AK
[2]Alaska Department of Fish and Game, Central Region Groundfish and Shellfish Research Biologist

EXECUTIVE SUMMARY

Summary of Major Changes

<u>Changes to the input data</u>

1. Total catch for GOA sharks from 2003-2011 has been updated (as of Oct 11, 2011).
2. NMFS longline and IPHC survey data has been updated, including IPHC survey RPNs.
3. New research catch tables and estimated bycatch in the halibut IFQ fishery are included in Appendix 20A.

<u>Changes in assessment methodology</u>

The assessment methodology used for sharks is the same as that used last year. For information, we summarize in the "Model Structure" section a demographic model for spiny dogfish developed by Tribuzio and Kruse (*in press a*), that may be used in the future to provide management advice for spiny dogfish. We do not make recommendations based on the demographic model at this time, as more models are under development, and we prefer to wait until results from multiple models can be compared.

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 2010 was 674 t and catch in 2011 was 417 t as of October 11, 2011. We recommend that the shark complex be managed with spiny dogfish as a Tier 5 species (OFL = F_{OFL}(0.097)*3 yr avg biomass, ABC = 0.75*OFL) and the remaining sharks as Tier 6 species (OFL = average catch 1997-2007, ABC = 0.75*OFL). **The recommended ABC is 6,028 t and OFL is 8,037 t for the shark complex combined.** 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. Spiny dogfish are allowed as retained incidental catch in some state managed fisheries, and salmon sharks are targeted by some sport fishermen in Alaska state waters. In 2010, spiny dogfish made up 59% of the shark catch and on average are 54% of total shark catch. Pacific sleeper sharks made up 24% of the total shark catch in 2010 and are on average 30% of the shark catch.

ABC and OFL Calculations and Tier 5 recommendations for spiny dogfish for 2011-2012.

Spiny Dogfish Quantity	As estimated or *specified last* year for: 2011	2012	As estimated or *recommended this* year for: 2012	2013
M (natural mortality rate)	0.097	0.097	0.097	0.097
Tier	5	5	5	5
Biomass (t)	79,257	79,257	76,979	76,979
F_{OFL}	0.097	0.097	0.097	0.097
Max F_{ABC}	0.073	0.073	0.073	0.073
F_{ABC}	0.073	0.073	0.073	0.073
OFL (t)	7,688	7,688	7,467	7,467

Max ABC (t)	5,766	5,766	5,600	5,600
ABC (t)	5,766	5,766	5,600	5,600
	As determined *last* year for:		As determined *this* year for:	
Status	2009	2010	2010	2011
Overfishing	No	n/a	No	n/a

ABC and OFL Calculations and Tier 6 recommendations for Pacific sleeper sharks, salmon sharks and other sharks for 2011-2012.

Pacific sleeper, salmon and other sharks	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2011	2012	2012	2013
Tier	6	6	6	6
OFL (t)	575	575	571	571
Max ABC (t)	431	431	428	428
ABC (t)	431	431	428	428
	As determined *last* year for:		As determined *this* year for:	
Status	2009	2010	2010	2011
Overfishing	No	n/a	No	n/a

Responses to SSC Comments

<u>Responses to SSC comments specific to this assessment</u>
From the December 2010 SSC minutes:

The SSC regards this year's catch specification procedures as provisional, pending further analysis. For the next assessment, the choice and use of reference points (M, F) should be carefully reconsidered and evaluated to determine the most appropriate rate for use in setting OFL and ABC. The demographic modeling approach and its implications on F_{ofl} and F_{abc} should be fully described in the assessment, along with the basis for the authors' recommendation
The methods used in the demographic model are described in the "Model Structure" section. We do not make a recommendation based on the demographic model at this time, as more models are under development and we are withholding a recommendation until we can compare the results of multiple models. We have included a discussion of the impacts of using F = M or F = 0.04 to set ABC/OFL in the "Projections and Harvest Alternatives" section.

The SSC also encourages the authors to continue to make progress toward estimating and incorporating shark bycatch from IFQ halibut and state-managed salmon, sablefish and cod fisheries. Clearly, a more complete accounting of total fishing mortality is a central problem with the current assessment. By making this request, the SSC acknowledges the difficulty in doing so, given lack of observer data. Creative use of ADF&G longline survey data, fishermen interviews or logbooks, or other novel approaches may be needed to make progress.
Catch estimates in numbers and weight from the IFQ halibut fleet are included in Appendix 20A. This format was requested by the Plan Team for 2011. We are working on adapting the HFICE methods to be used to estimate incidental catch of sharks in state groundfish fisheries..

While the SSC believes that this year's use of trawl survey data to develop minimum biomass estimates is a step forward for spiny dogfish, methods to estimate the off bottom fraction of the population should be explored and evaluated.
This is included in the research priorities. An ongoing satellite tagging study may help with this, but data has not been processed. Also, we intend to investigate biomass dynamic modeling for spiny dogfish prior to the next on-cycle assessment; in such a model we will estimate catchability for the trawl survey biomass estimates.

Finally, gaps in knowledge needed to improve the shark stock assessment should be developed and incorporated into lists of future research needs. Areas in need of research include evaluation of net

efficiency for spiny dogfish, shark distribution, seasonal movements, and estimation of natural mortality for sleeper sharks, and other species.
We have updated the research priorities section.

Introduction

Alaska Fisheries Science Center (AFSC) surveys and fishery observer catch records provide information on shark species known or suspected to occur (Table 20.1) in the Gulf of Alaska (GOA) (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 piked or 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). Beginning in 2010, spiny dogfish has been classified as *S. suckleyi* in the SAFE, but both names may be used to be consistent with data sources (e.g. RACEBASE survey data).

General Distribution

<u>Spiny Dogfish</u>

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

<u>Pacific Sleeper Shark</u>

Pacific sleeper sharks range 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 (Orlav and Moiseev 1999), and south along the Alaskan and Pacific coast and possibly as far south as the coast of South America (de Astarloa et al. 1999). However, Yano et al. (2004) reviewed the systematics of sleeper sharks and suggested that sleeper sharks in the southern hemisphere and the southern Atlantic 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).

<u>Salmon Shark</u>

Salmon sharks range in the North Pacific from Japan through the Bering Sea and 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 shallower than 50 m (Weng et al. 2005). While some salmon sharks migrate south during the winter months, others remain in the GOA throughout the year (Weng et al. 2005, Hulbert et al. 2006).

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 20.2).

Evidence of Stock Structure

Spiny Dogfish

Previous studies have shown complex stock structure for spiny dogfish in areas outside Alaska. British Columbia and Washington State have both local stocks that mix at very low rates, and migratory stocks that undertake large scale migrations (Compagno 1984, McFarlane and King 2003). Spiny dogfish tend to segregate by sex and by size; large males and large females are generally separate, and large sub-adults and small mature adults of both sexes tend to mix (Tribuzio et al. 2009). The observed ages in the GOA range 8-50 years throughout all areas of the GOA (Tribuzio et al. 2010).

Pacific Sleeper Shark

Little is known about sleeper shark migratory behavior, life history, distribution or growth. Size and sex distribution data is minimal. Surveys in the GOA have noted that sexually mature animals have never been captured. Tagging studies in Alaska have shown that some Pacific sleeper sharks reside in the GOA throughout the year, where they exhibit relatively limited geographic movement (< 100 km) (Hulbert et al. 2006). Sleeper sharks commonly migrate vertically throughout the water column (Orlav and Moiseev 1999, Hulbert et al. 2006), but generally do not migrate far from initial tagging locations in the GOA (Hulbert et al 2006). However, one tagged shark in Southeast Alaska made horizontal movements of 6 km/day (Courtney and Hulbert 2007).

Salmon Shark

Salmon sharks differ by length-at-maturity, age-at-maturity, growth rates, weight-at-length, and sex ratios between the western North Pacific (WNP) and the eastern North Pacific (ENP) separated by the longitude of 180^{o}W (Goldman and Musick 2006). The WNP is male dominated and the ENP is female dominated. In the WNP, a salmon shark pupping and nursery ground may exist just north of the transitional domain in oceanic waters in a band of high productivity at the southern boundary of the sub-arctic domain (~40 - 45˚N) of the North Pacific Ocean. Another pupping and nursery area may exist in the ENP and appears to range from southeast Alaska to northern Baja California in near coastal waters (Goldman and Musick 2006, 2008). Tagging studies suggest a complex migration, with some animals migrating along the coast, others moving in a straight north/south direction and others remaining relatively stationary, with minimal mixing across the 180^{o}W line (Weng et al. 2005, Hulbert et al. 2006).

Life History Information

Sharks are long-lived species with slow growth to maturity, a large maximum size, and low fecundity. Therefore, the productivity of shark populations is very low relative to most commercially exploited teleosts (Holden 1974, Compagno 1990, Hoenig and Gruber 1990). Shark reproductive strategies in general are characterized by long gestational periods (6 months - 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). In 2009, staff at AFSC calculated vulnerability scores for 21 GOA species based on life history and fishery susceptibility characteristics (http://www.afsc.noaa.gov/refm/docs/2009/GOAvulnerability.pdf). 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 GOA species calculated.

Spiny Dogfish

Eastern North Pacific spiny dogfish grow to a maximum size of 160 cm (Compagno 1984). The average length for spiny dogfish caught in the GOA biennial trawl survey was 78.8 cm TL_{ext} for females (measured from the tip of the snout to the tip of the upper caudal lobe with the tail depressed to align with the horizontal axis of the body), and 77.1 cm TL_{ext} for males (n = 1,995 females and n = 3,430 males, all survey years combined, Figure 20.2). The average length for females sampled in the AFSC longline survey (data only available for 2010 and 2011) was 77.6 cm TL_{ext} for females and 75.8 cm TL_{ext} for males (n = 949 females and n = 730 males, Figure 2). Spiny dogfish caught on the International Pacific Halibut Commission (IPHC) annual longline survey (2011 data only) were larger with averages of 89.5 cm TL_{ext} for females and 81.7 cm TL_{ext} average for males (n = 3,944 females and n = 2,772 males, Figure 2). Average size of females collected during a 2006 special project with the observer program was 83.9 cm TL_{ext} for females and 82.2 cm TL_{ext} for males (n = 604 females and n = 528 males Figure 2).

Historic estimates of spiny dogfish age-at-50%-maturity for the ENP range from 19 to 34 years. Recent studies in the GOA estimated ages-at-50% maturity to be 36 years for females and 21 years for males (Tribuzio and Kruse *in press b*), which is similar to estimates from BC of 35 years and 19 years respectively (Saunders and McFarlane 1993). Longevity in the ENP is between 80 and 100 years (Campana et al. 2006). Growth coefficients (κ) for this species are among the slowest of all shark species, κ = 0.03 for females and 0.06 for males (Tribuzio et al. 2010).

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 *in press b*). 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). Washington State spiny dogfish have a long pupping season, which peaks in October and November (Tribuzio et al. 2009). Pupping is believed to occur in estuaries and bays or mid-water over depths of about 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 *in press b*). The average litter size is 8.5 pups for spiny dogfish in the GOA (Tribuzio and Kruse *in press b*), 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 after the onset of maturity (Ketchen 1972, Tribuzio et al. 2009, Tribuzio and Kruse *in press b*).

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). A Greenland shark (*Somniosus microcephalus*), the North Atlantic cogener of the Pacific sleeper shark, was sampled in 1999 and was determined to have been alive during the 1950’s - 1970’s because it had high levels of DDT, which was used as an insecticide during this period (Fisk et al. 2002). The average lengths of *Somniosus* sp. captured in mid-water trawls in the Southern Ocean are 390 cm *TL* (total length with the tail in the natural position) +/- 107 cm (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 for females and 400 cm for males (Mecklenburg et al. 2002). Pacific sleeper sharks have been measured on AFSC longline surveys (2001 and 2002) and during biennial trawl surveys. Longline caught female Pacific sleeper sharks averaged 170 cm (n = 119) *PCL* (pre-caudal length, measured from the tip of the snout to the pre-caudal notch) and 166 cm (n = 79) *PCL* for males (Sigler et al. 2006). Sample size was low in bottom trawl survey samples so sexes were combined, average length was 270 cm (n = 74) *PCL*. Pacific sleeper sharks as large as 430 cm have been caught in the WNP, where the species exhibits sexual dimorphism, with females being shorter and heavier (avg. length = 138.9 cm, avg. weight = 28.4 kg) than males (avg. length = 140 cm, avg. weight = 23.7 kg) (Orlav 1999). The cartilage in sleeper sharks does not calcify to the degree of many other shark species, therefore aging is difficult and methods of age validation are under investigation.

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 that 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 long 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 long was caught off Trinidad, California (Gotshall and Jow 1965) with ovaries containing 300 large ova. Two recently born 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 long, 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* female was caught during the annual AFSC bottom 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 season is unknown for sleeper sharks.

<u>Salmon Shark</u>

Like other lamnid sharks, salmon sharks are active and highly mobile, maintaining body temperatures as high as 21.2 ^{o}C 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 κ for males and females are 0.17 and 0.14, 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). In the ENP, one record of a pregnant female salmon shark caught near Kodiak Island had four pups, two males and two females (Gallucci et al. 2008). 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). Size at parturition is between 60 - 65 cm *PCL* in both the ENP and WNP (Tanaka 1980, Goldman and Musick 2006).

FISHERY

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 Scott Meyer, 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. Sleeper sharks are uncommon in the recreational catch and rarely retained.

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, salmon shark, and Pacific sleeper shark.

Statewide estimates of retained sharks are available since 1998, and are presented in this report. Estimates of retained sharks from the SWHS are available for selected portions of the state since 1996, (i.e. Kodiak, Cook Inlet, and Prince William Sound) and are not presented here. Estimated annual retention of sharks (all species combined) was in the range 0 - 17 fish in the Western GOA, 152 - 834 fish (CV = 16 – 32%) in the Central GOA, and 180 - 749 fish (CV = 21 – 45%) in the Eastern GOA (Table 20.3).

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, 4,981 - 43,459 in the Central GOA, and about 4,643 - 32,027 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 63 - 284 fish over the years 1998 - 2009 (except 1999). About 60-65% of the retention in recent years has come from Prince William Sound. 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 to 2009 ranged from 216 to 236 cm. Average predicted round wt ranged from 124 to 158 kg. Females have dominated the retained catch each year (56 - 97%). Ages of fish sampled from 1997 - 2000 ranged from 5 to 17 years.

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 near Yakutat. Anecdotal reports indicate that many spiny dogfish are handled poorly when released. Discard mortality is unknown but probably substantial. Only 69 spiny dogfish were retained and sampled from the Southcentral Alaska sport fishery from 1998 through 2009. The mean total length (TL_{nat}) of these fish was 93 cm and mean predicted round weight was 4.1 kg.

Bycatch, Discards, and Historical Catches
Historical catches of sharks in the GOA are composed entirely of incidental catch, and nearly all shark catch is discarded. Mortality rates of discarded catch are unknown, but are conservatively estimated in this report as 100%. Aggregate incidental catches of the shark complex management category from federally prosecuted fisheries for Alaskan groundfish in the GOA are tracked in-season by the NMFS Alaska Regional Office (AKRO).

