A review of the Pacific sleeper shark *Somniosus pacificus*: biology and fishery interactions

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Abstract

The Pacific sleeper shark *Somniosus pacificus* is a large-bodied and broad-ranging squaliform shark that occupies diverse habitats throughout the Pacific Ocean. Despite its large size and occurrence as bycatch in various commercial fisheries, little is known about even the most basic aspects of its biology and ecology. Observed declines in certain parts of its range, coupled with life history characteristics associated with low productivity, have led to conservation concerns for this cryptic but charismatic species. Here, we provide a comprehensive review of the current state of knowledge regarding the distribution, diet, life history, and other aspects of the Pacific sleeper shark and present updated fisheries and survey data for the eastern North Pacific Ocean. The most pressing research gaps identified during the course of this review concern habitat use at different life stages and basic life history information. While work is currently in progress to expand our base of knowledge for this species, we recommend a precautionary approach to management until sufficient information becomes available to ensure its conservation.

Keywords

elasmobranch, bycatch, North Pacific Ocean, ecology, life history, deep-sea

Statements and Declarations

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Introduction

The Pacific sleeper shark *Somniosus pacificus* ranges broadly throughout the Pacific Ocean, yet it has been poorly studied. Deficiencies in our understanding are due in part to its lack of commercial value, its occupancy in habitats that are difficult to sample with traditional survey methods, and logistical challenges associated with safely landing, handling, and sampling such a large-bodied animal. The lack of data makes it challenging to adequately monitor and assess the stock status of this species. In general, the life history traits of elasmobranchs (e.g., slow growth, late maturity, high longevity) make them susceptible to overfishing (Musick et al. 2000; Simpfendorfer and Kyne 2009), and there is reason to believe that the Pacific sleeper shark may be especially vulnerable (Ormseth and Spencer 2011).

The first objective of this review was to collate the limited information that is known about the Pacific sleeper shark from the available published literature. The second objective was to identify and prioritize the most pressing knowledge gaps. The final objective was to outline potential directions of future research and describe the implications of that research for ultimately improving management of the species. This is particularly important as the International Union for Conservation of Nature and Natural Resources (IUCN) recently changed its Red List designation of the Pacific sleeper shark from Data Deficient to Near Threatened due to this species' high vulnerability and apparent population declines in portions of its range (Rigby et al. 2021). Furthermore, a recent review of the stock structure of the Pacific sleeper shark in Alaska waters highlighted potential conservation concerns, and the North Pacific Fishery Management Council's Scientific and Statistical Committee (SSC) acknowledged these concerns in recent stock assessment reviews for Alaska management areas (Matta et al. 2022; SSC 2022).

Here, we summarize the existing body of literature on the Pacific sleeper shark. We also present new information from the waters of Alaska, British Columbia, and the US West Coast on survey and fishery distribution, catch, and size. Whenever possible, we describe publications and data that are specific to the Pacific sleeper shark. However, for some topics where studies are limited, we refer to publications on its congener, the Greenland shark *Somniosus microcephalus*, to make inferences regarding the biology of the Pacific sleeper shark. Compared to the Pacific sleeper shark, more information is available for the Greenland shark, with an explosion in focused research studies in recent years. Literature was gathered from the Clarivate Web of Science (www.webofscience.com) using the search terms “sleeper shark”, “Greenland shark”, “*Somniosus*”, and “Somniosidae”, as well as from the citation sections of papers already in hand. We conclude with suggestions for new research on the Pacific sleeper shark to better understand how to more appropriately assess and manage this species.

Taxonomy and Population Dynamics

Species description and systematics

The Pacific sleeper shark (Fig. 1), first described by Bigelow and Schroeder (1944), is a member of the Order Squaliformes, a diverse taxonomic grouping that includes bramble (Echinorhinidae), lantern (Etmopteridae), rough (Oxynotidae), kitefin (Dalatiidae), gulper (Centrophoridae), sleeper (Somniosidae), and dogfish sharks (Squalidae). Sharks in Squaliformes are characterized as having two dorsal fins (with or without fin spines), spiracles, no anal fin or nictitating membrane, and five pairs of gill slits (Compagno 1984). The Pacific sleeper shark is a large-bodied shark with gray to brown or black dorsal coloration and slightly lighter coloration ventrally (Fig. 1a; Ebert 2003; Stevenson et al. 2007). This species, frequently described using adjectives such as “flabby” and “sluggish” in the literature, possesses small eyes, mouth, and teeth relative to its size (Fig. 1b), and a broad heterocercal tail (Ebert 2003).

Pacific sleeper sharks are members of the genus *Somniosus* (Family Somniosidae), found throughout the world from shallow polar waters to abyssal depths at temperate and tropical latitudes (Compagno 1984; Ebert 2003). Systematic classifications within this genus have varied over time, largely due to the rarity of encounters in many regions and similarities in appearance among *Somniosus* species. Studies on meristic and morphological characteristics have suggested that *Somniosus* comprises five species in two subgenera: subgenus *Somniosus* containing three large-bodied species (Greenland shark *S. microcephalus,* Pacific sleeper shark *S. pacificus*, and southern sleeper shark *Somniosus antarcticus*), and subgenus *Rhinoscymnus* containing two small-bodied species (frog shark *Somniosus longus* and little sleeper shark *Somniosus rostratus*) (Yano et al. 2004). Recently, a small-bodied shark collected from waters off Taiwan was proposed as a new species (the Taiwan sleeper shark, *Somniosus* (*Rhinoscymnus*) *cheni* sp. nov.)

(Hsu et al. 2020). Besides adult size, the two subgenera also differ in the level of calcification of their vertebral column, spiral valve and vertebral counts, tooth shape and the number of tooth rows, and dermal denticle shape (Yano et al. 2004).

Yano et al. (2004) proposed that morphological features including dorsal fin height and position, the number of spiral valves and vertebrae, and the distance from the tip of the snout to the first gill slit, could generally be used to distinguish among the three putative large-bodied *Somniosus* (*Somniosus*) species. Based on these findings, Yano et al. (2004) concluded that each of the species is largely confined to specific geographical regions, with *S. microcephalus* occupying the North Atlantic and Arctic oceans, *S. pacificus* occupying the North Pacific and Arctic oceans, and *S. antarcticus* occupying the Southern Hemisphere, despite some degree of overlap in the morphological characteristics measured. Additionally, ongoing, directed research suggests that the morphometric relationships identified in *S. pacificus* by Yano et al. (2004) are inconsistent with data collected *in situ* during optimal field conditions, further clouding the purported physical distinctions among the three species (Fuller et al. in prep.).

Genetic analyses have called into question the morphologically and geographically based classifications of species within the *Somniosus* subgenus. Comparison of nuclear and mitochondrial DNA markers has provided strong support for considering *S. microcephalus* and *S. pacificus* as distinct but closely-related sister species (Murray et al. 2008; Santaquiteria et al. 2017; Walter et al. 2017). However, there is genetic evidence to support possible hybridization between *S. pacificus* and *S. microcephalus* in the Canadian Arctic where their ranges may overlap (Hussey et al. 2015; Walter et al. 2017). A specimen collected from the Mid-Atlantic Ridge, near the Azores, had a genetic signature concordant with *S. pacificus*, and a *S. microcephalus*-*S. pacificus* hybrid was detected in the Gulf of Mexico (Walter et al. 2017), further complicating the simple distinction of species along geographical boundaries. Most strikingly, multiple investigators have concluded that there isn’t sufficient genetic variation in mitochondrial or nuclear DNA to distinguish between *S. pacificus* and *S. antarcticus*, suggesting that despite the morphometric differences noted by Yano et al. (2004), they comprise a single species ranging throughout the Pacific Ocean, warranting revision of the taxon (Murray et al. 2008; Christensen 2022; Timm et al. 2022). There is also currently little evidence to support the existence of subpopulations of *S. pacificus*. Using population genomics, Timm et al. (2022) noted a high degree of similarity among individuals, suggesting persistent gene flow and a lack of significant population genetic stock structure in either *S. pacificus* or *S. microcephalus*. However, Swintek and Walter (2021) found subtle, but significant, population genetic structure based on a suite of microsatellites for *S. microcephalus*. Such analyses may reveal similar distinctions that are slight within *S. pacificus,* and it is worthy of further investigation.