Data

Data regarding sharks are obtained from the following sources:

Source	Data	Years
AKRO Catch Accounting System	Non-target catch	2003 - 2011
(AFSC) Improved Pseudo Blend	Non-target catch	1997 - 2002
(AFSC) Pseudo Blend	Non-target catch	1990 - 1998
ADF&G	Sport catch	1998 - 2010
NMFS Bottom Trawl Surveys – GOA	Biomass Index	1984 - 2011
NMFS Sablefish Longline Survey	Survey catch numbers and CPUE	1989 - 2011
IPHC Longline Survey	Survey catch numbers, CPUE and RPNs	1998 - 2010

Incidental Catch

This report summarizes incidental commercial catches by species as three data time series: 1990 - 1998, 1997 - 2002, and 2003 - 2011 (Table 20.4). Discard rates for sharks are presented in Table 20.5. Generally, > 90% of sharks are discarded, however, “Other/unidentified sharks” are generally retained at a higher rate (64% discards on average) than identified shark species, and in 2009 only 7% of the “other/unidentified sharks” were discarded. In general, sharks that are retained (on average about 26 t) are nearly all used for fishmeal (T. Hiatt, pers. comm.).

Prior to 2003, shark catches, by species, were estimated by the AFSC by two different methods. The pseudo-blend method of Gaichas et al. (1999) was used to estimate catches of sharks by species for the years 1990 - 1998. For the years 1997 - 2002, Gaichas (2002) used an improved pseudo-blend method to estimate species group catches, and catches by species for sharks. 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. Catch estimates from 2003 - present are estimated by the AKRO (Cahalan et al. 2010) using the same methods as Gaichas (2002) and are comparable to the 1997 - 2002 time series.

On average, spiny dogfish composed 54% of total shark catch, however in 2009, they were 93% of the total shark catch. Pacific sleeper sharks are 30% of the total shark catch on average, but in 2009 were only 4%. Other/unidentifed sharks and salmon sharks are generally a smaller portion of the total shark catch (average 10% and 7%, respectively). Blue sharks and brown cat sharks were rarely identified in catches and were included with other/unidentified sharks. These two species are not delineated in the CAS catch estimates, but examination of the observer data showed that blue sharks are between 0% (2008 & 2009) and 60% (2006) of the other/unidentified shark catch. Brown cat sharks were at most < 1% (2006) of the other/unidentified shark catch.

Based on the 1997 – 2011 GOA catch estimates, spiny dogfish were caught primarily in the Pacific cod (27%) and sablefish (23%) fisheries (Table 20.6). Pacific sleeper sharks were caught primarily in the Pacific cod (37%) and pollock (36%) fisheries (Table 20.7), and salmon sharks were caught primarily in the pollock (90%) fishery (Table 20.8). Incidental catches of other and unidentified shark species were rare in the GOA except for a large catch in 1998 taken in the sablefish fishery (Table 20.9). Catch by species and target fishery is not available for 2002 because Gaichas (2002) estimated it for the years 1997-2001 and the CAS didn't start estimating catch by species and target fishery for non-target species until 2003. Examining the catch by week of the year shows that shark catch for the last four years has tended to occur in two seasons. The first season occurs around week 11 (March), which is mostly driven by spiny dogfish catch in the sablefish fishery, but also some Pacific sleeper shark catch in the pollock fishery. The second season occurs around week 36 (September) and consists mostly of spiny dogfish caught in the Pacific cod fishery (Figure 3).

The majority of vessels fishing in the GOA are smaller vessels that are either unobserved or subject to 30% observer coverage, although some target fisheries (i.e. rockfish) are conducted by larger vessels with 100% observer coverage. In making these catch estimates, we are assuming that shark catch aboard observed vessels is representative of shark catch aboard unobserved vessels throughout the GOA. These catch estimates do not include unobserved fisheries such as the halibut IFQ fishery or ADF&G managed fisheries such as the salmon gillnet fisheries, both of which are thought to have high levels of shark bycatch. Estimates of shark catch in the halibut IFQ fishery are presented in Appendix 20A.

Observer data was used to map the spatial distribution of catch for the years 2007 - 2010. Data is available through the Fisheries Monitoring and Analysis division website (http://www.afsc.noaa.gov/FMA/spatial_data.htm). As explained above, only 40% of the groundfish tonnage is observed and observers are not randomly distributed on vessels and trips and so actual spatial distribution of catch may differ from available data. Data presented here represent only non-confidential data aggregated by 400km^2 grids of observed catch. Bycatch of spiny dogfish within observed commercial fisheries (Figure 20.4) occur predominately off Kodiak Island with some catch spread along the shelf. Spiny dogfish catch was especially high in 2008. The spatial distribution of observed Pacific sleeper sharks catch (Figure 20.5) is more limited than spiny dogfish. Pacific sleeper shark catch primarily occurs within Shelikof Strait in the Central GOA, and along the Alaska Peninsula. Both 2007 and 2010 had higher catches of Pacific sleeper sharks within observed commercial fisheries. 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.

Relative CPUEs were calculated for observed catch of Pacific sleeper shark and spiny dogfish (Figure 20.6). CPUEs were calculated as either catch (t) per minute of haul duration (for observed trawl hauls) or catch (t) per hook fished (for observed longline sets), then scaled to 1 for comparison. Detailed analysis of CPUE has not been conducted. Spiny dogfish relative CPUE is highly variable, but peaked in 2004 for longline gear and again in 2008 for trawl gear, both have been relatively low since those peaks. Pacific sleeper shark longline relative CPUE has declined steadily from a peak in 2007, but has been variable and does not appear to be trending in trawl fisheries.

Survey Biomass Estimates

NMFS AFSC bottom trawl survey biomass estimates are available for the three primary shark species in the GOA (1984 - 2011, Table 20.10). The efficiency of bottom trawl gear is not known for sharks, and these biomass estimates should be considered a minimum biomass estimate for shark species until more formal analyses of survey efficiencies by species can be conducted. For example, pelagic species such as salmon shark are caught during net deployment and retrieval and thus biomass estimates are unreliable. Also, 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 very small number of individual hauls within a given survey and a very small number of individual sharks within a haul. Consequently, these biomass estimates can be highly uncertain. Analyses of GOA biomass trends are subject to several caveats regarding the consistency of the survey time series. Surveys in 1984, 1987, and 1999 included deeper strata than the 1990-1996 surveys; therefore the biomass estimates for deeper-dwelling species are not comparable across years. The 2011 survey had both a reduced number of stations and the 700 – 1000 m depth stratum was not sampled. The 2001 survey did not include all areas of the Eastern GOA and consequently, the 2001 survey may not be comparable with the other surveys for species such as spiny dogfish which appear to be relatively abundant in the Eastern GOA.

Trawl survey catch of spiny dogfish is highly variable from year to year. It is likely that the trawl survey biomass estimate for spiny dogfish is an underestimate and should be considered a minimum biomass. Tagging data show that spiny dogfish spend a significant amount of time in near surface waters or shallow depths during the summer (Tribuzio, unpublished data) and are thus likely poorly sampled. The 1984 - 2011 GOA bottom trawl surveys indicate an increasing biomass trend for spiny dogfish through 2007 (Table 20.10, Figure 20.7). The 2009 survey biomass estimate for spiny dogfish was the lowest since 1987 and had the lowest CV of any previous biomass estimate. The spatial distribution of the catch of spiny dogfish for the two most recent surveys is similar, however, the areas with the greatest catches changed (Figure 20.8). In 2009, peak catches were northeast of Kodiak Island, the Fairweather grounds and inside Southeast Alaska, but in 2011 peak catches were in Cook Inlet and the Fairweather gounds.

Pacific sleeper sharks are caught in a small number of hauls each year. Biomass estimates increased through 2005 and have decreased steadily since then (Table 20.10, Figure 20.7). The spatial distribution of Pacific sleeper shark catch on the bottom trawl survey is limited to Shelikof Strait and southwest of Kodiak Island (Figure 20.9). Salmon shark biomass has been relatively stable based on trawl survey biomass estimates, but CVs often overlap zero, as this survey does not sample this pelgic species well. No salmon sharks were encountered in either the 1999, 2001 or 2009 survey. The total NMFS survey catch of all sharks in trawl surveys is listed in Appendix 20A.

Other Data Sources

<u>IPHC Annual Bottom Longline Survey</u>

The IPHC annual bottom longline survey provides the best data for catch of shark species because of the spatial coverage and consistent catch of the primary species. The survey uses a stratified, random sampling design along the continental shelf from 1 - 500 meters. At each station, ~500 hooks are set, but only ~20% of hooks are observed for species other than Pacific halibut. More information on this survey can be found in Soderlund et al. (2009). Relative population numbers (RPNs) are calculated for the IPHC survey for the time period from 1997 - 2010. First, an average CPUE (numbers caught per effective hook) was calculated by depth stratum (0 – 99 m, 100 – 199 m, 200 – 299 m, 300 – 499 m) for each region (WGOA, CGOA, WY, EY/SE). Second, the CPUE was multiplied by the area size of that stratum to determine the stratum RPN. Finally, a regional RPN was calculated by summing the RPNs of all strata in the region. Area sizes from the RACE trawl survey were utilized for IPHC RPN calculations. The IPHC survey catches about 31,000 spiny dogfish and 2,800 Pacific sleeper shark on average, resulting in the RPNs in Figure 20.10. The spiny dogfish RPNs do not appear to be trending when looking at the entire time series, but for Pacific sleeper shark the RPNs have decreased steadily since a peak in 2001, with 2008-2010 being the lowest values of the entire time series. To facilitate comparisons with other data sources, we scaled Gulf wide CPUE to 1 (Figure 20.6).

Examination of the spatial distribution of both spiny dogfish and Pacific sleeper shark catch in the IPHC survey shows the broad distribution for these two species. During 2007 – 2010 spiny dogfish were caught in most stations across the continental shelf, with less catch west of Kodiak Island. The highest catches were in waters surrounding Yakutat Bay and the Fairweather grounds (Figure 20.11). In 2008, spiny dogfish catch on the Fairweather grounds was particularly high, as well as much of the Southeast Alaska area. Pacific sleeper shark catch is generally greatest in Shelikof Strait, but areas of high catch are also in Prince William Sound and inside Southeast Alaska (Figure 20.12).

AFSC Annual Longline Survey

The AFSC annual longline survey has a standard series of stations fished every year and is a longer time series than the available IPHC survey data, however, due to the spatial limitations and habitat surveyed, it is not as useful for shark species. RPNs are not available at this time, but we calculated a relative CPUE (numbers caught per effective hook scaled to 1) for comparison to other surveys and observer data (Figure 20.6). Similar to the IPHC survey, the relative CPUE for spiny dogfish appears stable, but the Pacific sleeper shark relative CPUE has declined steadily since 2001. Both longline surveys show this declining trend in sleeper sharks. This trend in Pacific sleeper shark abundance indices will require further investigation in future assessments. One caveat with both longline surveys is that hook competition has not been examined for sharks.

Spatial distribution of shark catch on the AFSC longline survey is more limited than the IPHC survey, due in part to fewer stations covering a narrower area. Spiny dogfish are regularly caught at handful of gully stations outside of Prince William Sound, Yakutat Bay and Southeast Alaska (Figure 20.13). However, magnitude of catch is variable. Catch of Pacific sleeper sharks generally occurs in Shelikof Strait, but occasionally they are caught stations farther east (Figure 20.14).

ANALYTIC APPROACH, MODEL EVALUATION, AND RESULTS

Model Structure

At this time a formal analytic model is not used to provide stock assessment advice for sharks. However, in this section we provide a summary of a demographic model for spiny dogfish developed by Tribuzio and Kruse (*in press a*). In theory, this model can be used to estimate a sustainable harvest rate and to conduct a risk analysis under varying harvest scenarios. We do not make a recommendations based on the demographic model at this time, as more models are under development and we prefer to wait until we can compare the results of multiple models. Demographic models are convenient and easily implemented for data limited species because they only require basic life history information such as birth and death rates (Simpfendorfer 2005). Here, the model is an age-structured Leslie matrix type demographic model (Brewster-Geisz and Miller 2000; Caswell 2001; Frisk et al. 2002) with the basic formulation of:

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

where N is the vector of numbers of animals at each age class at time t and $\mathbf{M}$ is the transition or projection matrix composed of survival and fecundity for each age (Caswell 2001; Simpfendorfer 2005). All animals in each year class must move to the next year class, thus $\mathbf{M}$ is of the form (Caswell 2001; Aires-da-Silva and Gallucci 2007):

$$\mathbf{M} = \begin{bmatrix} f_0 & f_1 & \cdots & f_{i-1} & f_i \\ l_0 & 0 & \cdots & 0 & 0 \\ 0 & l_1 & \cdots & 0 & 0 \\ 0 & 0 & \cdots & l_{i-1} & 0 \end{bmatrix}, \tag{2}$$

where i is the age class, l is the age-specific survivorship and f is age-specific per-capita fecundity rate (fertility). Survivorship was calculated as a function of l_{i-1} and the total mortality (Z), which is the sum of fishing (F) and natural mortality (M):

$$l_i = l_{i-1}e^{-Z}. \quad (3)$$

We assumed a birth-pulse, post-breeding census, where birth occurs at the end of the year and fertility (f_i) is given by:

$$f_i = l_i b_i, \quad (4)$$

where b_i is the age-specific female fecundity (the number of female pups produced by each female each year). *S. suckleyi* 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).

Model results were calculated by solving the Euler-Lotka equation (Caughley 1977). Resultant parameters included: instantaneous rate of increase r (also called the rebound potential where $\lambda = e^r$), 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 stock to increase by R_0 ($T = lnR_0/ln\lambda$), the mean age of the parents of a cohort (μ_1), and the stock doubling time ($t_{x2} = ln(2)/r$).

Three scenarios were run for the demographic model: 1) no fishing; 2) with fishing effects; and 3) with fishing effects and with varying age at first entry into the fishery. The model was first run with $F = 0$ (scenario 1) to determine the parameters of an assumed virgin stock (i.e. $Z = M$), and then F was included at varying levels (scenario 2) to examine the effects of different fixed harvest rates on the stock ($Z = F+M$). We applied varying ages of entry into the fishery to examine for which combinations of age of entry and F resulted in a value of r that was above 0, and thus sustainable (scenario 3). Fishing mortality was applied uniformly across the ages that were susceptible to fishing (i.e. knife edge selectivity).

While many studies have been conducted regarding the age, growth, life history, and movement of *S. suckleyi*, there remains a great deal of uncertainty in parameter estimates. Statistical distributions were assumed for input parameters to account for this uncertainty or natural variability (Cortes 2002). Monte Carlo simulations were run that randomly generated each input parameter from the assumed distributions. The average of 10,000 replications was taken as the parameter value with 95% confidence intervals being the 2.5th and 97.5th percentile. Model calculations and simulations were run using Poptools (www.poptools.org).

Stochasticity for l and longevity (t_{max}) was based on the distribution of M. A triangular pdf was defined for M based on Tribuzio and Kruse (*in press b*) with the median M estimate (0.054) as the most likely value and the minimum (0.011) and maximum (0.101) estimates forming the range. The estimates of M were converted to survivorship ($l = e^{-Z}$, where $Z = F+M$). The t_{max} was calculated as $t_{max} = -\ln(0.01)/M$ (Hewitt and Hoenig 2005), and a similar triangular pmf was used with the minimum, median and maximum longevity estimates. Age at first capture (t_c) (or age of entry into the fishery) was fixed at 4 years (the youngest age encountered in GOA dogfish sampling) for scenarios 1 and 2, and allowed to vary uniformly between zero and 60 years for scenario 3. The pdf for the age at 50% maturity (t_m) was a normal distribution with a mean of 34 years and standard deviation of 7 years (Tribuzio and Kruse *in press b*). Female fecundity (b), was based on the total number of pups, a 1:1 sex ratio of pups and a two-year reproductive cycle (Tribuzio *et al.* 2009). The random normal pdfs were defined by the averages and standard deviations of b_i for each age class (4.9 ± 1.7 female pups/female, Tribuzio and Kruse *in press b*).

Parameters Estimated Independently

Parameters estimated independently are identified for the major shark species in the GOA or North Pacific where data are lacking (Table 20.12). Tribuzio and Kruse, (*in press b*) derived an estimate of the natural mortality rate (M = 0.097) for spiny dogfish in the GOA. The value of M (0.097) for the GOA is similar to the previously published estimate of M from British Columbia spiny dogfish of 0.094 (Wood et al. 1979). Goldman (2002) derived an M estimate for salmon shark in the central GOA of 0.18. A natural mortality estimate is not available for Pacific sleeper sharks. Maximum reported age for central GOA salmon shark is 30 years (Goldman and Musick 2006) and for spiny dogfish in the eastern North Pacific 80 - 100 years (Beamish and McFarlane 1985). Age at first recruitment to a commercial fishery is assumed to be 5 years old for central GOA salmon sharks (Goldman, 2002). Maximum age and age of first recruitment are not available for spiny dogfish or Pacific sleeper sharks, however, Tribuzio et al. (2010) report the youngest encountered dogfish in fishery dependent sampling was 8 years old. Ages are not currently available for Pacific sleeper shark as methods to age the species have not been developed.

Weight-at-length and average length and weight values for all three species are presented in Table 20.11. Length-at-age models for the GOA have been published for salmon sharks (Goldman and Musick 2006), and spiny dogfish (Tribuzio et al. 2010). Parameters of the von Bertalanffy growth model are presented in Table 20.11. Because of the difficulty with aging Pacific sleeper sharks and the lack of length-weight data, growth models are not available for this species. While sharks are slow-growing compared to teleost fish, the spiny dogfish has the slowest growth rate of any modeled shark species.

Parameters Estimated Conditionally

Demographic analyses have been performed for both GOA spiny dogfish (as described above) and ENP salmon sharks (Goldman 2002) to estimate rebound potential and sustainable fishing levels. Assuming an unfished stock, the spiny dogfish stock has an estimated rate of increase of 3.4% (1.2 - 6%, 95% confidence intervals, Tribuzio and Kruse, *in press a*) and salmon shark are increasing at a rate of 1.2% (-1.5 - 4.1%, 95% confidence intervals, Appendix B in Courtney et al. 2006). Sustainable fishing levels for spiny dogfish were at $F < 0.04$ and for salmon shark $F < 0.05$. Results of this modeling exercise should be considered a "base-case" scenario because of the assumed virgin, closed stock and uniform F. The assumption that shark stocks are unfished is not realistic because the actual fishing mortality is > 0, yet the level of F is unknown. Bycatch in unobserved state fisheries such as the salmon gillnet fisheries is also unknown and may have very high spiny dogfish mortality in some years. Further, salmon sharks, while rare in federal commercial fisheries, may occur in salmon seine fisheries and there is a small sport fishery for the species, suggesting that $F > 0$ for that species as well. As more data such as migration rates become available, they can be incorporated into the model to more accurately reflect the stock dynamics.

RESULTS

Model Evaluation

Model estimates from Scenario 1 for the unfished GOA stock are $r = 0.034\ y^{-1}$ (0.012-0.06 y^{-1}, 95% confidence intervals) and $\lambda = 1.035\ y^{-1}$ (1.012-1.064 y^{-1}). The net reproductive rate, R_0, is 4.794 female pups (1.967-8.445 female pups). The mean generation time is 46.3 y (33.6-59.5 y), stock doubling time is 20.4 y (11.1-56.7 y), and the mean age of parents is 49.0 y (38.0-60.9 y). The inclusion of F in Scenario 2 dramatically impacted the model. The r value dropped to negative values (and thus unsustainable) at $F >$ 0.04. Both R_0 and t_{x2} decreased to negative values with $F > 0.03$. Likewise, μ_1 also decreased. The T only decreased slightly. Not surprisingly, delaying age of entry into the fishery (Scenario 3) increases the values of F that are sustainable. Fishing at all levels is sustainable if the $t_c > 50$ y, and sustainable for $t_c =$ 40 y at $F < 0.03$.

Projections and Harvest Alternatives

The shark complex is managed as a combination of Tier 5 and Tier 6 species, with the complex ABC and OFL being the sum of the individual species ABC and OFLs. Because of limited biological information, Pacific sleeper sharks, salmon sharks and other sharks are managed under Tier 6, with an OFL based on the average catch from 1997-2007. Spiny dogfish were moved to Tier 5 for the 2011 fishery. The SSC "regards this year's catch specification (i.e. the 2011 ABC and OFL) as provisional, pending further analysis. For the next assessment, the choice and use of reference points (*M*, *F*) should be carefully reconsidered and evaluated to determine the most appropriate for use in setting OFL and ABC". To that end, we are including a discussion of the two Tier 5 methods shown in the table below.

Status Quo Tier 5		ABC	OFL
Tier 5 (OFL=0.097*Avg Biomass, ABC=0.75*OFL)	Spiny Dogfish	5,600	7,467
Tier 6 (OFL=avg Catch 97-07)	Pacific Sleeper Shark	234	312
	Salmon Shark	53	71
	Other Sharks	141	188
Shark Complex Total		6,028	8,037
Alternate Tier 5			
Tier 5 (OFL=0.04*Avg Biomass, ABC=0.75*OFL)	Spiny Dogfish	2,309	3,079
Tier 6 (OFL=avg Catch 97-07)	Pacific Sleeper Shark	234	312
	Salmon Shark	53	71
	Other Sharks	141	188
Shark Complex Total		2,738	3,650

Two approaches to Tier 5 ABC/OFL calculations have been discussed: 1) Status quo Tier 5, which assumes the $F = M$; and 2) Alternate Tier 5 where $F = 0.04$, the estimated sustainable fishing rate. We are recommending retaining the status quo at this time because we are developing biomass production models for spiny dogfish and are holding off making a recommendation until we can compare multiple models.

Another issue of concern is the halibut fishery catch estimates (Appendix 20A). While these estimates cannot be added to the CAS estimates due to potential overlap with the current CAS estimates, that overlap is likely small for sharks because they are rarely retained. For the sake of this discussion, we are assuming that the overlap is negligible. Here we are providing information regarding the potential impact of the halibut fishery incidental catch estimates (HIFICE) on the ABC and potential for exceeding catch limits, we are not making recommendations with the HFICE estimates. If the HFICE and CAS catch estimates are added together for Tier 5 spiny dogfish, they would not exceed the Status quo Tier 5 ABC (based on the estimated biomass). The Tier 6 species are more complicated because the ABC is based on average historical catch. The time series of the HFICE catch estimates (2001 – 2010) does not match the time series used to calculated average historical catch (1997 – 2007) and thus cannot simply be included in the historical average catch. Further, there are the inherent issues with Tier 6, mainly that Tier 6 assumes that historical average catch is sustainable. The HFICE estimated catch for Pacific sleeper sharks is large, and the biological and management impacts of these catch estimates need to be investigated further. Salmon shark and Other/Unidentified shark catches are sporadic and low in magnitude.

We recommend that the Tier 5 and 6 methods be reassessed as inclusion of data sources (e.g. halibut IFQ fleet or research catches) changes. Recommended Tier 5/6 for the GOA shark complex ABC and OFL are presented below both for individual species and for sharks as a complex. Examining the catch history from 1997 to the present shows that catches have not exceeded the recommended ABC (Figure 20.15).

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on Stock, and Fishery Effects on Ecosystem

Understanding shark species stock dynamics is fundamental to describing ecosystem structure and function in the GOA. Shark species are top level predators as well as scavengers and likely play an important ecological role. Studies designed to determine the ecological roles of spiny dogfish, Pacific sleeper sharks, and salmon sharks are ongoing and will be critical to determine the effect of fluctuations in shark stocks on community structure in the GOA.

Spiny dogfish
Previous studies have shown spiny dogfish to be opportunistic feeders (Alverson and Stansby 1963), not wholly dependent on one food source. Small dogfish are limited to consuming smaller fish and invertebrates, while the larger animals will eat a wide variety of foods (Bonham 1954). Diet changes are consistent with the changes of the species assemblages in the area by season (Laptikhovsky et al. 2001). Spiny dogfish in the northwest Atlantic can eat twice as much in summer as in winter (Jones and Geen 1977). Spiny dogfish have also been shown to prey heavily on out-migrating salmon smolts (Beamish et al. 1992). In the GOA, preliminary diet studies further suggest that spiny dogfish are highly generalized, opportunistic feeders (Tribuzio, unpublished data).

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). The more current hypothesis is that these sharks make vertical oscillations throughout the water column searching for prey as well as scavenging. Evidence for this behavior was documented in a tagging study in the GOA (Hulbert et al. 2006). Also, a 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 that 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. Although Pacific sleeper sharks share the same areas as pupping Stellar sea lions (*Eumetopias jubatus*) in the GOA, they were not found to prey on newborn sea lions but did have tissues from other marine mammals in their stomachs (Sigler et al. 2006). Taggart et al. (2005) found that Pacific sleeper sharks in Glacier Bay were only caught in traps at locations where harbor seals were at their highest concentrations. However, they did not find any seal tissue in their stomachs and concluded that Pacific sleeper sharks may either be a predator of the seals or might be attracted to the same food sources as the seals, such as walleye pollock (*Theragra chalcogramma*), cephalopods, flounder, or capelin (*Mallotus villosus*).

Analyses of mercury and other elemental concentrations in the tissues of Pacific sleeper sharks show that they are at a lower trophic level than ringed seals (*Pusa hispida*) and were at a similar level as flathead sole (*Hippoglossoides elassodon*) (McMeans et al. 2007). Another study used stable isotopes to determine the trophic level of Greenland sharks and found that larger sharks were at a higher trophic level than smaller sharks because larger sharks were more likely to feed on marine mammals (Fisk et al. 2002).

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, including salmon (*Oncorhynchus* sp.), rockfishes (family Sebastes), sablefish (*Anoplopoma fimbria*), lancetfish (family Alepisaurus), daggertooth (family Anotopterus), lumpfishes (family Cyclopteridae), sculpins (family Cottidae), Atka mackerel (*Pleurogrammus*), mackerel (family Scomber), pollock and tomcod (family Gadidae), herring (family Clupeidae), spiny dogfish, tanner crab (family Chionoecetes), squid, and shrimp (Sano 1960 and 1962, Farquhar 1963, Hart 1973, Urquhart 1981, Compagno 1984 and 2001, Nagasawa 1998). Seasonal foraging movements and migratory patterns of salmon sharks in the northeast Pacific Ocean have been described in Hulbert et al. (2005) and Weng et al. (2005).

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
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 (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

Data Gaps and Research Priorities

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

1. Length frequency data from commercial fishery observations, expand on or continue with special projects
2. Estimate bycatch from unobserved fisheries: Adapt HFICE methods to state groundfish fisheries. State salmon fisheries have no method available to document bycatch at this time.
3. Define the stock structure and migration patterns (i.e. tagging studies, genetics): Ongoing satellite tagging study of spiny dogfish
4. Determine or clarify existing estimates of life history parameters for use in models: Examining methods for estimation of *M* for Pacific sleeper sharks. NPRB funded aging study to begin Jan 2012, to include improving aging of spiny dogfish and investigate potential methods to age Pacific sleeper shark
5. Examine survey efficiency for species of interest: Tagging data may help elucidate how susceptible spiny dogfish are to existing surveys. Future work could include examining Pacific sleeper shark distribution in relation to survey grids.

SUMMARY

Over fishing is not occurring for any shark species in the GOA because catch limits of the shark complex were not exceeded. However, declining trends in survey indices for Pacific sleeper sharks warrant further investigation. There are currently no directed commercial fisheries for shark species in federal or state managed waters of the GOA, and most incidentally captured sharks are not retained. Spiny dogfish are allowed as retained incidental catch in some ADF&G managed fisheries, and salmon sharks are targeted by some sport fishermen in Alaska state waters. Incidental catches of shark species in GOA fisheries have been very small compared to catch rates of target species. Preliminary comparisons of incidental catch rates with available biomass by species suggest that current levels of incidental catches are low relative to available biomass for spiny dogfish and Pacific sleeper sharks in the GOA. In the GOA, average catch of spiny dogfish from 1997 - 2010 (556 t) represented about 1% of the estimated spiny dogfish biomass from GOA bottom trawl surveys 1996 - 2009 (average of 61,216 t, Table 20.10). Average catch of Pacific sleeper sharks from 1997 - 2010 (265 t) represented less than 1% of the available Pacific sleeper shark biomass from GOA bottom trawl surveys 1996 - 2009 (average of 38,088 t, Table 20.10). Average catch of salmon sharks from 1997 - 2010 (64 t) was relatively small compared to the other two shark species. GOA bottom trawl survey biomass estimates for salmon sharks are unreliable because trawl gear is an inefficient sampling technique for salmon sharks and salmon sharks were only caught in 6 hauls from 1996 - 2009 (Table 20.10). We recommend retaining the Status quo Tier 5 ABC/OFL (OFL = 0.097*3 yr avg biomass) for spiny dogfish and Status quo Tier 6 (OFL = avg historical catch 1997 – 2007) for the remaining species in the shark complex.

2012 and 2013 recommendations	Spiny Dogfish	Pacific Sleeper Shark	Salmon Shark	Other/Unid Sharks	Total Sharks
Tier	5	6	6	6	6
M	0.097	Unk	0.18	unk	unk
Biomass 3 YR AVG	76,979	36,273	5,369	NA	118,621
Average Catch	530	312	71	188	1,100
ABC	5,600	234	53	141	6,028
OFL	7,467	312	71	188	8,037

ACKNOWLEDGMENTS

We gratefully acknowledge the following individuals: Michael Martin (AFSC) provided bottom trawl survey biomass estimates for the Gulf of Alaska (1984-2011); Claude Dykstra (IPHC) and Tom Kong (IPHC) provided IPHC longline survey data and commercial fishery data; Scott Meyer (ADF&G) provided recreational fishery data; Mary Furuness (NMFS AKRO in Juneau, Alaska) and Olav Ormseth provided incidental catch estimates for shark species for 2003 – 2010; Sarah Gaichas provided catch estimates for 1997-2003; and Bob Ryzner and Camille Kohler (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.

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.

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.

Beamish, R.J., and G.A. McFarlane. 1985. Annulus development on the second dorsal spine of the spiny dogfish (*Squalus acanthias*) and its validity for age determination. Can. J. Fish. Aquat. Sci. 42:1799-1805.

Beamish, R.J., B.L. Thomson, and G.A. McFarlane. 1992. Spiny dogfish predation on Chinook and Coho salmon and the potential effects on hatchery-produced salmon. Trans Amer Fish Soc. 121:444-455.

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.

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.

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

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

Cahalan, J., J. Mondragon, J. Gasper. 2010. Catch sampling and estimation in the federal groundfish fisheries off Alaska. NOAA Tech Memo. NMFS-AFSC-205. 51.pgs.

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

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

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

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

Caughley, G. 1977. 'Analysis of Vertebrate Populations.' (Wiley: London.)

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 shark 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.

Compagno, L.J.V. 2001. Sharks of the World. An annotated and illustrated catalogue of shark species known to date. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fishery Purposes, No. 1, Vol. 2 Rome, FAO. 269 p.