Distribution and abundance

The Pacific sleeper shark is broadly distributed over the continental shelves and slopes of the Pacific Ocean. Its range in the North Pacific Ocean extends from Palau to Taiwan, Korea, Japan, and Siberia, throughout the Bering Sea and Gulf of Alaska, and along the west coast of Canada and the USA to Baja California, Mexico (Tanaka et al. 1982; Applegate et al. 1993; Orlov and Moiseev 1999; Ebert 2003; Wang and Yang 2004; Grigorov and Orlov 2014; Kang et al. 2015; Becerril-Garcia et al. 2020; Tribuzio et al. 2022; Claassens et al. 2023). Its distribution north of the Arctic Circle (66º30' N) is uncertain, and due to a possible overlap in ranges between the two regional species, it may be confused with the Greenland shark in the Canadian Arctic (Ebert 2003). One positively identified specimen washed up on the shore at Point Hope, Alaska, on the Chukchi Sea (Benz et al. 2004), although it is possible that this individual drifted northward from the Bering Sea (Love et al. 2005). The Pacific sleeper shark has also been reported in the Salish Sea, the inland waters of Washington State, USA, and British Columbia, Canada, though it is thought to be very rare in this area (Pietsch and Orr 2015).

In the Southern Hemisphere, Pacific sleeper sharks have been reported in both the Pacific and Atlantic oceans (e.g., Francis et al. 1988; Crovetto et al. 1992; Cione 1998; de Astarloa et al. 1999; Brito 2004). Based on the species descriptions of Yano et al. (2004), these observations had previously been considered likely misidentifications of *S. antarcticus* (Love et al. 2005; Ebert et al. 2017). However, recent next-generation sequencing has provided a lack of support for *S. antarcticus* as a separate species and suggests that identifications of *S. pacificus* in the South Pacific Ocean are legitimate (Christensen 2022; Timm et al. 2022). Broader genetic sampling is needed to confirm whether the range of *S. pacificus* extends outside the Pacific Ocean into regions such as the South Atlantic and Indian oceans (Timm et al. 2022). At tropical low latitudes, Pacific sleeper sharks have been recorded by submersibles, drop cameras, and remotely operated vehicles in deep (1,000-2,000 m) waters off Hawaii, Palau, the Solomon Islands, and Revillagigedo Archipelago National Park, Mexico (Lee 2015; Becerril-Garcia et al.

2020; Claassens et al. 2023; see also observations from the Hawai'i Undersea Research Laboratory: https://www.soest.hawaii.edu/HURL/).

Fisheries-independent surveys differ in their presumed efficacy at catching Pacific sleeper sharks, and therefore it is difficult to accurately estimate population abundance for this species. Catchability is composed of availability (i.e., sharks occur in the same area and depth as the gear) and susceptibility to the gear. Based on available data, it is not possible to evaluate if low levels of catch in fishery-independent surveys, which operate differently from commercial fisheries, are due to Pacific sleeper sharks not being present in the survey area or differences in susceptibility to survey trawl or longline gears. (In this paper, the word “longline” refers to fishing gear that uses extended groundlines with hooks stretched across the seafloor, whereas three-dimensional pots, either fished singularly or strung together on a line, are referred to as “pots”.) Further complicating matters is the fact that mature individuals are rarely encountered, either due to occupation of unsurveyed habitats (i.e, not available to the gear) or to susceptibility to the gear (i.e., selectivity). Therefore, a potentially large portion of the population is currently unobserved. Indices of abundance based on trawl survey catches in Alaska waters are generally not considered reliable because they are frequently extrapolated from a relatively small number of hauls with catch (Tribuzio et al. 2022). In some years, particularly in the Bering Sea and Aleutian Islands regions, no specimens are captured during the trawl surveys, despite occurring in trawl fisheries (Tribuzio et al. 2022). Fishery-independent longline surveys, such as those operated by the International Pacific Halibut Commission (IPHC) and the Alaska Department of Fish and Game (ADFG), may therefore be better indicators of stock trends (Matta et al. 2022).

Despite the limitations associated with certain gear types, the available survey indices from the waters off Alaska, British Columbia, and the US West Coast appear to indicate long-term variation in the abundance of Pacific sleeper sharks (Fig. 2; Tribuzio et al. 2022). While it is important to note that none of the existing surveys were designed to explicitly target Pacific sleeper sharks, it may be possible to infer trends in relative abundance over time. Consistently across almost all areas and surveys, including the IPHC longline survey, which is considered to be the most reliable survey index (Matta et al. 2022), catches were highest in the late 1990s and early 2000s, and have since declined to lower levels (Fig. 2). These trends are reflected in fisheries catches as well (Tribuzio et al. 2022). Mueter and Norcross (2002) noted a significant increase in Pacific sleeper sharks between 1984 and 1996 in the waters off Chirikof and Kodiak

Islands, and similarly, a small survey of fishers in Aleut communities provides anecdotal evidence for an increase in this and other shark species in the Bering Sea, eastern Aleutian Islands, and western Gulf of Alaska in the late 1990s and early 2000s (Okey et al. 2007). Subsequent surveys have indicated large reductions in abundance since the mid- to late 2000s to current low levels (Fig. 2). A reduction in the spatial extent of fisheries catches and IPHC survey catches has also been noted in Alaska waters, with fewer sharks observed in the Gulf of Alaska and around the Aleutian Islands in recent years than in the late 1990s to mid-2000s (Matta et al. 2022). Similarly, the population off Taiwan, which was once large enough to support a fishery, has since declined (Rigby et al. 2021). However, trawl surveys indicate that Pacific sleeper shark abundance in Russian waters appears to have increased over the past 40 years (Rigby et al. 2021). Even though many survey indices represent imperfect estimates of abundance of Pacific sleeper sharks due to issues with catchability and the short length of these time series relative to the potential generation time, they can still identify trends in local stock abundance that may inform stock status and conservation assessments. Technological advances, such as eDNA assays, may help to improve estimates of relative abundance of Pacific sleeper sharks in the future, particularly in environments that cannot be sampled using conventional means (Thomsen et al. 2016).

Some older and anecdotal accounts of Pacific sleeper sharks have described them as “common” (e.g., Compagno 1984). This may be due to occasions where multiple, and in some cases, large numbers of sharks are caught in a set, such as reported both contemporarily and historically by fishers operating in certain areas of Southeast Alaska and Prince William Sound (K. R. Fuller, G. C. Dunne, and C. A. Tribuzio, personal communication). Scientific surveys have also occasionally encountered localized large numbers of Pacific sleeper sharks with relatively little fishing effort. For example, two recent charters targeting Pacific sleeper sharks for a research study succeeded in catching 63 sharks in under seven days at inshore locations in Southeast Alaska (K. R. Fuller and C. A. Tribuzio, unpublished data). Another instance occurred in 2002, when the Resource Assessment and Conservation Engineering (National Oceanic and Atmospheric Administration, NOAA) eastern Bering Sea bottom trawl survey of the continental slope caught over 5,000 kg of immature Pacific sleeper sharks in a single tow (Hoff and Britt 2003). The temporal persistence of areas of high catch has been somewhat difficult to ascertain, due to the lower effectiveness of trawl gear as a surveying tool for this species relative to longline gear, changes in fishery dynamics (e.g., vessels switching from longline to pot gear, which likely have different catchabilities), and because reporting requirements vary among fisheries sectors and between state and federal waters. However, there is some indication that Shelikof Trough, an extensive glacier-carved depression off Kodiak Island in the western Gulf of Alaska, could represent a persistent "hotspot" of Pacific sleeper sharks. High catches of Pacific sleeper sharks have been consistently reported here in IPHC surveys and NOAA longline surveys for sablefish *Anoplopoma fimbria* (Courtney and Sigler 2007; Matta et al. 2022) as well as in commercial fisheries (Fig. 3). Within the eastern Bering Sea, catches are high in some areas; however, this is more likely a function of fishing effort in the highly valuable walleye pollock *Gadus chalcogrammus* fishery, with catch spread across the eastern Bering Sea shelf and highest catches generally just north of Unimak Pass. In the western North Pacific Ocean, regular areas of high Pacific sleeper shark abundance have been reported off Sakhalin Island, south of the Kamchatka Peninsula, and between Cape Navarin and Karagin Island (Orlov and Baitalyuk 2014; Dyldin and Orlov 2018). Due to the spatiotemporally patchy nature of Pacific sleeper shark catch, and given that this species is a large, slow-growing, and long-lived, high trophic level predator, it is possible that any appearance of high abundance may be due to situations that may cause sharks to aggregate, such as high concentrations of prey or habitats that support biologically important functions, such as nursery areas.