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

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

Courtney, D. L., and L. Hulbert. 2007. Shark research in the Gulf of Alaska with satellite, sonic, and archival tags, p. 26-27. In P. Sheridan, J. W. Ferguson, and S. L. Dowling (editors), Report of the National Marine Fisheries Service Workshop on Advancing Electronic Tag Technologies and Their Use in Stock Assessments. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-82.

Courtney, D. L., C. A. Tribuzio, K. J. Goldman, J. Rice. 2006. Appendix E: GOA Sharks. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.pp. 481-562.

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.

Farquhar, G.B. 1963. Sharks of the family Lamnidae. Technical Report of the US Naval Oceanographic Office (TR-157). 22 pp.

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

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.

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., M. Ruccio, D. Stevensen, 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.

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

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.

Goldman, K.J. and J.A. Musick. 2008. Biology of the Salmon Shark, *Lamna ditropis*. *In* Sharks of the open ocean. E.K. Pikitch and M. Camhi, eds. Blackwell Scientific.

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

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

Hoenig, J. M. 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. B., Sigler, M. F., and Lunsford, C. R. 2006. Depth and movement behaviour of the Pacific sleeper shark in the northeast Pacific Ocean. Journal of Fish Biology 69 (2), 406-425.

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

Jones, B. C. and G. H. Geen. 1977. Food and feeding of spiny dogfish (*Squalus acanthias*) in British Columbia Waters. J Fish Res Bd Canada. 34:2067-2078.

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.

Laptikhovsky, V.V., A.I. Arkhipkin, A.C. Henderson. 2001. Feeding habits and dietary overlap in spiny dogfish *Squalus acanthias* (Squalidae) and narrowmouth catshark *Schroederichthys bivius* (Scyliorhinidae). J Mar Bio Assoc UK. 81:1015-1018.

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

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

McMeans, B.C., K. Borga, W.R. Bechtol, D. Higginbotham, and A.T. Fisk. 2007.

Essential and non-essential element concentrations in two sleeper shark species collected in arctic waters. Environmental Pollution 148: 281-290.

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

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

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

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

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

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.

Sano, O. 1960.The investigation of salmon sharks as a predator on salmon in the North Pacific, 1959. Bulletin of the Hokkaido Regional Fisheries Research Laboratory, Fisheries Agency 22:68–82 (in Japanese).

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 Straight of Georgia, British Columbia, Canada. Environ Biol Fish 38:49-57.

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

Sigler, M. F., Hulbert, L. B., Lunsford, C. R., Thompson, N. H., Burek, K., Hirons, A. C. O'Corry-Crowe, G. M. 2006. Diet of Pacific sleeper shark, a potential Steller sea lion predator, in the northeast Pacific Ocean. Journal of Fish Biology 69 (2), 392-405.

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

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., Anderson, E., Dykstra, C.L., Geernaert, T, and Ranta, A.M. 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.

Taggart, S. J., A.G. Andrews, J. Mondragon, and E.A. Mathews. 2005. Co-occurrence of Pacific sleeper sharks *Somniosus pacificus* and harbor seals *Phoca vitulina* in Glacier Bay. Alaska Fish. Res. Bull. 11(2): 113-117.

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

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

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

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

Tribuzio, C.A., G. H. Kruse, and J. T. Fujioka. 2010. Age and growth of spiny dogfish (*Squalus acanthias*) in the Gulf of Alaska: Analysis of alternative growth models. Fishery Bulletin 108:119-135.

Tribuzio, C.A. and G. H. Kruse. *in press a*. Demographic and risk analysis of the Gulf of Alaska spiny dogfish (*Squalus acanthias*) using an age based and stage based Leslie matrix model.

Tribuzio, C. A., and Kruse, G. H. *in press b*. Life history characteristics of spiny dogfish (*Squalus suckleyi* Girard) in the Gulf of Alaska. Submitted to the *Journal of Fish Biology*.

Urquhart, D.L. 1981. The North Pacific salmon shark. Sea Frontiers 27(6):361-363.

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., K. S. Ketchen, R. J. Beamish. 1979. Population dynamics of spiny dogfish (*Squalus acanthias*) in British Columbia waters. J Fish Res Board Can 36:647-656.

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

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

Yano, K., J.D. Stevens, and L.J.V. Compagno. 2004. A review of the systematics of the sleeper shark genus *Somniosus* with redescriptions of *Somniosus* (Somniosus) *antarcticus* and *Somniosus* (Rhinoscymnus) *longus* (Squaliformes: Somniosidae). Ichthyol Res. 51:360-373.

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

Table 20.1. Shark species in the Gulf of Alaska (GOA) including life history and biological characteristics. Missing information is denoted by "?". Lengths presented as total length (TL) except as precaudal length (*PCL*) when noted in table.

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]	?	? yrs, 4m[1]	Predator[6]	22-108[1]	2,500[10]
Lamna ditropis	salmon shark	305[1]	20[11]	6-9 yrs, 165 cm *PCL*[11]	Predator[6]	3-5[7]	668[12]
Prionace glauca	blue shark	400[16]	15[13]	5 yrs[5], 221 cm[14]	Predator[6]	15-30 (up to 130)[15]	150[16]
Somniosus pacificus	Pacific sleeper shark	700[1]	?	?	Benth/Scav[17]	Up to 300[1]	2,700[18]
Squalus suckleyi	Spiny dogfish	125[19]	107[20]	34 yrs, 80 cm[19]	Pred/Scav/Bent[19]	7-14[19]	300[3]

[1]Compagno 1984; [2]Eschmeyer et al. 1983; [3]Mecklenburg et al. 2002; [4]Scott and Scott 1988; [5]Smith et al. 1998; [6]Cortes 1999; [7]Gilmore 1993; [8]Mooney-Seus and Stone 1997; [9]Castro 1983; [10]Last and Stevens 1994; [11]Goldman and Musick 2006, [12]Hulbert et al. 2005; [13]Stevens 1975; [14] ICES 1997; [15] White et al. 2006; [16]Smith 1997; [17]Yang and Page 1999; [18]www.nurp.noaa.gov; [19]Tribuzio unpublished data; [20]G. A. McFarlane pers. comm.

Table 20.2. Time series of Other Species TAC, Other Species and shark catch, and ABC for sharks. Note that the decrease in TAC in 2008 was a regulatory change and not based on biological trends.

Year	TAC	Other Sp. Catch	Est. 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	6,262	750	N/A	Other Species TAC
2004	12,592	3,580	573	N/A	Other Species TAC*
2005	13,871	2,512	1,102	N/A	Other Species TAC
2006	13,856	3,882	1,602	N/A	Other Species TAC
2007	12,229	3,026	1,406	1,792	Other Species TAC
2008	4,500	2,984	619	1,792	Other Species TAC
2009	4,500	2,085	1,167	777	Other Species TAC
2010	4,500	1,724	478	957	Other Species TAC
2011	6,197	NA	417	6,197	Shark Complex TAC#

*Skates were removed from the GOA Other Species category in 2004.

#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 2003-2010 from AKRO Catch Accounting System (CAS, queried through AKFIN on Oct 11, 2011).

Table 20.3. Estimated numbers of harvested and discarded sharks in the Alaska Department of Fish and Game managed recreational fishery. 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 charter logbook and only reflect catch in the charter fleet.

All Sharks Combined

	Western			Central			Eastern			Total Est
Year	Retained	CV	Discarded	Retained	CV	Discarded	Retained	CV	Discarded	Catch
1998	0	--	0	494	0.16	9,575	269	0.23	5,226	15,564
1999	0	--	0	426	0.24	4,981	247	0.34	13,316	18,970
2000	0	--	0	351	0.24	8,283	402	0.39	16,561	25,597
2001	17	0.94	20	392	0.20	15,943	550	0.30	16,799	33,721
2002	0	--	0	347	0.27	6,833	239	0.41	4,643	12,062
2003	0	--	30	702	0.22	23,521	497	0.26	12,205	36,955
2004	0	--	37	342	0.22	16,015	403	0.30	9,529	26,326
2005	0	--	108	834	0.18	43,459	749	0.27	24,791	69,941
2006	0	--	0	441	0.25	37,816	426	0.21	20,287	58,970
2007	0	--	0	534	0.21	42,592	588	0.31	32,027	75,741
2008	0	--	410	546	0.22	21,846	371	0.38	29,827	53,000
2009	0	--	0	200	0.32	19,422	196	0.45	13,279	33,097
2010	0	--	13	152	0.34	17,374	180	0.44	12,054	29,773

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	0	0	0

Table 20.4. NMFS estimated catch (tons) of sharks (by species) and Other Species (in aggregate) in the Gulf of Alaska. 1990-1998 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999). 1997-2002 catch estimated with NMFS new pseudo-blend estimation procedure (Gaichas 2002). Years 2003-2010 from NMFS AKRO (queried through AKFIN on Oct 11, 2011). Breaks in the table represent different catch estimation periods.

Year	Spiny dogfish	Pacific sleeper shark	Salmon shark	Other/ Unident shark	Total sharks	Total other species	% of Other Species Catch
1990	171	20	53	30	274	6,289	4%
1991	141	49	42	108	340	5,700	6%
1992	321	38	142	17	517	12,313	4%
1993	383	215	89	340	1027	6,867	15%
1994	160	120	25	56	360	2,721	13%
1995	141	63	55	49	308	3,421	9%
1996	337	66	28	53	484	4,480	11%
1997	233	118	25	59	436	5,439	8%
1998	298	161	79	132	669	3,748	18%
-	-	-	-	-	-	-	-
1997	657	136	124	123	1,041	5,439	19%
1998	865	74	71	1,380	2,390	3,748	64%
1999	314	558	132	33	1,036	3,858	27%
2000	398	608	38	74	1,117	5,649	20%
2001	494	249	33	77	853	4,801	18%
2002	117	226	58	26	427	4,040	11%
-	-	-	-	-	-	-	-
2003	357	270	35	53	716	6,266	12%
2004	184	282	41	39	546	1,705	34%
2005	443	482	60	69	1,054	2,513	44%
2006	1,169	252	34	83	1,539	3,881	41%
2007	831	295	151	107	1,385	3,035	46%
2008	533	65	7	12	617	2,967	21%
2009	1,027	50	9	24	1,110	3,188	37%
2010	398	160	107	9	674	1,724	28%
2011	387	23	5	2	417	NA	NA
1997-2007 Average	530	312	71	188	1,100	530	
Avg % of Total Sharks	54%	30%	7%	10%			

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 11, 2011

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%	77%
2007	96%	100%	100%	90%
2008	93%	98%	94%	59%
2009	97%	98%	99%	7%
2010	95%	95%	98%	27%
2011	99%	96%	98%	46%
Average	85%	97%	78%	64%

Table 20.6. Estimated catch (tons) of spiny dogfish in the Gulf of Alaska by fishery. 1990-1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999). 1997-2001 catch estimated with NMFS new pseudo-blend estimation procedure (Gaichas 2002). Years 2003-2010 from NMFS AKRO using the improved pseudo-blend estimation procedure (queried through AKFIN on Oct 11, 2011). Catch by target fishery and species are not available for 2002. Spiny dogfish do not occur in the Atka Mackerel fishery. Bycatch in the halibut fisheries has been estimated by NMFS AKRO since 2003, but it is based only on landed sharks and does not include discarded catch. See Appendix 20A for halibut fishery incidental catch estimates.

Fishery	Pollock	Pacific Cod	Flatfish	Rockfish	Halibut	Sablefish	Grand Total	Year % of Total 97-11
1990	57.6	36.0	13.5	1.8		59.0	170.9	
1991	29.3	52.6	16.2	16.4		26.2	141.2	
1992	84.4	50.5	116.0	22.4		40.7	320.6	
1993	137	10.1	138.5	2.4		95.3	383.4	
1994	22	16.9	83.4	2.5		35.4	160.2	
1995	2.8	28.1	24.1	18.4		50.7	140.6	
1996	2.9	15.3	182.6	19.8		79.5	336.9	
1997	2.8	57.6	137.2	326.2		133.7	657.5	8%
1998	4.9	727.2	69.0	3.1		59.6	864.9	10%
1999	8.6	160.2	56.6	4.8		83.4	313.6	4%
2000	18.7	29.4	66.3	146.6		136.6	397.6	5%
2001	11.6	172.8	162.5	25.1		122.1	494.0	6%
2002	-	-	-	-	-	-	-	
2003	6.1	43.6	166.0	35.5	6.6	17.3	275.0	3%
2004	9.2	19.6	15.5	2.3	13.4	123.2	183.2	2%
2005	15.2	27.9	50.1	2.8	17.3	329.3	442.7	6%
2006	50.0	113.2	122.9	2.0	713.2	147.4	1,148.6	14%
2007	47.6	250.2	151.4	6.2	210.5	165.6	831.4	10%
2008	59.6	289.6	87.3	4.8	0.5	91.1	533.0	7%
2009	17.6	113.7	204.8	7.0	603.2	80.7	1,027.1	13%
2010	19.8	118.1	164.0	3.5	21.4	70.8	397.7	5%
2011	1.5	20.0	46.8	0.7	69.1	248.9	387.1	5%
Fishery % of Total	3%	27%	19%	7%	21%	23%		

Table 20.7. Estimated catch (tons) of Pacific sleeper sharks in the Gulf of Alaska by fishery. 1990-1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999). 1997-2001 catch estimated with NMFS new pseudo-blend estimation procedure (Gaichas 2002). Years 2003-2010 from NMFS AKRO using the improved pseudo-blend estimation procedure (queried through AKFIN on Oct 11, 2011). Catch by target fishery and species is not available for 2002. Bycatch in the halibut fisheries has been estimated by NMFS AKRO since 2003, but it is based only on landed sharks and does not include discarded catch. See Appendix 20A for halibut fishery incidental catch estimates.

Fishery	Pollock	Pacific Cod	Flatfish	Rockfish	Atka Mackerel	Halibut	Sablefish	Grand Total	Year % of Total 97-11
1990	2.9	9.9	0.4	4.3	0		2.2	19.7	
1991	27.2	2.8	3.1	0	0		16.2	49.4	
1992	1.1	27.4	2.7	0	0		6.4	37.6	
1993	156.5	21.8	1	0	0		35.5	214.8	
1994	79.6	16.6	0.8	1.3	0		21.2	119.5	
1995	16.9	13.7	20.7	0.1	0		11.6	63	
1996	14.5	11.9	12.1	0	0.2		26.4	65.9	
1997	22.3	59.3	46	0.9	0		7.5	135.9	4%
1998	32.4	19.6	10.1	0.2	0		11.3	74	2%
1999	34.1	505.8	6	3	0		8.7	557.7	17%
2000	178.4	376.8	35.9	0.3	0		16.7	608.2	18%
2001	145.9	65.8	6.3	0.7	0		30.3	249	7%
2002	-	-	-	-	-		-	-	
2003	50.3	56.3	93.0	0.3	0.0	59.1	9.2	268.1	8%
2004	168.9	25.5	73.7	0.8	0.0	8.4	4.2	281.3	8%
2005	196.0	133.8	129.6	0.2	0.0	2.2	18.9	480.7	14%
2006	153.5	13.5	60.4	0.4	0.0	0.8	23.1	251.7	7%
2007	58.9	9.1	222.7	0.0	0.0	3.7	0.7	295.1	8%
2008	47.5	13.2	2.0	1.1	0.0	0.0	0.7	64.6	2%
2009	30.2	4.3	14.5	0.3	0.0	0.0	0.2	49.5	1%
2010	149.6	2.0	7.9	0.0	0.0	0.0	0.4	159.8	5%
2011	2.7	3.9	9.9	2.1	0.0	0.0	4.3	22.9	1%
Fishery % of Total	36%	37%	21%	0%	0%	2%	4%		

Table 20.8. Estimated catch (tons) of salmon sharks in the Gulf of Alaska by fishery. 1990-1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999). 1997-2001 catch estimated with NMFS new pseudo-blend estimation procedure (Gaichas 2002). Years 2003-2010 from NMFS AKRO using the improved pseudo-blend estimation procedure (queried through AKFIN on Oct 11, 2011). Catch by target fishery and species is not available for 2002. Salmon shark do not occur in the Atka Mackerel fishery. Bycatch in the halibut fisheries has been estimated by NMFS AKRO since 2003, but it is based only on landed sharks and does not include discarded catch. See Appendix 20A for halibut fishery incidental catch estimates.