Biology and Ecology

Size, age, and growth

Data on body size and age are highly important to understanding demographic rates and assessing health of fish populations. Unfortunately, infrequent encounter rates, handling difficulty, and low commercial value of Pacific sleeper sharks have limited the availability of age and growth data to support stock assessments. Biological data collection in the eastern North Pacific Ocean has mostly been opportunistic across a variety of platforms, including scientific surveys and commercial fishing operations. Due to their size, accurate length and weight measurements of Pacific sleeper sharks, especially of larger individuals, are difficult to obtain. Weight data in particular are scarce, as Pacific sleeper sharks caught as bycatch frequently are not landed in commercial longline fisheries or are too large for at-sea observers to weigh, in which case a reference table is used to estimate weight from length. The best available data collected to date are presented here.

Shark body length can be measured in several different ways (FAO 2016), and the length method presented for a given species isn't always uniform among studies. We are only aware of a single study in which precaudal length (PCL), fork length (FL) and total length (TL, measured with the upper caudal fin lobe in a natural position) were all measured from the same individual Pacific sleeper sharks (Hulbert et al. 2006), although the data were not published in their resulting manuscript. Hulbert et al. (2006) have kindly shared their unpublished length data with us, permitting us to produce equations to allow conversions among length measurement types reported in published literature (Fig. 4). Unless otherwise noted, lengths hereafter in this review are presented as units of TL.

Large Pacific sleeper sharks are rare in the catch records, and much of the length data available come from animals less than 220 cm TL (Fig. 5a). Due to the difficulty associated with obtaining reliable measurements of large individuals, there is some debate on the accuracy of maximum body size for Pacific sleeper shark. The largest confirmed Pacific sleeper shark landed to date was a 465 cm TL female caught in October 2021 in the eastern Aleutian Islands that was measured by a trained fisheries observer. The largest reliably measured Greenland shark was 510 cm TL (Campana et al. 2015, as cited in Nielsen 2017), with most individuals caught ranging between 288 and 504 cm in length (MacNeil et al. 2012). Sleeper sharks estimated as exceeding 700 cm in length have been photographed in very deep water, and though these length records are far less precise and difficult to confirm with certainty, they do appear to be significantly larger than sharks encountered during normal fishing or survey operations (Isaacs and Schwartzlose 1975; Compagno 1984; Clark et al. 1990; Stevenson et al. 2007). An individual observed during a submersible dive in Suruga Bay, Japan, at a depth of about 1,200 m was photographed next to an object of known size, and it was estimated to exceed 23 feet (700 cm) in length (Clark et al. 1990). We compared the photograph of this shark to measurements made from photographs of sharks caught during surveys and deemed their estimate reliable (our own estimates of length for the Suruga Bay individual ranged from 21.7 to 23.5 feet, or 660-720 cm TL).

Some authors have suggested that female sleeper sharks grow larger than males. Sexual dimorphism in size has been noted in Greenland sharks (MacNeil et al. 2012; Nielsen 2017) and Pacific sleeper sharks (Yano et al. 2007; Orlov and Baitalyuk 2014). Examination of data pooled coast-wide from Alaska to Baja California indicates no significant difference between overall length distributions of male and female Pacific sleeper sharks in the eastern North Pacific Ocean (Fig. 5a; two-sample Kolmogorov-Smirnov test: $D = 0.069$, $p = 0.0504$, $n = 1{,}562$). However, as noted earlier, large individuals are seldom encountered, and it is unknown whether female Pacific sleeper sharks are capable of attaining larger maximum sizes than males in unobserved parts of the ocean.

Size distributions of Pacific sleeper sharks appear to differ regionally. Along the west coast of North America, sharks are on average smallest in the Bering Sea (mean = 150 cm TL) and along the US West Coast (mean = 143 cm TL) (Fig. 6). Average size is greatest in the Gulf of Alaska (mean = 210 cm TL), but a small number of relatively large (> 350 cm TL) individuals have also been caught off British Columbia and the US West Coast (Fig. 6). However, the largest individuals have been reported, both empirically and anecdotally, from the Aleutian Islands (Fig. 6), despite the number of small individuals also present and limited number of observations where size was recorded (Tribuzio et al. 2022). Biological inferences are difficult to make due to the mostly opportunistic nature of Pacific sleeper shark length data collections, and it is possible that regional differences in fishing gear can at least partially explain these patterns. For example, targeted surveys in the Southeast Alaska region found no individuals under 260 cm TL; one proposed reason for this is the size of the hooks of the commercial Pacific halibut *Hippoglossus stenolepis* gear that was used (K. R. Fuller and C. A. Tribuzio, unpublished data). However, regional differences in size distributions have also been reported in the western North Pacific Ocean, with Pacific sleeper sharks in the western Bering Sea generally being larger than those caught off the Kuril Islands and Kamchatka Peninsula (Orlov and Moiseev 1999). Some regional variation in size may be expected given the differences among the ecosystems of the eastern and western North Pacific Ocean (Aydin et al. 2002, 2007). Spatial variation in size distribution has similarly been observed in Greenland sharks, indicating potential shifts in habitat usage among sharks at different life stages or by sex (Edwards et al. 2019). Indeed, segregation by sex and size has been observed in many shark species (Bres 1993); the extent to which Pacific sleeper sharks exhibit similar behavior is worthy of further investigation.

Length and weight data have been opportunistically collected in Alaska waters since the 1980s by fisheries observers aboard commercial vessels and during scientific survey operations (n = 674). These fish were landed and measured to generate a dataset from which accurate length-weight parameters could be estimated, presented here for comparison with relationships previously published for this species. Sex was determined in most cases, but for some individuals, sex was not recorded (n = 77). There were also two obvious transcription errors in the dataset (a 40-cm shark weighing 27 kg and a 93-cm shark weighing 62 kg) that were omitted from further analysis. Based on these data, there was no detectable difference between males and females in the length-weight relationship (Fig. 7a). This contrasts with Orlov and Baitalyuk (2014), who found large differences in the length-weight parameters between the sexes, though their estimates were based on relatively few individuals. Our length-weight relationship for both sexes combined is fairly similar to those previously published for Pacific sleeper sharks (Fig. 7b). The *b* parameter (exponent) in the exponential length-weight relationship is 3.043, indicating slightly positive allometric growth.

The ages of elasmobranchs are most commonly estimated from counts of growth band pairs visible in hard structures including vertebrae, spines, and caudal thorns (Natanson et al. 2019). Multiple researchers have attempted to use these structures to determine the age of Pacific sleeper sharks with no success (Wischniowski 2009; Matta et al. 2017). This is due in part to poor calcification of their hard structures, a phenomenon that has been noted in a variety of other deepwater sharks (Cailliet 1990, 2015). Despite testing various preparation methods, no discernable banding patterns have been detected, and Pacific sleeper sharks do not possess alternate structures such as spines or thorns. Moreover, the presumed annual periodicity of banding patterns visible in the vertebrae of other elasmobranch species has increasingly been called into question. There is evidence that these patterns may form due to increases in size (somatic growth) rather than as a function of time, or that they may be annual in juvenile stages but cease forming following maturity or upon approaching maximum size (Passerotti et al. 2014; Natanson et al. 2018; James 2020). Thus, even if banding patterns could be detected in the skeletal structures of Pacific sleeper sharks, there would be no assurance that band-pair counts would represent age. Lastly, even if age determination was possible for the Pacific sleeper shark, low encounter rates and difficulty in handling large sharks preclude the ability to generate traditional estimates of catch-at-age that could be used in stock assessments.

These limitations necessitate alternative methods of age determination to estimate growth rates and longevity of the Pacific sleeper shark. Such metrics are highly desirable as they can be used in conjunction with reproductive information to indirectly estimate natural mortality and intrinsic rates of population increase (Denney et al. 2002; Hamel and Cope 2022). These parameters are often the foundation in emerging methods to assess and protect marine resources for which data are limited or unavailable (e.g., Carruthers et al. 2014).

Age determination results based on alternative methods suggest slow growth and high longevity of Greenland sharks. A recent study analyzed bomb-produced and naturally occurring radiocarbon (^{14}C) in Greenland shark eye lenses to estimate age (Nielsen et al. 2016). Vertebrate eye lenses are composed of fiber cells that are continually deposited in concentric layers around a core area that is formed during pre-natal development and conserved throughout the life of the animal (Quaeck-Davies et al. 2018). Bomb-produced radiocarbon can act as a time-specific marker in hard or conserved tissues of marine organisms, allowing for accurate dating of individuals alive during the 1950s and 1960s, a period of intensive atmospheric testing of thermonuclear bombs (Kalish 1993). Based on radiocarbon analysis of eye lens cores, the Greenland shark study proposed an age at maturity of 156 years and a longevity of 392 years by restricting age probabilities with measures of fish length (Nielsen et al. 2016). Some authors have raised doubts regarding the accuracy of these ages, and suggest that while the Greenland shark could certainly be capable of a centenarian life span, the maximum age may be overestimated due to the assumptions made regarding age-at-length coupled with the interpretation of pre-bomb radiocarbon values (Alex 2016; Natanson et al. 2019). This observation is supported by recent adjustments to some of the assumptions and additional ^{14}C measurements that have led to a revised lifespan of ~262 years (Olsen et al. 2022). However, others suggest that metabolic theory and our limited knowledge of Greenland shark life history characteristics indicate the estimated life span of 392 years may be too low (Augustine et al. 2017). In support of this observation, an early tag-recapture study reported extremely slow growth, where an individual at liberty for 16 years grew only 8 cm (262 to 270 cm TL; Hansen 1963), and based on its length, the individual would have been immature.

In contrast to the recent findings for Greenland shark, a pilot study of radiocarbon in the cores of both eye lenses of a 3.1 m Pacific sleeper shark indicated that the growth rate, while still very slow compared to most fishes, is approximately two times faster than estimated for

Greenland sharks (Fig. 8). The limits placed on age-at-length by alignment of the measured values to the bomb-produced radiocarbon rise period (late 1950s to early 1960s) — similar in manner to the minimum age set for a small Greenland shark individual (Nielsen et al. 2016) — led to an age of no more than ~50 years, as opposed to an estimated 105 years based on the Greenland shark growth curve (Fig. 8). These radiocarbon values (Δ^{14}C = 9.4 and –51.1‰) are considered diagnostic because it is very unlikely that measured radiocarbon levels of this magnitude were present in the marine environment prior to these estimated formation years of ~1962-1965. In addition, it is likely that the lowest value (Δ^{14}C =–51.1‰) was not much earlier than the early to mid-1960s, indicating the age of this individual was not much less than 50 years, unless the signal is significantly phase-lagged, as is the case for porbeagle shark *Lamna nasus* (Campana et al. 2002). It should be noted when the pilot study was initiated, eye lens core extraction methods were still being developed, which may explain the difference in Δ^{14}C values and consequently the three-year difference in the estimated birth year for the same fish. A small amount of material left on one of the cores could have increased its value (the rise period for bomb-produced radiocarbon shows a rapid increase within just a few years following the bomb testing period). Since the pilot study, core extraction methodology has been refined and a full investigation into the plausible age range and growth of Pacific sleeper sharks using radiocarbon analysis of eye lenses is underway (C. A. Tribuzio, personal communication).

Reproduction

Little is known about reproduction in Pacific sleeper sharks due to infrequent observations of large sharks and difficulty in assessing reproductive status of large animals. Most of what is currently understood is based on the Greenland shark, for which the number of observations is somewhat greater, allowing directed assessments of maturity (Nielsen et al. 2020). Adult Pacific sleeper sharks are rarely encountered in fisheries or during scientific surveys, and to date, no pregnant female has ever been retained. The only reported case of a pregnant female being landed occurred on a trawl vessel operating in waters off British Columbia in the mid-1990s. An at-sea observer reported that between 8 and 12 live pups were actively birthed by the female before she was released back into the water (C. Dykstra, IPHC, personal communication). Unfortunately, no scientific data or photographs of this event were recorded, and it is unknown whether the number of pups observed represented the full litter.

Sleeper sharks employ lecithotrophic viviparity (sometimes referred to as “ovoviviparity” or “aplacental viviparity”), wherein embryos are nourished primarily by yolk and females give birth to live young (Ebert et al. 2017; Carter and Soma 2020). Histotrophy (in which embryos are fed by maternal uterine secretions) is believed to be minimal (Carter and Soma 2020). The fecundity and gestation period of the Pacific sleeper shark are uncertain, with most inferences drawn from related species. Litter sizes of the few observed pregnant females of any *Somniosus* species have been somewhat variable but generally small. To date, a single pregnant 5-m female Greenland shark has been observed that had 10 near-term embryos of similar size in its right uterus (Koefoed 1957). A 134 cm TL pregnant female of the putative new species of small-bodied sleeper shark off Taiwan, *Somniosus* (*Rhinoscymnus*) *cheni* sp. nov., contained 33 mid-term embryos with a mean size of 14 cm TL (Hsu et al. 2020). There are several reports of pregnant individuals of the little sleeper shark from the Mediterranean Sea, in which litters have varied from 5 to 17 embryos per female (multiple sources in Capapé et al. 2020). Size at birth of Pacific sleeper sharks is thought to be near 40 cm (Francis et al. 1988; Yano et al. 2007), though there have been reports of larger free-swimming individuals bearing umbilical scars (Ebert et al. 1987). Mature female Greenland and Pacific sleeper sharks have been observed with high numbers of yolked ovarian eggs (Gotshall and Jow 1965; Ebert et al. 1987; Nielsen et al. 2020), leading some to speculate that litter sizes may be quite large (>200 pups). However, this seems improbable due to the relatively large size at birth, oxygen limitations within the uterus during gestation, and small litter sizes observed in other members of Somniosidae (Carter and Soma 2020). It may be more likely that the majority of these ovarian eggs constitute a reserve, or that these eggs are resorbed by the mother (Augustine et al. 2022).

Estimates of the size at maturity of Pacific sleeper sharks are based on relatively few observations. While male maturity state can be inferred from external examination of the claspers, maturity state of females must be verified by internal examination of the reproductive organs, which presents logistical challenges associated with dissecting large animals at sea. Because verified mature or maturing individual Pacific sleeper sharks have not been captured in sufficient numbers, the estimate of the size of maturity should be considered more of a general approximation than a precise figure. Based on the smallest recorded mature female Pacific sleeper shark (Gotshall and Jow 1965) and examination of 15 additional individuals captured off California, Ebert et al. (1987) estimated that females mature at around 370 cm TL. However, larger individuals that were believed to be immature have been observed (Bakes and Nichols 1995; Tribuzio et al. 2022), including a 428 cm TL female captured during a bottom trawl survey in the Aleutian Islands in 2022 (J. R. Hoff, AFSC, personal communication). Maturity stage was not recorded for the largest landed Pacific sleeper shark (465 cm TL) mentioned in the previous section. Adult Greenland sharks have been more frequently encountered, and therefore, estimates of length at maturity in that species are more refined. Based on the available data, there appears to be sexual dimorphism in size at maturity of Greenland sharks, with males and females attaining 50% maturity at 284 and 419 cm TL, respectively (Nielsen et al. 2020). As there is a paucity of observations of mature Pacific sleeper sharks, more work is needed to determine whether maturity in that species is similarly disparate among males and females.