Fishery	Pollock	Pacific Cod	Flatfish	Rockfish	Halibut	Sablefish	Grand Total	Year % of Total 97-11
1990	45.3	3.2	0.2	0.7		2.1	51.5	
1991	36.2	0.0	0.0	0.0		5.3	41.5	
1992	123.1	16.5	0.2	0.0		2.1	141.9	
1993	86.7	0.0	2.5	0.0		0.0	89.2	
1994	24.2	0.0	0.0	0.0		0.0	24.2	
1995	25.9	21.6	3.2	0.2		3.1	54.0	
1996	26.9	0.0	0.0	0.0		0.2	27.1	
1997	19.8	0.1	0.0	0.0		0.0	19.9	2%
1998	69.7	0.0	0.8	0.4		0.0	70.9	9%
1999	111.8	0.7	0.7	0.0		18.4	131.6	16%
2000	32.7	0.0	3.7	0.8		0.6	37.8	5%
2001	29.5	0.0	1.5	1.8		0.0	32.8	4%
2002		-	-	-		-	-	
2003	34.6	0.0	0.3	0.0	0.0	0.1	35.0	5%
2004	33.1	1.7	5.4	0.1	0.0	0.4	40.7	5%
2005	43.1	0.8	15.7	0.5	0.0	0.0	60.1	8%
2006	31.4	0.6	1.6	0.6	0.0	0.0	34.3	5%
2007	141.6	0.0	9.0	0.5	0.1	0.0	151.2	20%
2008	6.4	0.0	0.1	0.7	0.0	0.0	7.2	1%
2009	6.9	0.0	2.0	0.4	0.0	0.0	9.2	1%
2010	103.7	0.0	1.0	2.4	0.1	0.0	107.2	14%
2011	4.6	0.0	0.0	0.1	0.0	0.0	4.8	1%
Fishery % of Total	90%	1%	6%	1%	0%	3%		

Table 20.9. Estimated catch (tons) of other/unidentified sharks in the Gulf of Alaska by fishery. 1990-1996 catch estimated by pseudo-blend estimation procedure (Gaichas et al. 1999). 1997-2001 catch estimated with NMFS new pseudo-blend estimation procedure (Gaichas 2002). Years 2003-2010 from NMFS AKRO using the improved pseudo-blend estimation procedure (queried through AKFIN on Oct 11, 2011). Catch by target fishery and species is not available for 2002. Other/unidentified sharks do not occur in the Atka Mackerel fishery. Bycatch in the halibut fisheries has been estimated by NMFS AKRO since 2003, but it is based only on landed sharks and does not include discarded catch. See Appendix 20A for halibut fishery incidental catch estimates.

Fishery	Pollock	Pacific Cod	Flatfish	Rockfish	Halibut	Sablefish	Grand Total	Year % of Total 97-10
1990	4.1	21.3	0.8	1.4		2.9	30.5	
1991	17.8	36.7	35.5	4.4		13.7	108.1	
1992	3.3	8.4	3.5	0.1		1.5	17.2	
1993	138.3	38.1	3.7	0.0		159.3	339.6	
1994	41.6	2.3	3.0	0.0		8.9	55.8	
1995	4.0	3.4	10.6	9.7		14.3	49.3	
1996	14.2	3.1	17.8	1.9		16.0	53.4	
1997	8.9	13.4	9.0	47.5		43.9	123.4	6%
1998	24.2	10.2	17.9	2.3		1,325.2	1,379.8	66%
1999	6.1	12.3	8.1	0.1		6.4	33.0	2%
2000	12.3	3.5	34.0	4.8		18.7	73.6	4%
2001	35.0	1.4	1.5	1.4		37.7	77.0	4%
2002		-	-	-		-	-	
2003	7.6	6.4	18.2	0.2	17.5	3.1	53.0	3%
2004	11.1	2.7	18.8	0.2	2.6	3.3	38.7	2%
2005	34.7	1.2	21.5	0.2	0.2	11.0	68.8	3%
2006	40.9	11.9	24.4	1.6	0.0	4.3	83.1	4%
2007	13.9	38.3	49.6	0.4	0.0	4.9	107.0	5%
2008	4.3	2.4	2.4	0.0	0.0	2.8	12.1	1%
2009	10.4	2.7	10.6	0.0	0.0	0.0	23.7	1%
2010	3.7	0.2	4.0	1.2	0.2	0.0	9.3	0%
2011	0.2	0.2	1.5	0.0	0.0	0.1	2.1	0%
Fishery % of Total	10%	5%	11%	3%	1%	70%		

Table 20.10. Gulf of Alaska AFSC trawl survey estimates of individual shark species total biomass (metric tons) with Coefficient of Variation (CV), and number of hauls with catches of sharks. Data updated October, 2011 (RACEBASE). Analysis of GOA biomass trends are subject to the following caveats regarding the consistency of the survey time series. Survey efficiency in the GOA may have increased for a variety of reasons between 1984 and 1990, but should be stable after 1990 (Gaichas et al. 1999). Surveys in 1984, 1987, and 1999 included deeper strata than the 1990-1996 surveys; therefore the biomass estimates for deeper-dwelling species are not comparable across years. The 2001 survey did not include all areas of the Eastern GOA and consequently, the 2001 survey may not be comparable with the other surveys for species such as spiny dogfish which appear to be relatively abundant in the Eastern GOA. Source: Gaichas et al. (1999), RACEBASE.

		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	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	0.66	13	12,462.0	0.297	33,061.0
1993	775	166	33,645.1	0.204	13	8,656.8	0.5	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	52,880.8
1999	764	168	31,742.9	0.138	13	19,362.0	0.399	0	NA	NA	51,104.9
2001	489	75	31,774.3	0.45	15	37,694.7	0.362	0	NA	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	47,926.1	0.17	26	57,022.0	0.263	1	2,455.3	1	107,403.4
2007	820	164	161,965.1	0.35	15	39,634.8	0.39	2	12,339.7	0.75	213,939.6
2009	884	182	27,879.9	0.120	8	39,687.7	0.446	0	NA	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
3 yr AVG			76,979.3			36,272.9			5,368.5		

Table 20.11. Life history parameters. 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, with L_∞ either being the *PCL* or the TL_{ext} (total length in cm measured from the tip of the snout to the tip of the upper caudal lobe with the tail depressed to align with the horizontal axis of the body). Sources: NMFS sablefish longline surveys 2004-2006, NMFS GOA bottom trawl surveys in 2005; Sigler et al. (2006), Goldman and Musick (2006) and Tribuzio and Kruse (*in press b*).

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

		von Bertalanffy Parameters		
Species	**Sex**	L_∞ **(cm)**	**κ**	t_0 **(years)**
Spiny Dogfish	M	93.7 (TL_{ext})	0.06	-5.1
Spiny Dogfish	F	132.0 (TL_{ext})	0.03	-6.4
Pacific Sleeper Shark	M	NA	NA	NA
Pacific Sleeper Shark	F	NA	NA	NA
Salmon Shark	M	182.8 (*PCL*)	0.23	-2.3
Salmon Shark	F	207.4 (*PCL*)	0.17	-1.9

Table 20.12. Natural mortality (*M*) parameter estimates for shark species in the Gulf of Alaska (GOA). Source: GOA spiny dogfish (Tribuzio and Kruse *in press a*); eastern North Pacific (ENP) spiny dogfish (Wood et al. 1979); salmon shark (Goldman 2002).

Species	Area	*M* for Tier calc	Max age	Age of first recruit
Spiny dogfish	GOA	0.097	NA	NA
Spiny dogfish	ENP	0.094	80 – 100	NA
Pacific sleeper shark	NA	NA	NA	NA
Salmon shark	GOA	0.18	30	5

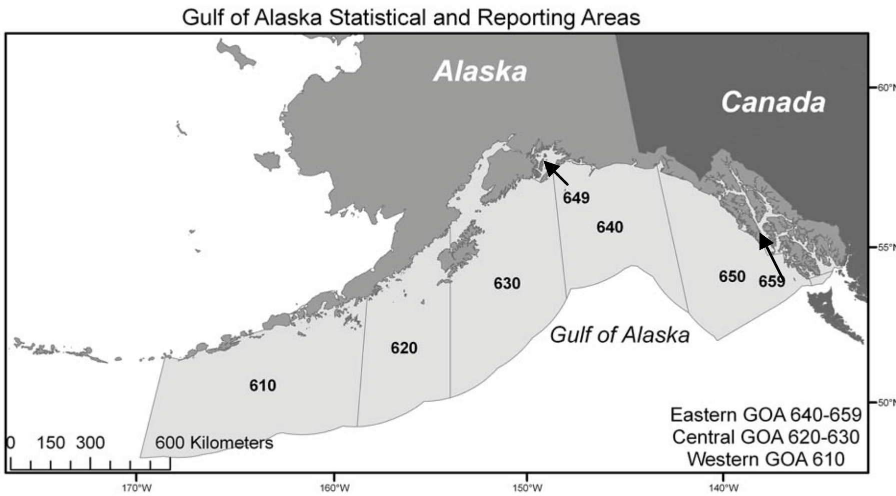

Figure 20.1. The statistical areas for NMFS observer data in the Gulf of Alaska.

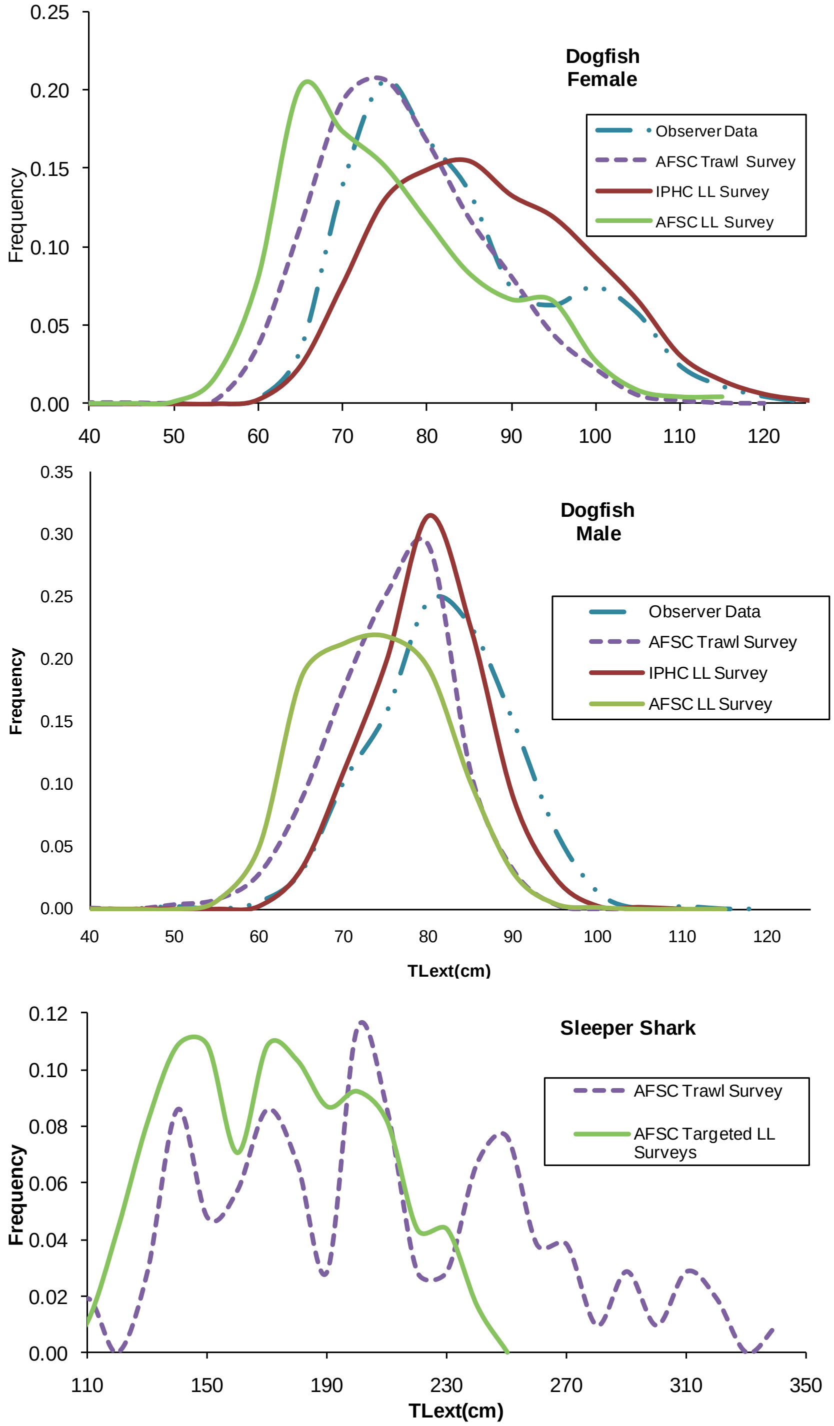

Figure 20.2. Observed length frequencies for female spiny dogfish (top) and male spiny dogfish (center) from the most recent NMFS trawl and longline surveys, the IPHC longline survey and observer special projects. Pacific sleeper shark (bottom) length frequencies from all years of the NMFS trawl survey and a targeted longline survey in 2001 near Kodiak Island.

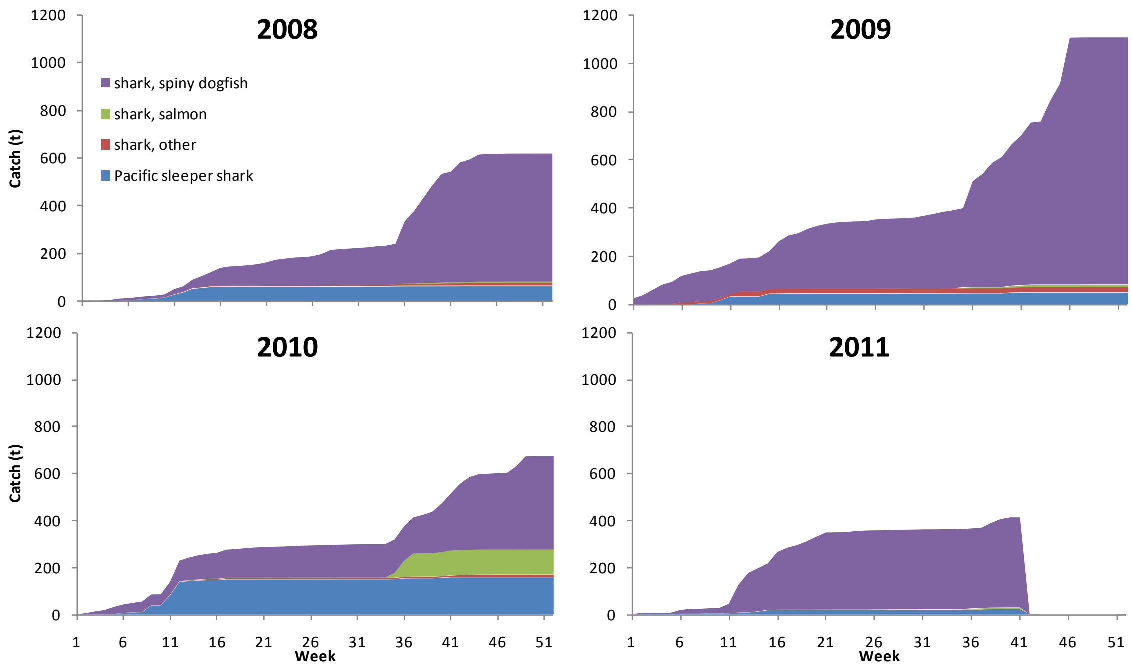

Figure 20.3. Cumulative catch of all sharks by week for the last four years. Data was queried through AKFIN on Oct 11, 2011, thus catch for that panel ends at week 41.