The majority of Pacific sleeper sharks caught in the eastern Bering Sea and eastern North Pacific Ocean are likely immature (Fig. 6), suggesting that adults primarily inhabit waters not well-sampled by commercial fisheries or scientific surveys. Similarly, catches in Russian waters are predominantly immature fish (Orlov 1999; Orlov and Baitalyuk 2014). Adult males seem to be particularly rare (Ebert 2003); however, one of the authors of this review observed what appeared to be a mature male from visual external examination of the claspers (Fig. 9) during a fishery-independent longline survey in the Gulf of Alaska in 2019 (C. A. Tribuzio, unpublished data). As has been observed in many other elasmobranch species, habitat use may vary by sex and reproductive stage (Bres 1993). This appears to be the case for the Greenland shark, with adult females occupying different waters than juveniles (Edwards et al. 2019). Of Pacific sleeper sharks caught from Alaska to California, sex ratios are nearly even in the Bering Sea and are approximately 58% female in the Gulf of Alaska (Fig. 5b). While the other regions have relatively few observations, it is interesting to note that females have been caught nearly 2.6 times more often than males off British Columbia (Fig. 5b). Additional measurements may help ascertain the degree to which the sex ratio varies across their range in the eastern North Pacific Ocean.

Nothing is known of the mating or pupping habits of Pacific sleeper sharks, or whether these aspects are seasonal in nature. Bjerken (1957) speculated that the reason so few pregnant Greenland sharks have been detected is that they may move to deep waters during the gestation period. An alternative hypothesis is that they may migrate through the deep scattering layer of the open ocean, a region of the water column associated with a high abundance of marine organisms (Campana et al. 2015). Female Greenland sharks that appeared to be gravid have also been observed in relatively shallow waters of the St. Lawrence Estuary (Harvey-Clark et al. 2005; Gallant et al. 2016). Based on capture locations of pregnant females in the Mediterranean Sea, Capapé et al. (2020) theorized that the little sleeper shark uses shallow coastal areas as nursery grounds. Nursery habitat utilization has also been posited as an explanation for observed large aggregations of juvenile Pacific sleeper sharks in Alaska waters. For example, there are reports of large catches of small Pacific sleeper sharks in Prince William Sound around the late 1990s, suggesting that this area could represent a nursery area, though due to a lack of formal reporting requirements, these catches are largely anecdotal (G. C. Dunne, personal communication). Numerous anecdotal reports exist from local fishers (usually longlining) of capturing many, even hundreds, of small Pacific sleeper sharks of similar size in glacial fjords in Alaska (C. A. Tribuzio, personal communication), suggesting that they may function as important habitats during the juvenile life stage. Another possible nursery area has been identified in the southeastern Bering Sea near Unalaska Island, due the detection of a sibling pair of small (96 cm and 111 cm) sharks 10 days apart and repeated captures of other immature sharks in the vicinity (Matta et al. 2022; Timm et al. 2022). Repeated captures of juvenile Greenland sharks have also been observed at specific sites in the eastern Canadian Arctic, with smaller animals generally having longer residency times, suggesting that these areas may serve as nursery or juvenile habitats (Hussey et al. 2015; Edwards et al. 2022a). The largest aggregation of Pacific sleeper sharks on record occurred during a trawl survey along the upper continental slope of the eastern Bering Sea (Hoff and Britt 2003). During the 2002 survey, 119 individuals were caught in a single tow at a depth of approximately 700 m at the northern end of Zhemchug Canyon, a massive underwater canyon located about 300 km northwest of the Pribilof Islands. These fish were all immature and ranged in length from 104 to 237 cm. Due to the fact that all of the sharks captured were immature, there was some speculation that Zhemchug Canyon could represent an important nursery or juvenile habitat for Pacific sleeper sharks. However, even despite resampling in the same area in the years since, the 2002 occasion remains the only time when more than a few individuals were caught at that location. Further work, such as tagging studies, could help determine whether Pacific sleeper sharks utilize certain habitats with fidelity.

Trophic ecology

The Pacific sleeper shark fulfills an ecologically important role as a top predator, occupying a relatively high trophic position (Courtney and Foy 2012; Bizzarro et al. 2017). The species was long characterized primarily as a benthic-oriented scavenger, and indeed, its keen sense of smell (Yopak et al. 2019) likely allows it to detect food oases such as whale falls in the deep ocean (Smith et al. 2002; Smith and Baco 2003). However, diet analysis and tagging studies have indicated that Pacific sleeper sharks are opportunistic and, in addition to scavenging, are capable of consuming live prey, such as salmon or other pelagic species, throughout the water column (Orlov and Moiseev 1999; Hulbert et al. 2006; Sigler et al. 2006). Sleeper sharks are very slow-swimming compared to other fishes and are not believed to be capable of fast bursts of speed (Watanabe et al. 2012; Shadwick et al. 2018; Fujiwara et al. 2021). Instead, it is believed that sleeper sharks hunt using stealth, taking advantage of their slow movements and cryptic coloration to ambush fast-swimming fish and sleeping seals (Ebert et al. 1987; Watanabe et al. 2012; Lydersen et al. 2016). The Pacific sleeper shark has teeth that differ in shape between the upper and lower jaws, with the upper teeth being longer and lance-like and the lower teeth having short oblique cusps and high narrow roots (Compagno 1984; Yano et al. 2004; Stevenson et al. 2007). This specialization of upper teeth for grabbing and lower teeth for tearing, along with the ability to suction feed (Bizzarro et al. 2017; Grant et al. 2018), may afford Pacific sleeper sharks greater flexibility in the types of prey they can consume.

The Pacific sleeper shark has a varied diet, consuming teleost fishes, cephalopods, pinnipeds, cetaceans, crustaceans, and offal (Gotshall and Jow 1965; Ebert et al. 1987; Orlov and Moiseev 1999; Yang and Page 1999; Schaufler et al. 2005; Sigler et al. 2006; Yano et al. 2007). Most direct studies on the diet of Pacific sleeper sharks are based on only a few individuals. Comparison across the patchwork of existing regional studies appears to suggest that the diet of Pacific sleeper sharks is both spatially and temporally heterogeneous, perhaps owing to their opportunistic nature (Sigler et al. 2006; Courtney and Foy 2012). One of the more comprehensive studies noted a seasonal shift in the diet of sharks caught in the Gulf of Alaska from teleosts to cephalopods, likely due to changes in relative prey availability, though marine mammals remained important throughout the study period (Sigler et al. 2006). An ontogenetic shift in the diet has also been noted, whereby smaller sharks generally consume prey of lower trophic levels (e.g., cephalopods) and increasingly consume higher trophic level prey (e.g., fish and marine mammals) as they grow (Sigler et al. 2006; Yano et al. 2007; Courtney and Foy 2012; Orlov and Baitalyuk 2014). Sex and depth may also contribute to differences in diet (Orlov and Moiseev 1999; Orlov and Baitalyuk 2014).

Somewhat surprisingly, fast-swimming midwater and epipelagic fishes such as salmon *Oncorhynchus* sp., mahi mahi *Coryphaena hippurus*, wahoo *Acanthocybium solandri*, and albacore *Thunnus alalunga* have been found in the stomachs of Pacific sleeper sharks (Ebert et al. 1987; Wang and Yang 2004; Sigler et al. 2006). While it is possible they could have been consumed as carrion on the seafloor, some prey items in these stomach content studies were fresh and intact, suggesting that they were captured through ambush attacks (Ebert et al. 1987; Wang and Yang 2004; Sigler et al. 2006). In addition to pelagic species, groundfish species, including rockfishes (Sebastidae), flatfishes (Pleuronectiformes), cods (Gadidae), eelpouts (Zoarcidae), and sculpins (Cottidae) have also been reported in Pacific sleeper shark stomachs, indicating that they feed throughout the water column (Gotshall and Jow 1965; Ebert et al. 1987; Orlov and Moiseev 1999; Yang and Page 1999; Sigler et al. 2006; Gorbatenko et al. 2009).

Marine mammals are an important component of the Pacific sleeper shark diet, particularly of larger sharks (Sigler et al. 2006; Yano et al. 2007). A 393 cm female caught in very shallow water in Kachemak Bay, Cook Inlet, Alaska, was found to have at least three harbor seals *Phoca vitulina* in its stomach (Bright 1959). Numerous bite marks attributed to scavenging Pacific sleeper sharks have been observed on carcasses of gray whales *Eschrichtius robustus* that were killed by killer whales *Orcinus orca* in shallow waters near Unimak Island; annual killer whale predation events may attract the sharks to the area every spring (Barrett-Lennard et al. 2011). Pacific sleeper sharks of varying size (estimated 150-350 cm TL) have also been photographed voraciously feeding on whale falls in deep water off California (Smith et al. 2002; Smith and Baco 2003). Consistent with these observations was the landing of approximately 50 small individuals (all near a meter in length) that were caught together by a bottom trawler off Carmel Canyon, south of Monterey Bay, California, of which the stomach contents of some individuals contained bite-sized and -shaped pieces of red meat (A. H. Andrews, personal observation at Moss Landing Marine Laboratories in the mid-1990s). The presence of an intact fetus, along with adult female genital tissue, of southern right whale dolphins *Lissodelphis peronii*, in the stomach of a 360 cm Pacific sleeper shark led Crovetto et al. (1992) to conclude that the shark attacked a pregnant female. Fatty acid analysis has indicated the relative importance of cetaceans, as well as fish, in the Pacific sleeper shark diet (Schaufler et al. 2005). The Pacific sleeper shark has also been implicated as a predator of juvenile Steller sea lions *Eumetopias jubatus* based on a small study that surgically implanted sea lions with temperature-recording satellite tags (Horning and Mellish 2014). However, direct evidence of Steller sea predation has never been established (Schaufler et al. 2005; Sigler et al. 2006), and any predation that may occur is thought to be low (Loughlin and York 2000). Still, there is opportunity for overlap between the two species in the winter months, when juvenile Steller sea lions dive to deeper depths (Bishop et al. 2019). Modeling exercises suggest that sea lions, as well as harbor seals (a known prey item), may alter their foraging behavior to avoid areas where predation risk by Pacific sleeper sharks is greater (Frid et al. 2006, 2008, 2009).

In Alaska waters, the majority of Pacific sleeper shark mortality is due to fisheries bycatch (Aydin et al. 2007). However, an offshore killer whale population has been documented feeding on Pacific sleeper sharks (Ford et al. 2011). This killer whale ecotype may be specialist consumers of Pacific sleeper sharks and other elasmobranchs, which may comprise an important component of their diet (Ford et al. 2011). A necropsy on a recently dead 304 cm TL Pacific sleeper shark that washed ashore at Sunshine Cove in March 2022 near Juneau, Alaska, provides further evidence of predation by killer whales. Bruising and puncture marks consistent with the size and shape of killer whale teeth were visible on the body, and the throat, tongue, liver, and heart were ripped out (Fig. 10; Tribuzio et al. in prep). The removal of only the relatively nutritionally dense organs could indicate selective feeding by the killer whales.

Behavior, habitat use, and movement

Sleeper sharks are often regarded as slow-moving and sluggish. The genus name *Somniosus* is apropos for describing the behavior of these species upon capture. As Hansen (1963) noted, it is often difficult to tell whether they are alive or dead, as most individuals move little on longlines at the surface or once on deck. Whether their on-deck behavior represents that *in situ* has been somewhat debated, as they are capable of catching fast-moving prey (see Trophic Ecology). However, they have been noted to be among the slowest swimming of the fishes (Watanabe et al. 2012; Fujiwara et al. 2021) and likely rely on the power of ambush to capture prey.

Pacific sleeper sharks occupy a variety of habitats, ranging from very shallow water in the intertidal zone to oceanic depths of at least 2,000 m (Bright 1959; Compagno 1984;

Stevenson et al. 2007). It is unknown whether or to what extent Pacific sleeper sharks utilize habitats of the abyssal plain. While Pacific sleeper sharks can be found in shallow water at high latitudes, they occur deeper in subtropical and tropical waters (Ebert 2003; Walter et al. 2017). Different studies have reported conflicting results on the relationship between latitude and depth for the Greenland shark. Yano et al. (2007) observed a negative relationship off western Greenland, whereas Nielsen et al. (2014) did not detect any discernable trend over a wider geographic and latitudinal range around Greenland. However, Campana et al. (2015) found that Greenland sharks in the Arctic Ocean were in significantly shallower and colder waters than those in the northwest Atlantic Ocean, suggesting that the latitude-depth relationship may be more relevant at greater spatial scales. The majority of Greenland shark catches occur in waters below 5ºC (MacNeil et al. 2012), though archival tagging work in the northwest Atlantic Ocean has demonstrated that they are capable of tolerating temperatures up to 17.2ºC (Campana et al. 2015). In a study of tagged Pacific sleeper sharks in the Gulf of Alaska, ambient temperatures ranged from 4.4 to 11.8ºC but were mostly between 5.5 and 8.2ºC (Hulbert et al. 2006).

Little is known about the life cycle of Pacific sleeper sharks, quite possibly due to a mismatch between their distribution or catchability during certain life stages and fisheries and survey data. Because mature individuals are encountered so rarely, it is possible they typically occupy abyssal habitats that are inaccessible to standard fishing gear. Very large sleeper sharks, putatively identified as *S. pacificus* based on geographic locations, have been observed near the seafloor in deep water by submersibles and remote cameras (Isaacs and Schwartzlose 1975; Clark et al. 1990). While juveniles typically are captured in the bottom waters of the continental shelf and slope, they have also been caught in midwater trawls over very deep water (Ebert 2003). It is possible that Pacific sleeper sharks actively seek out certain habitats, such as deepwater canyons and troughs, as refugia. There is some indication that, at least in Alaska waters, they may also prefer relatively inshore habitats that are poorly sampled by federal bottom trawl surveys. In particular, glacial fjords have also been identified as potentially important nursery areas due to large catches of small sharks in these areas (see Reproduction). Glacial fjords share many of the same conditions of deepwater offshore environments, thereby providing refugia to cold-adapted organisms despite their proximity to shore (Häussermann et al. 2021; Smith et al. 2022). Clearly, more work is needed to elucidate the distribution, preferred habitats, life history, and behavior patterns of Pacific sleeper sharks across life stages.

A tagging study in the western Gulf of Alaska indicated that Pacific sleeper sharks are capable of making long-distance horizontal movements of at least several hundred kilometers over the course of a year, but in general they appear to stay relatively localized, with most recoveries occurring within 100 km of tagging locations (Hulbert et al. 2006). Stable isotope studies, which provide a long-term snapshot of diet, have found distinct differences between the Bering Sea and Gulf of Alaska, suggesting that there is little exchange between the two regions (Courtney and Foy 2012), in contrast with a recent genetics study that reported that Pacific sleeper sharks are genetically homogenous throughout the Pacific Ocean, suggesting mixing among regions (Timm et al. 2022). Hulbert et al. (2006) noted that tagged individuals made "extensive, nearly continuous vertical movements", spending the majority of their time at depths between 150 and 450 m, but frequently rising to depths shallower than 100 m, including one individual that regularly rose to the surface (0-2 m) (Hulbert et al. 2006). However, despite these frequent ascents, they spent relatively little time at the shallower depths, remaining below the photic zone during the day and moving shallower at night, which the authors speculated may be related to foraging (Hulbert et al. 2006). The high levels of alkyldiacylglycerols in the very large liver (20-30% of body mass) of Pacific sleeper sharks may facilitate these regular vertical migrations through buoyancy regulation (Phleger 1998). Additional tagging studies are currently in progress to gain a better understanding of Pacific sleeper shark movements and behavior.