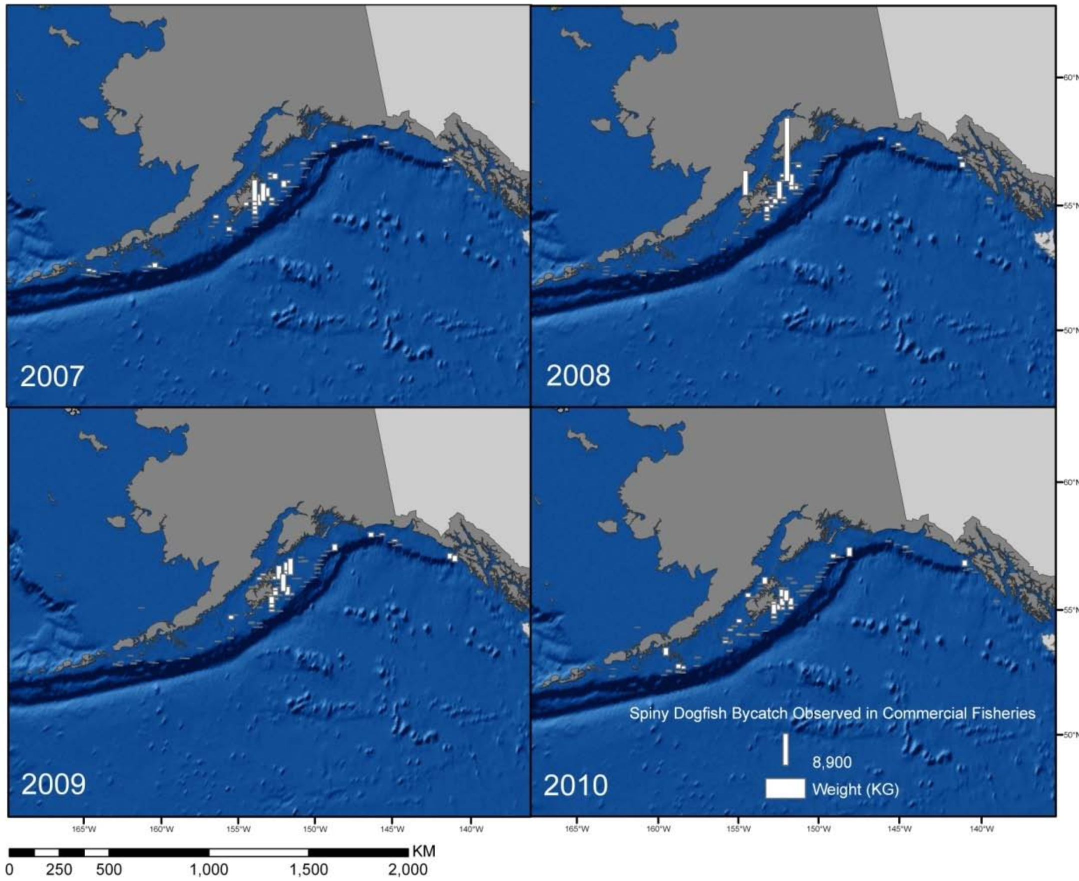

Figure 20.4. Spatial distribution of observed spiny dogfish catch in the GOA from 2007 – 2010 (all gear types). Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 19, 2011 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

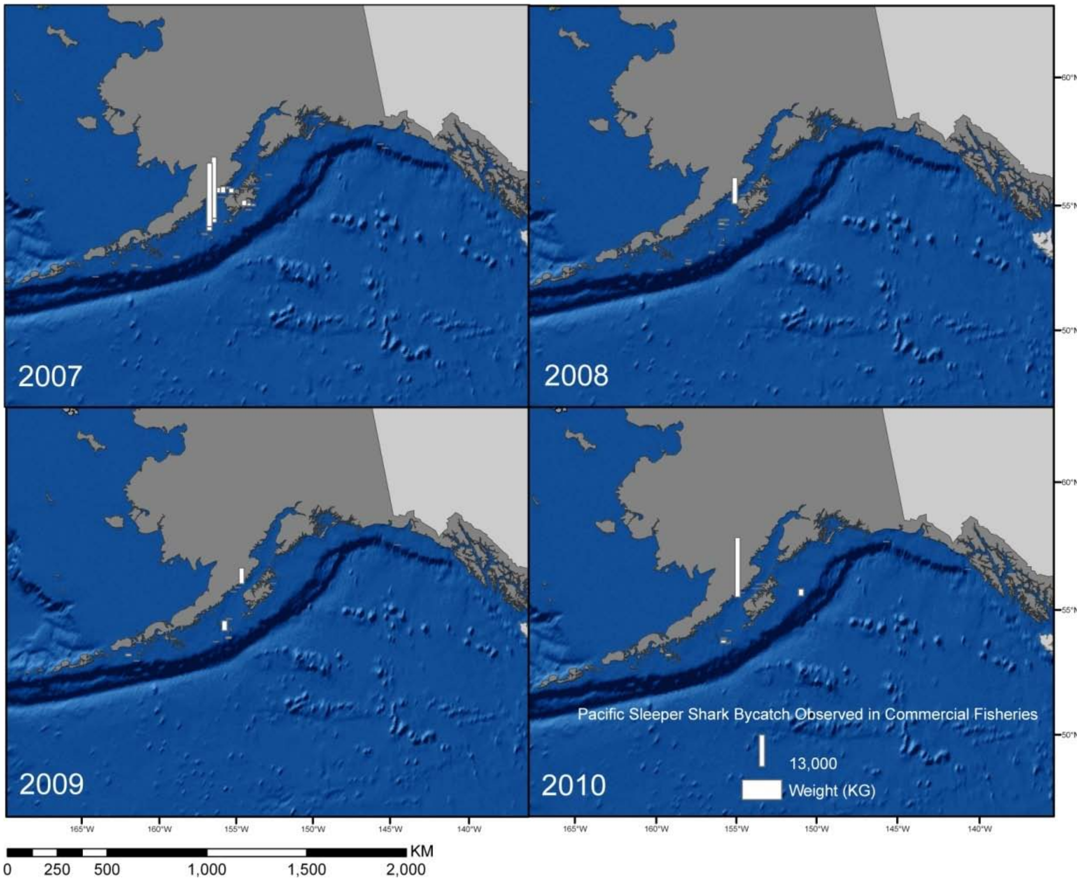

Figure 20.5. Spatial distribution of observed Pacific sleeper shark catch in the GOA from 2007 - 2010. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 19, 2011 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

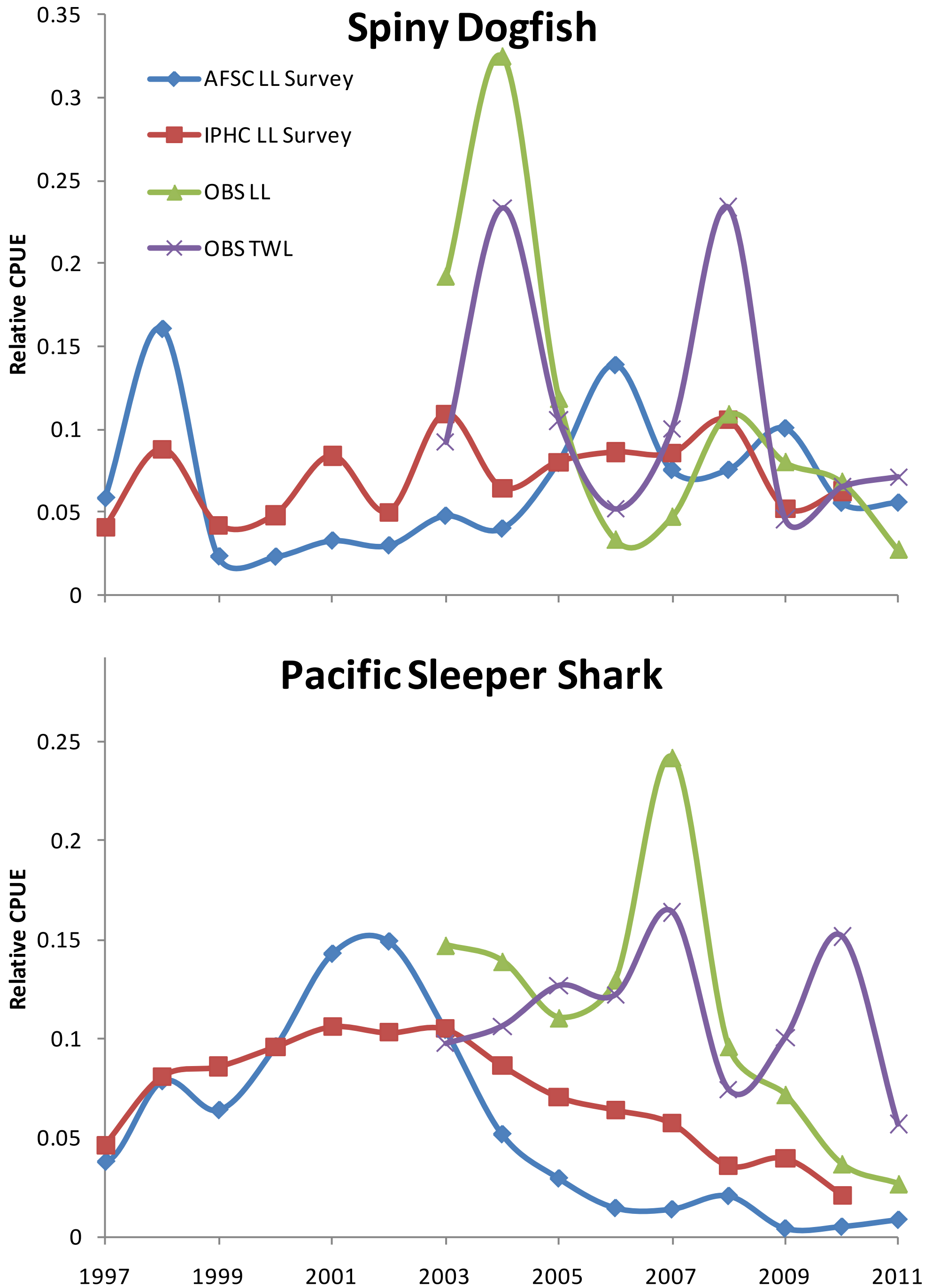

Figure 20.6. Relative CPUEs calculated for observed catch on longline and trawl gear, and the IPHC and AFSC annual longline surveys. Top panel is spiny dogfish and bottom panel is Pacific sleeper shark. The y-axis is relative and does not denote actual stock values.

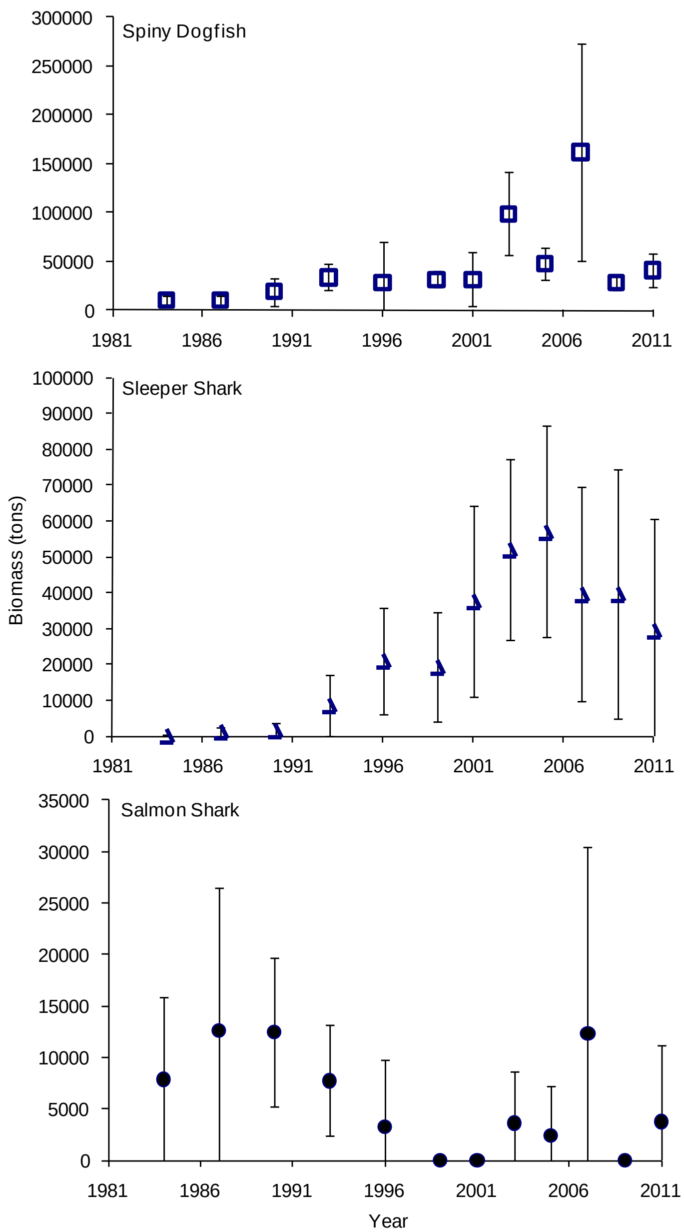

Figure 20.7. Trends in Gulf of Alaska (GOA) AFSC bottom trawl survey estimates of individual shark species total biomass (t) reported here as an index of relative abundance. Error bars are 95% confidence intervals. Source: Gaichas et al. (1999), RACEBASE.