Movements and habitat preferences of the Greenland shark are more well-known. Greenland sharks make large horizontal and vertical movements across a range of temperatures (Fisk et al. 2012; Campana et al. 2015). Similar to the Pacific sleeper shark, Greenland sharks have been observed making diel vertical migrations in certain areas including the Gulf of St. Lawrence and the Canadian Arctic, residing in deeper, colder waters during the day and shallower, warmer waters at night (Skomal and Benz 2004; Stokesbury et al. 2005; Gallant et al. 2016), though they do not appear to exhibit this behavior consistently through their range (Fisk et al. 2012; Campana et al. 2015). Greenland sharks have also been observed making excursions into shallow waters, including nearshore and brackish habitats (Stokesbury et al. 2005; Gallant et al. 2016). Hussey et al. (2018) found evidence of migration routes between Canada and Greenland, including movements into deepwater fjords. Long-term acoustic telemetry has revealed migrations of Greenland sharks between coastal and offshore locations in Baffin Bay, Canada, with some individuals displaying site fidelity across multiple years (Edwards et al.

2022a, b). The inshore-offshore migrations observed in Baffin Bay appear to be related to seasonal ice cycles, with sharks residing in coastal fjords during the summer and fall ice-free period and in offshore waters during the period of ice formation and cover (Edwards et al. 2022b). Juveniles have longer occupancy times in the coastal fjords than sub-adults (Edwards et al. 2022a), lending further support to these habitats as important refugia during more vulnerable life stages.

Internal anatomy and physiology

Sleeper sharks possess anatomical and physiological features that make them well-suited to their environment. Their slow swimming speeds likely allow them to conserve energy and reduce metabolic demands, important attributes for an opportunistic predator (Fujiwara et al. 2021; Smith et al. 2022). Furthermore, their large livers, composed primarily of diacylglyceryl ethers and triacylglycerols, play a key role in energy storage and likely allow them to regulate buoyancy during their extensive vertical migrations (Bakes and Nichols 1995; Phleger 1998). As a result of these adaptations, the energy budgets of sleeper sharks are estimated to be relatively low, despite having metabolic rates that are similar to those of other sharks when scaled for temperature (Ste-Marie et al. 2020; Smith et al. 2022). For instance, field and captive respirometry studies have demonstrated that an 84.5 kg Pacific sleeper shark would be expected to burn 153 kcal/day under average swimming conditions and that the maintenance ration of an average Greenland shark weighing 224 kg is only 61-193 g of fish or mammal tissue daily, suggesting that these sharks require relatively little energy (Ste-Marie et al. 2020, 2022; Smith et al. 2022).

The immune functioning of sleeper sharks is not well-studied. The Greenland shark possesses Leydig’s organ, a lymphomyeloid tissue found only in certain elasmobranchs. Based on high lysozyme activity observed in Leydig’s organ, the pancreas, and the spleen, the Greenland shark may have a strong immune response to bacterial and viral infections (Fänge et al. 1980). It has not been noted in the scientific literature whether Leydig’s organ is also present in Pacific sleeper sharks. There is no macroscopically visible epigonal organ in male or female sleeper sharks (Yano et al. 2007). The epigonal organ, another lymphomyeloid tissue unique to chondrichthyans, is associated with the gonads and is part of the immune system, possibly involved with leukocyte production (Honma et al. 1984; Luer et al. 2004; Bircan-Yildirim et al.

2011). Whether the epigonal organ is greatly reduced or completely absent in sleeper sharks is unknown.

Examination of the structures of the brains of sleeper sharks reveal some differences compared to other shark species. Unlike other large-bodied sharks, the cerebellum, the region that controls motor function, is small and smooth in both Greenland and Pacific sleeper sharks, suggesting lower activity levels in these species (Yopak et al. 2019). Additionally, the optic tectum, a part of the brain responsible for visual processing, is reduced while the olfactory regions are some of the largest of any shark species studied, indicating that sleeper sharks likely rely far more on their sense of smell than their visual acuity (Ferrando et al. 2015; Yopak et al. 2019). Further supporting this hypothesis are their ability to detect carrion below the photic zone in deep oceanic waters and their seeming indifference to corneal infections of parasitic copepods (see Parasites).

Parasites

Individuals of the parasitic copepod species *Ommatokoita elongata* have long been observed attached to the corneas of Greenland sharks (Berland 1961; Beck and Mansfield 1969). The species was first documented on the eyes of Pacific sleeper sharks in Prince William Sound, Alaska, with infections appearing to be quite common (Benz et al. 1998, 2002). Parasitic copepod infections can cause lesions of the cornea, which likely lead to vision impairment or even blindness (Borucinska et al. 1998; Benz et al. 2002). It is questionable to what degree this adversely affects the sharks since they appear to rely more on their olfactory senses than their visual acuity for detecting prey, and infected sharks appear to be otherwise healthy (Borucinska et al. 1998; Benz et al. 2002). Greenland sharks in the St. Lawrence Estuary have been reported to be largely copepod-free; it has been postulated that the sharks enter brackish waters in an attempt to rid themselves of the copepods and other parasites (Harvey-Clark et al. 2005; Gallant et al. 2016). The St. Lawrence Estuary sharks appear to be highly visual and display different behaviors than Greenland sharks in the Arctic Ocean, where parasitic copepod infections are endemic (Harvey-Clark et al. 2005).

Other parasites of sleeper sharks appear to be far rarer in occurrence and may vary geographically. Ho et al. (2003) observed the ectoparasitic copepod *Dinemoura ferox* on the heads or fins of four of 27 Pacific sleeper sharks caught off eastern Taiwan. Interestingly, while

Ho et al. (2003) also noted infections of *O. elongata* attached to the corneas of eight of the sharks they examined, none of those same sharks had concurrent *D. ferox* infections. An unidentified species of copepod, possibly *D. ferox*, was observed on the pelvic fin of a juvenile male Pacific sleeper shark in 2022 on a survey out of Petersburg, Alaska (K. R. Fuller, personal communication). The same parasite was found on a number of Pacific sleeper sharks near Juneau, Alaska, indicating a fairly high rate of occurrence at a local level (K. R. Fuller, personal communication). Wang and Yang (2004) observed *D. ferox* on the skin and monogeneans (Polyopisthocotylea), a type of flatworm, on the gills of Pacific sleeper sharks caught off eastern Taiwan, as well as apparent wounds caused by cookie-cutter sharks *Isistius* sp. Causey (1926) noted flukes (Trematoda) on the gills of sleeper sharks in Excursion Inlet, Alaska. Tapeworms (Cestoda) and nematodes (Nematoda) have been periodically reported from the stomachs of Pacific sleeper sharks (Gotshall and Jow 1965; Wang and Yang 2004; Taggart et al. 2005). A sea lamprey *Petromyzon marinus* was observed attached to a 3-m male Greenland shark in the St. Lawrence Estuary, although this doesn't appear to be a common occurrence as this is the only known report of a lamprey on a sleeper shark (Gallant et al. 2006). Finally, there is a single record of the parasitic barnacle (*Anelasma squalicola*) inside the cloaca of a 275 cm TL female Greenland shark collected from Tremblay Sound in the eastern Canadian Arctic (Ste-Marie et al. 2023).

Contaminants

Naturally occurring and anthropogenic toxins, such as heavy metals and persistent organic pollutants (POPs), tend to be higher in long-lived, upper trophic level organisms due to the process of bioaccumulation. Toxic contaminants including mercury, cadmium, lead, selenium, and various POPs have been detected in the muscle, liver, pancreas, and other organs of Greenland sharks, with loads varying among tissues (Strid et al. 2007; Corsolini et al. 2014). Dichlorodiphenyltrichloroethane (DDT), an insecticide that was widely used from the 1940s to 1970s, has been detected in liver and muscle tissue of Greenland sharks with concentrations varying geographically, which could be due to differences in contamination levels or in feeding ecology among regions (Fisk et al. 2002; Corsolini et al. 2014; Cotronei et al. 2018). Polychlorinated biphenyls (PCBs), another group of organic chemicals that persist in the environment despite widespread bans enacted in the mid-1970s, have also been found to vary spatiotemporally in Greenland sharks (Lu et al. 2014). Similarly, endocrine-disrupting compounds including bisphenol A vary regionally and among tissue types in Greenland sharks (Ademollo et al. 2018).