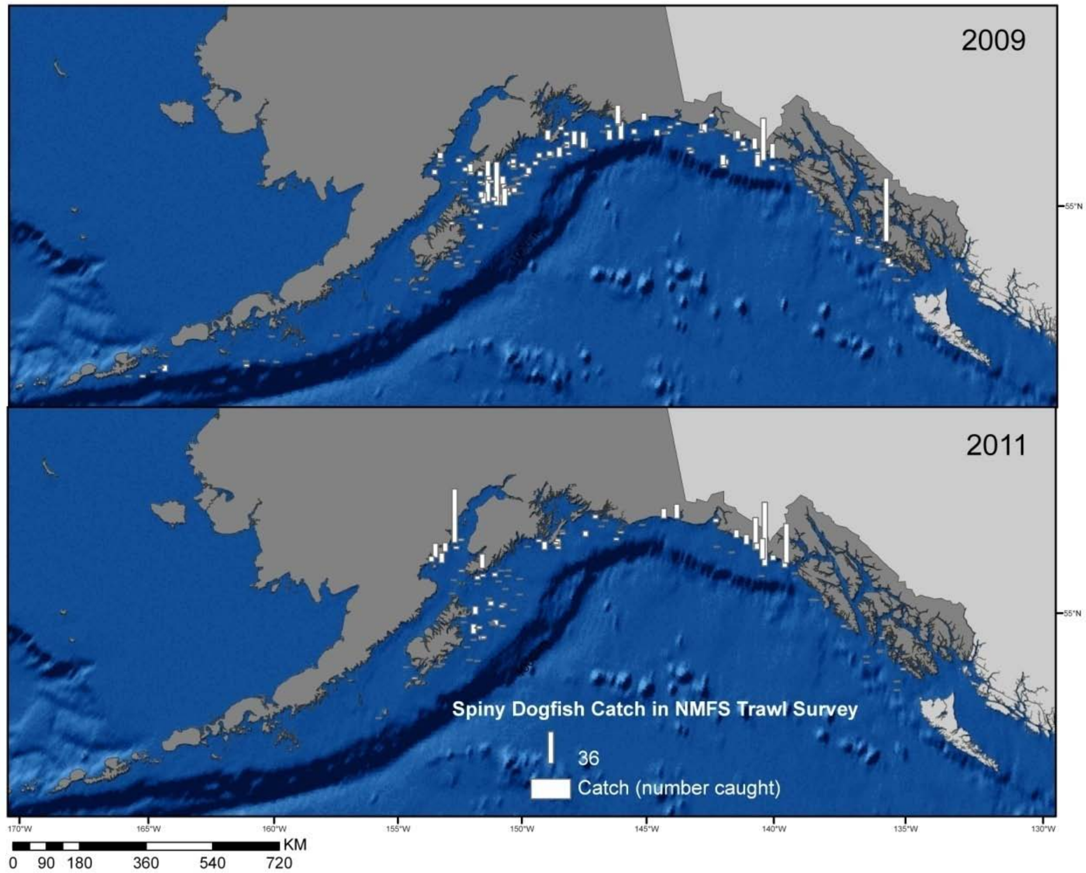

Figure 20.8. Spatial distribution of the catch of spiny dogfish during the 2009 and 2011 NMFS biennial trawl survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

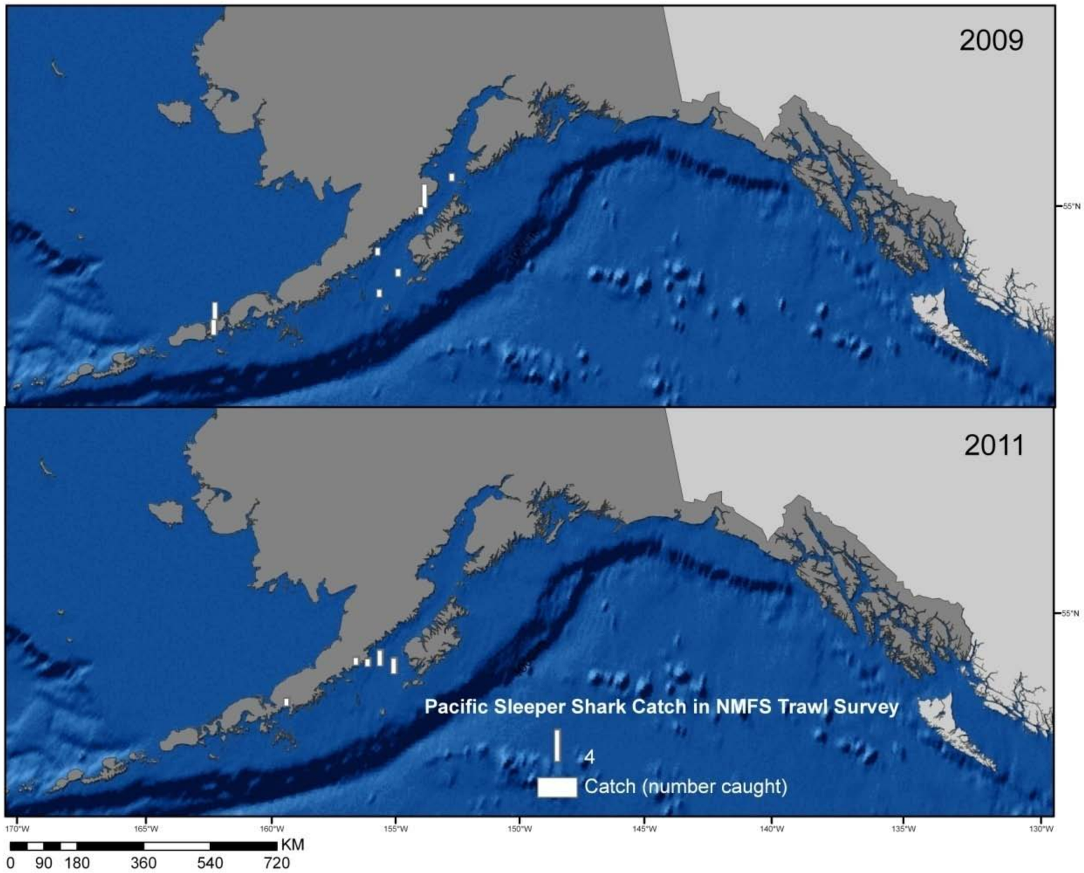

Figure 20.9. Spatial distribution of the catch of Pacific sleeper shark during the 2007 and 2009 NMFS biennial trawl survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

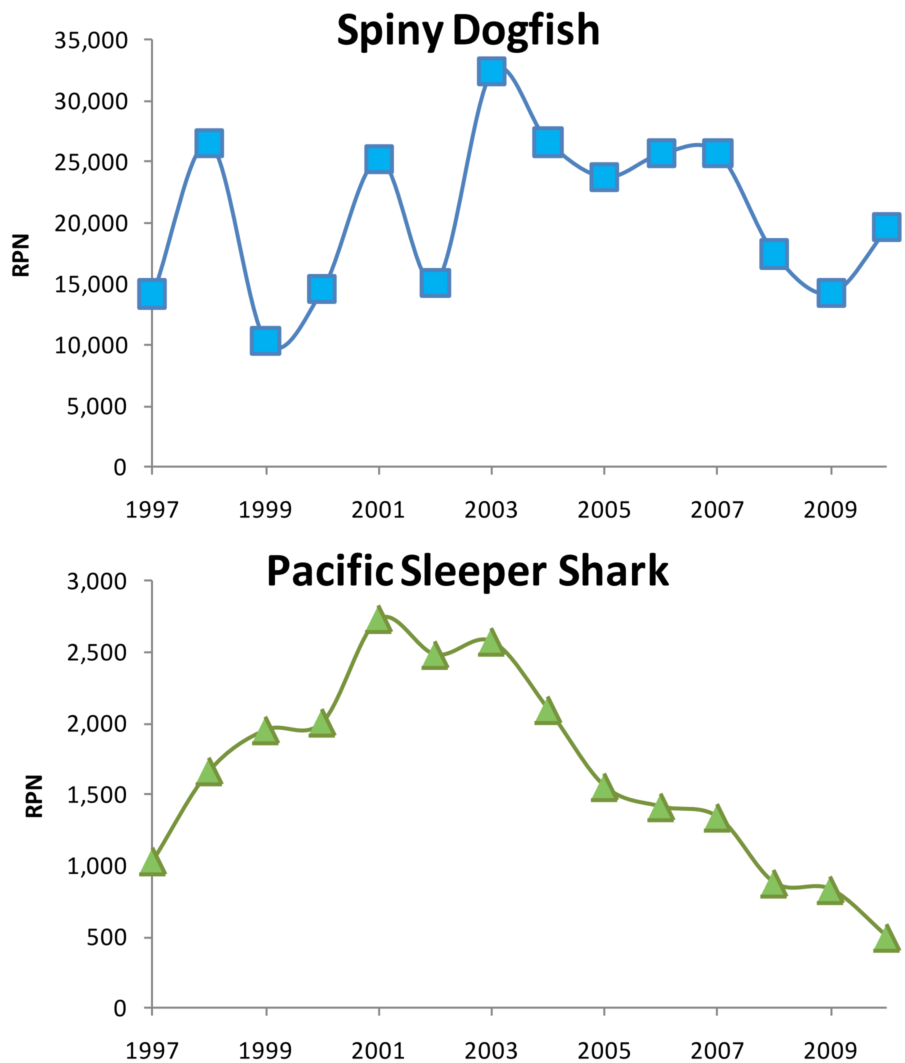

Figure 20.10. Relative population numbers (RPNs) from the IPHC longline survey for (top) spiny dogfish and (bottom) Pacific sleeper sharks. RPNs are a relative value and the values on they-axis do not represent true stock values. Source: C. Dykstra, IPHC.

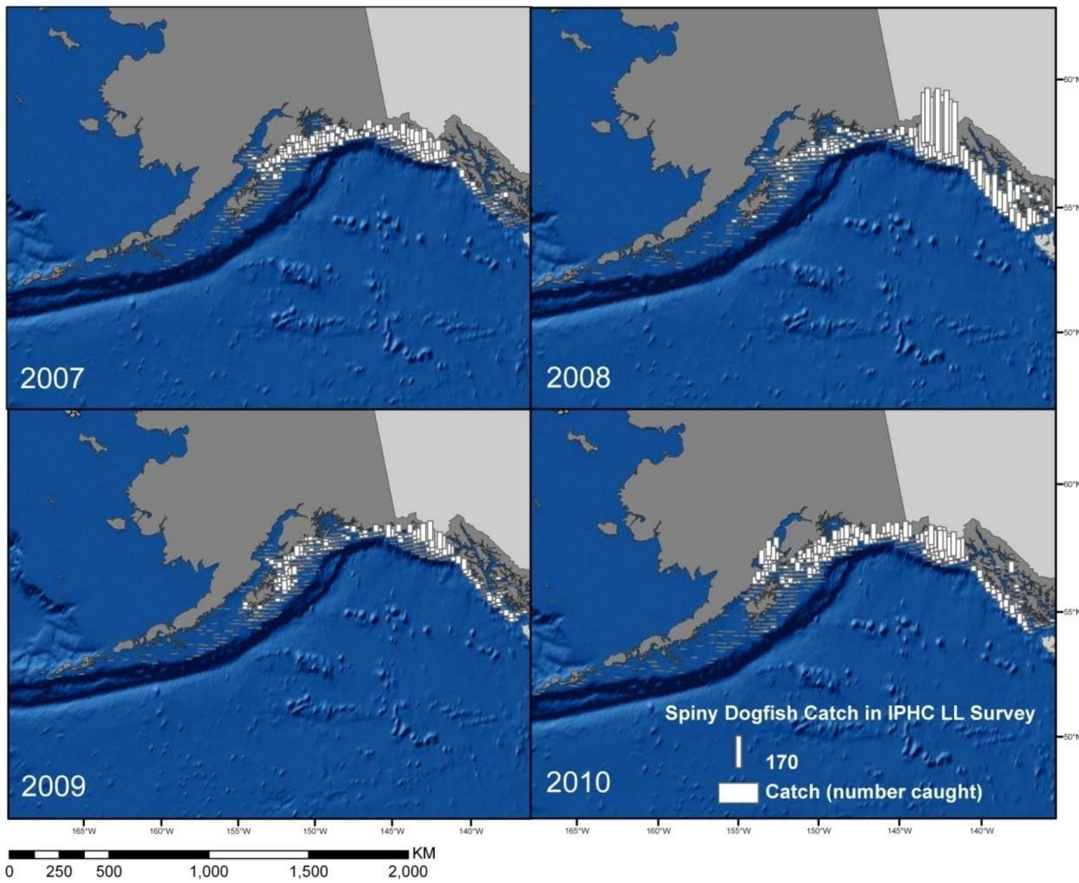

Figure 20.11. Spatial distribution of the catch of spiny dogfish during the 2007 - 2010 IPHC longline survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

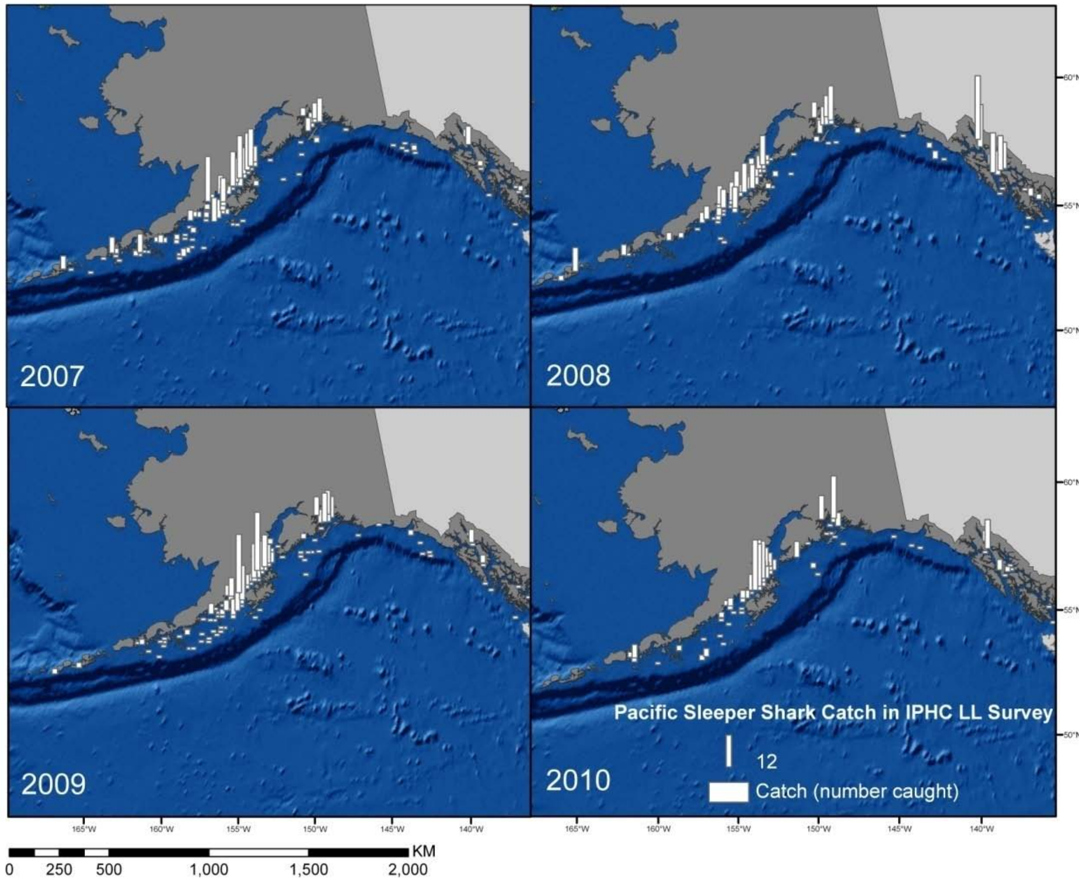

Figure 20.12. Spatial distribution of the catch of Pacific sleeper shark during the 2007 - 2010 IPHC longline survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

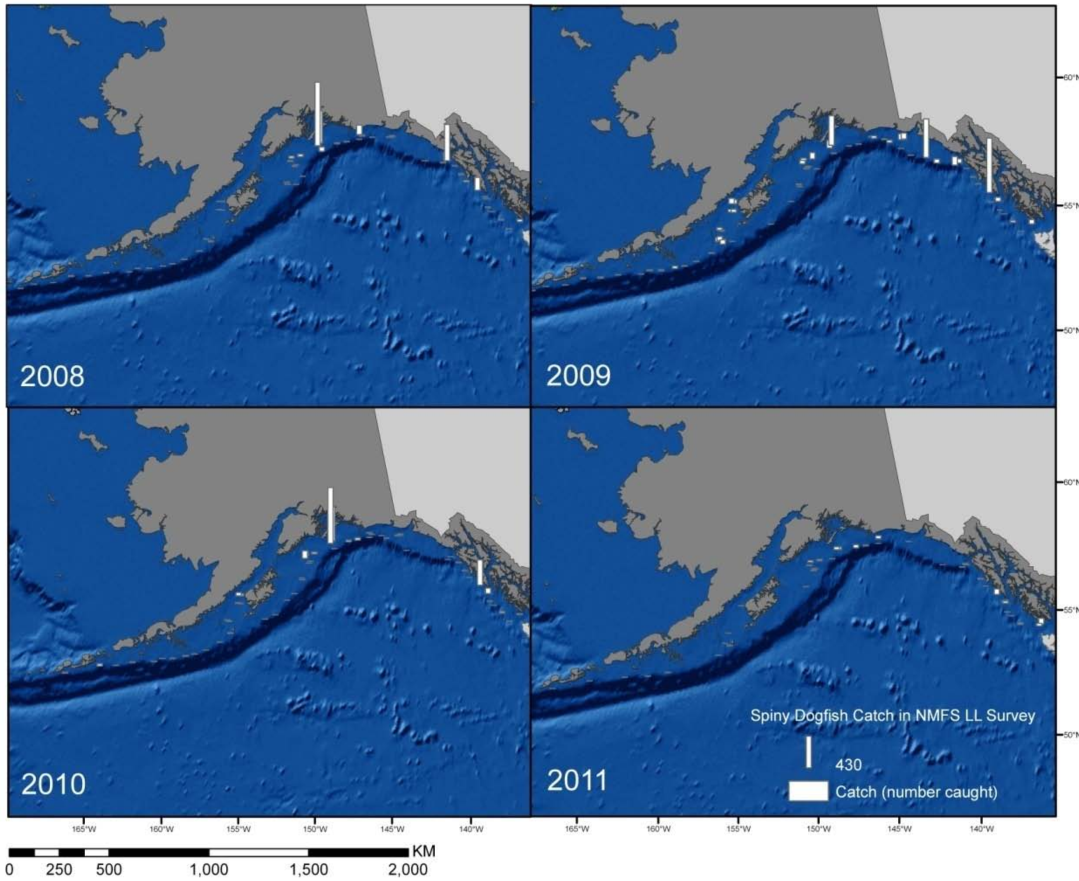

Figure 20.13. Spatial distribution of the catch of spiny dogfish during the 2008 - 2011 NMFS longline survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

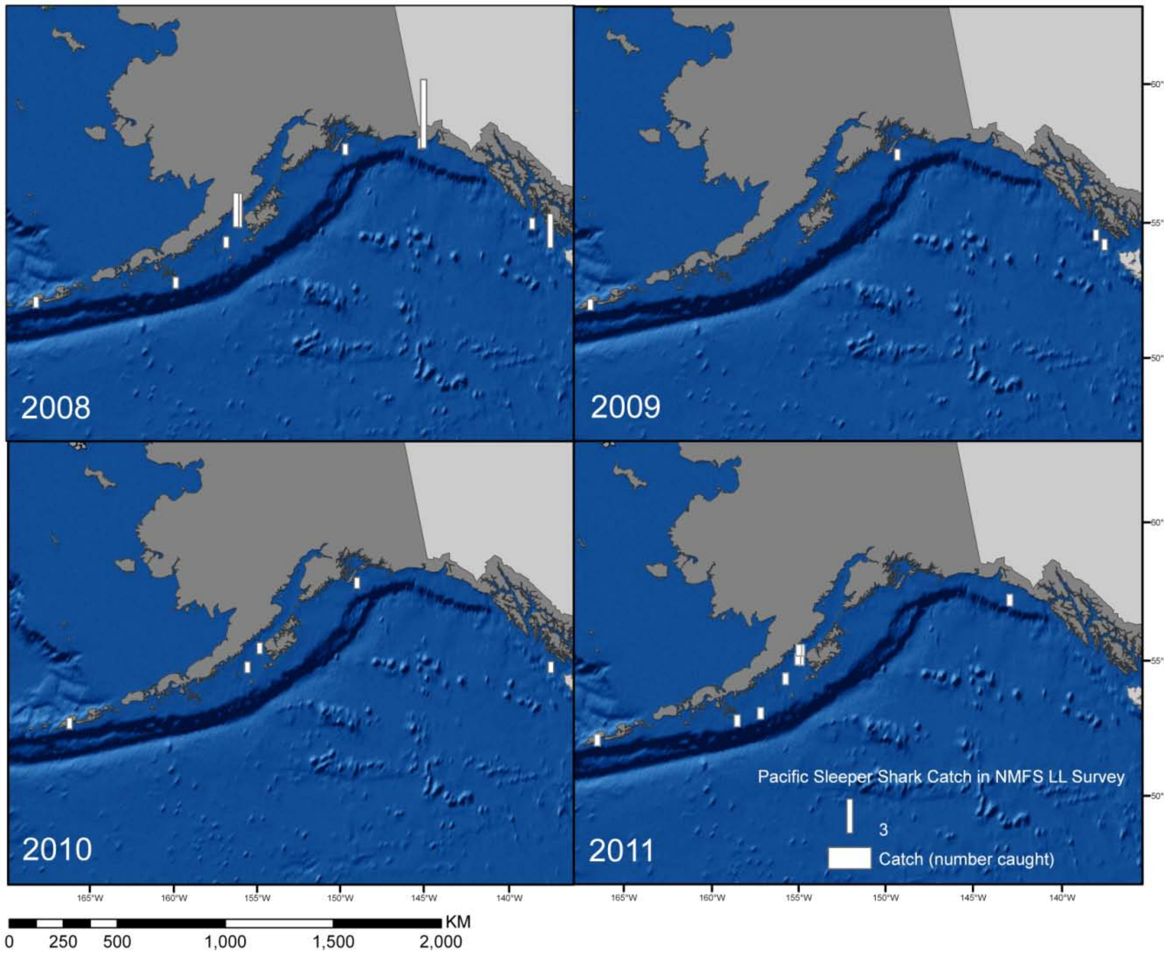

Figure 20.14. Spatial distribution of the catch of Pacific sleeper shark during the 2008 - 2011 NMFS longline survey. Height of the bar represents the number of sharks caught. Each bar represents one survey haul and hauls with zero catch were removed for clarity.

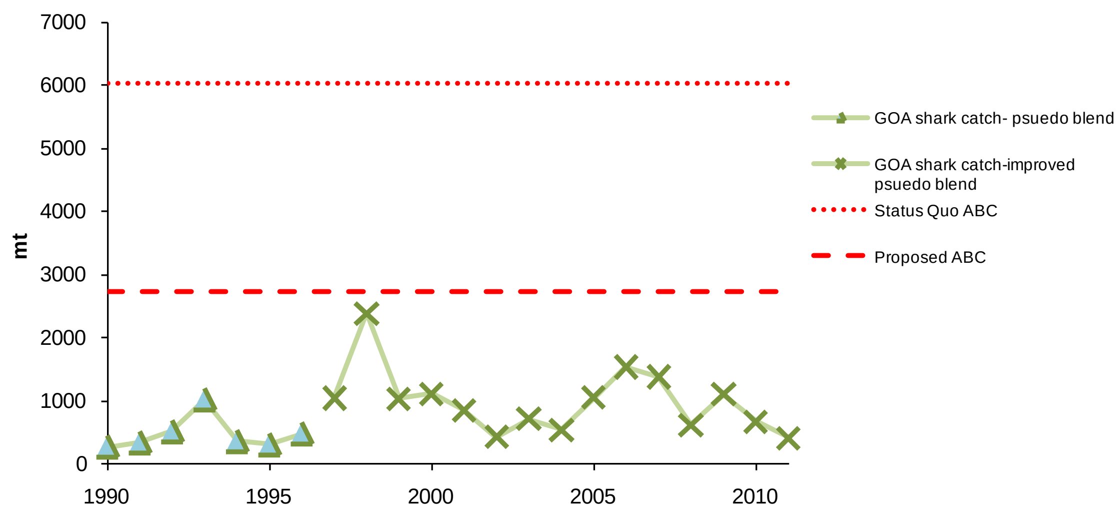

Figure 20.15 Top: comparison of total GOA shark catch relative to total Other Species catch and Other Species TAC. Bottom: total GOA shark catch per year plotted relative to 2010 ABC and OFL options for the GOA shark complex under Tier 6. Catch data updated as of October 10, 2010.

Appendix 20A.—Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska. The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System (CAS) estimates. For sharks, these estimates can be compared to the research removals reported in previous assessments (Tribuzio et al. 2010) (Table 20A.1). The shark research removals are substantial relative to the fishery catch. The IPHC longline survey is by far the most substantial source of non-commercial removals. In 2010, NMFS surveys accounted for only 7 t of catch. Recreational removals constitute the greatest source of removals in ADF&G areas. Total removals from activities other than directed fishery were near 408 tons in 2010. This is 6.6% of the 2011 recommended ABC of 6,197 and 14.9% of the recommended ABC for 2012 of 2,738 and represents a relatively low risk to the shark stock.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011).

These estimates are for total catch of groundfish species in the halibut IFQ fishery and do not distinguish between “retained” or “discarded” catch. These estimates should be considered a separate time series from the current CAS estimates of total catch. Because of potential overlaps, HFICE removals should not be added to the CAS produced catch estimates. The overlap will occur when groundfish are retained or discarded during an IFQ halibut trip. IFQ halibut landings that also include landed groundfish are recorded as retained in eLandings and a discard amount for all groundfish is estimated for such landings in CAS. Discard amounts for groundfish are not currently estimated for IFQ halibut landings that do not also include landed groundfish. For example, catch information for a trip that includes both landed IFQ halibut and sablefish would contain the total amount of sablefish landed (reported in eLandings) and an estimate of discard based on at-sea observer information. Further, because a groundfish species was landed during the trip, catch accounting would also estimate discard for all groundfish species based on available observer information and following methods described in Cahalan et al. (2010). The HFICE method estimates all groundfish caught during a halibut IFQ trip and thus is an estimate of groundfish caught whether landed or discarded. This prevents simply adding the CAS total with the HFICE estimate because it would be analogous to counting both retained and discarded groundfish species twice. Further, there are situations where the HFICE estimate includes groundfish caught in State waters and this would need to be considered with respect to ACLs (e.g. Chatham Strait sablefish fisheries). Therefore, the HFICE estimates should be considered preliminary estimates for what is caught in the IFQ halibut fishery. Improved estimates of groundfish catch in the halibut fishery may become available following restructuring of the Observer Program in 2013.

The HFICE estimates of shark catch by the halibut fishery are substantial and in 2010 represented approximately 31% of the 2010 shark ABC (Table 20A.2) and is 83% greater than the average total shark catch from 1997-2010 (1,036 t). It is unknown what level of shark catch reported here is already accounted for as IFQ harvest in the CAS system because the HFICE estimates do not separate retained and discarded catch. It is likely that even a small amount of retention of sharks is rare. The halibut IFQ fleet represents the vast majority of shark removals in the GOA, but these removals are not counted against TAC and do not currently run the risk of limiting other fisheries. However, because they are not included in current management, high catch rates and potential for overfishing may be overlooked. Catch of Pacific sleeper shark is of particular concern if these estimated catches are representative of true catch, but without observer data we are unable to validate these estimates. Because Pacific sleeper sharks are highly susceptible to overfishing due to their slow growth rate and late maturity, and data to manage the species is extremely limited, the impacts of these catch estimates warrant further investigation.

References:

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Tribuzio, CA, K Echave, C Rodgveller, J Heifetz, KJ Goldman. 2010. Assessment of the sharks in the Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 695-744.

Tribuzio, CA, S Gaichas, J Gasper, H Gilroy, T Kong, O Ormseth, J Cahalan, J DiCosimo, M Furuness, H Shen, K Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams of the North Pacific Fishery Management Council.

Table 20A.1. Research and other non-commercial catches of sharks between 1977 and 2010 in the Gulf of Alaska (GOA). The AFSC LL and IPHC LL survey catches are provided in numbers prior to 2010. The total catch numbers from the IPHC survey are estimated based on the subsample of observed hooks. Beginning in 2010 all research and other non-commercial catch is provided by the AKRO.

Year	**Source**	**GOA Trawl surveys (t)**	**GOA LL Survey (#s)**	**GOA LL Survey (t)**	**IPHC LL Survey (#s)**	**IPHC LL Survey (t)**	**ADF&G (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				
1990		3.52	583				
1991		0.15	2,039				
1992		0.12	3,881				
1993		5.03	2,557				
1994		0.43	2,323				
1995		0.57	3,882				
1996		3.48	2,206				
1997		0.52	2,822				
1998		0.58	7,701		42,361		
1999		NA	1,185		21,705		
2000		NA	1,212		29,257		
2001		0.45	1,726		34,227		
2002		NA	1,576		22,028		
2003		7.36	2,372		68,940		
2004		NA	1,964		48,850		
2005		7.13	3,775		44,082		
2006		0	6,593		41,355		
2007		14.06	3,552		34,023		
2008		0.73	3,606		24,655		
2009		4.03	4,709		29,299		
2010	AKRO	0.07	2,622	6.94		391	9.65

Table 20A.2. Estimates of shark catch (t) by GOA NMFS Regulatory Area from the Halibut Fishery Incidental Catch Estimation (HFICE) working group.

Area	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
610	2,063	1,038	1,664	2,226	1,445	580	1,133	38	22	15
620	3,341	2,146	1,924	2,888	3,216	1,864	1,978	195	364	66
630	1,423	423	1,281	571	508	859	2,063	517	592	772
640/649	1,100	780	1,071	756	2,434	1,891	1,578	357	271	367
650	1,063	777	1,902	966	1,781	1,802	1,656	992	808	501
659*	723	501	1,099	275	2,825	935	1,649	313	115	175
Total	9,712	5,664	8,941	7,682	12,208	7,931	10,057	2,413	2,173	1,896

*These areas include removals from the state of Alaska.

Table 20A.3. Estimates of shark catch (t) by species in the GOA from the Halibut Fishery Incidental Catch Estimation (HFICE) working group.

Shark Species	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Blue	0	4	0	7	9	0	0	1	0	0
Misc	3	46	0	0	128	1	0	0	0	0
Salmon	2	10	0	0	0	41	2	5	0	40
Sixgill	0	19	0	0	0	0	0	0	0	0
Pacific Sleeper	8,406	4,709	5,422	6,108	9,618	5,168	7,375	588	493	165
Soupfin	0	0	0	0	0	0	0	0	0	0
Spiny Dogfish	1,301	876	3,518	1,568	2,453	2,722	2,681	1,818	1,680	1,691
Total	9,712	5,664	8,941	7,682	12,208	7,931	10,057	2,413	2,173	1,896

(This page intentionally left blank)