We know of only one study that has examined contaminants (non-essential elements) in Pacific sleeper sharks, and concentrations were generally higher than those in Greenland sharks, likely due to geographic differences in levels of exposure or to differences in diet (McMeans et al. 2007). In the studies to date, concentrations of various contaminants do not appear to be related to shark size, with most observed differences attributed to diet variation (McMeans et al. 2007, 2015; Strid et al. 2010; Cotronei et al. 2018). It has been suggested that the high levels of POPs in blood plasma of Greenland sharks off Norway may interfere with vitamin A and vitamin E homeostasis, though more work is needed to confirm any adverse effects on physiological and developmental processes (Molde et al. 2013).

Toxicity

The fresh flesh of sleeper sharks has long been believed to be toxic due to a case in which sled dogs exhibited symptoms consistent with trimethylamine poisoning after consuming large quantities of raw Greenland shark meat (Boje 1939; Anthoni et al. 1991; MacNeil et al. 2012). These symptoms mimic acute alcohol intoxication, and have anecdotally been noted in dogs as well as people (Jensen 1914; Clark 1915). Greenland sharks, like many other elasmobranchs, possess high levels of trimethylamine oxide, which is converted to trimethylamine during digestion (Anthoni et al. 1991). However, the amount of shark flesh that would be necessary to induce an adverse response is likely larger than a person could reasonably consume in one sitting (MacNeil et al. 2012; Nielsen 2017). Adequate preparation is also thought to reduce any potential effects of trimethylamine toxicity (Jensen 1914; Clark 1915; Anthoni et al. 1991; Orlov 2017), though Wang and Yang (2004) write that Pacific sleeper shark meat is consumed fresh in Taiwan as a substitute for whale shark *Rhincodon typus*, despite being “rather bland and tasteless”. Fermented Greenland shark, known as the national delicacy *kæstur hákarl* in Iceland, is typically only eaten in small amounts due to its pungent taste. Microbes, such as *Pseudomonas aeruginosa*, introduced by the fermentation process are hypothesized to detoxify trimethylamine and trimethylamine oxide in *hákarl* (Osimani et al. 2019).

Fishing Pressure and Management

Catch and fishery interactions

While the Greenland shark has been fished for its liver oil and meat at times throughout history (Jensen 1914; Compagno 1990; MacNeil et al. 2012; Davis et al. 2013), the Pacific sleeper shark has, to the best of our knowledge, never been targeted on a commercial scale except for a localized fishery in the waters off Hualien, Taiwan (Wang and Yang 2004). There are also a few anecdotal reports of fishers in Southeast Alaska targeting Pacific sleeper sharks to sell the livers during the brief shark liver fishery that also existed for the Pacific spiny dogfish *Squalus suckleyi* in that region (C. A. Tribuzio, personal communication). However, no official records of this activity exist.

There are relatively little reliable historic data available on incidental catches of Pacific sleeper sharks, as any sharks caught are not typically retained. Increased interest in shark conservation and awareness of their relative vulnerability has resulted in improved catch reporting over the past two decades. Prior to 2003, shark catches in Alaska waters were reported in aggregate, requiring estimation of species-specific removals, but since have much improved thanks to the introduction of the NOAA Fisheries Catch Accounting System (Cahalan et al. 2015a, b). Similarly, improved species identification and reporting of shark catches were initiated in 2001 in Canadian waters, which resulted in an increase in reporting of discards of Pacific sleeper sharks (King et al. 2017). However, given the data-limited nature of the stock assessment and lack of exploitable biomass estimates, exploitation rates cannot be determined and are likely highly uncertain (Courtney et al. 2016).

Somniosus species are generally regarded as a nuisance when they are caught incidentally in other target fisheries (Nielsen 2017; Orlov 2017). They frequently become entangled in longlines and are cumbersome on deck when caught in bottom trawls, both requiring long handling times to discard (Orlov 2017; Grant et al. 2018). An ongoing study aimed at developing tools that can more accurately identify and size-grade large shark species from video taken on vessels participating in an electronic monitoring program for fixed-gear fisheries in Alaska (i.e., vessels carrying cameras in lieu of at-sea observers) found that out of 57 Pacific sleeper sharks captured across 11 fishing vessels since 2015, 15 (26.3%) were entangled with the line in some fashion, and six sharks (10.5%) required more than three minutes to extricate (K. R. Fuller, unpublished data). Over 60% of these sharks were removed from the line by cutting one or more gangions (K. R. Fuller, unpublished data). Greenland and Pacific sleeper sharks have also been implicated in longline depredation of valuable target species, such as Greenland halibut *Reinhardtius hippoglossoides* and Pacific halibut (Wright and Hulbert 2000; Grant et al. 2018; Madigan et al. 2022). Research efforts on modifications of fishing gear have shown promise for reducing bycatch of Greenland sharks in target fisheries (Munden 2013; Folkins 2019; Grant et al. 2020).

Catches of Pacific sleeper sharks off British Columbia are variable year-to-year but are generally low (Fig. 11; Anderson et al. 2019). Bottom-trawl and longline fisheries for more valuable target groundfish species comprise the majority of the Pacific sleeper shark catch (Fig. 11). Estimates of discards in trawl fisheries prior to 1996 and in non-trawl fisheries prior to 2006 are considered less reliable, as this is when at-sea observer coverage was implemented in each sector, respectively. Nearly all of the catch of Pacific sleeper sharks in British Columbia waters is discarded.

In federal waters off Alaska, Pacific sleeper sharks are most frequently taken in the commercial walleye pollock, Pacific halibut, mixed flatfish, and Pacific cod *Gadus macrocephalus* fisheries (Fig. 12a). They are also caught incidentally in state recreational fisheries for Pacific halibut and other bottomfish (Baumer et al. 2019; Tribuzio et al. 2022). Increases in bycatch were observed from the early to late 1990s in the Prince William Sound longline fishery (Wright and Hulbert 2000), which coincided with trends in abundance throughout the Gulf of Alaska at that time (Mueter and Norcross 2002). Fishery catches of Pacific sleeper sharks have decreased since the mid-2000s, with shifts in the proportion taken by each target fishery (Fig. 12b). The exception to this trend is from federal fisheries operating within the inside waters of the Gulf of Alaska (e.g., the Individual Fishing Quota Pacific halibut fishery); however, this trend is more likely driven by changes to data collection procedures in 2013 that expanded observer coverage to inside waters. Very little (1% in the Gulf of Alaska and 10% in the Bering Sea, on average) of these incidental catches is retained due to low commercial value (Tribuzio et al. 2022). Similarly, nearly all catches of Pacific sleeper sharks off the US West Coast are discarded (Jannot et al. 2021). The survival rate of discarded Pacific sleeper sharks is unknown, but likely varies according to fishing gear and behavior (Morgan and Burgess

2007; Braccini et al. 2012). Preliminary tagging data suggest that trawl-caught Pacific sleeper sharks are all deceased when released (C. A. Tribuzio, unpublished data). The degree of stress associated with capture and handling, indicated by blood glucose and lactate levels, is variable in Greenland sharks but has been found to be correlated with body size and depth of capture (Barkley et al. 2016).

Catches of *Somniosus* species tend to occur in spatially clustered hotspots that may be temporally variable (Menon 2004; Cosandey-Godin et al. 2015). In Alaska waters, fisheries catches are broadly distributed but have been historically highest in Shelikof Strait and the heads of submarine canyons along the continental slope of the Bering Sea, particularly Bering Canyon north of Unimak Pass (Fig. 3). Menon (2004) demonstrated that bycatch of Pacific sleeper sharks had a weak, positive relationship with depth and a negative relationship with abundance of Pacific spiny dogfish. The spatial distribution of Pacific sleeper shark catch in Alaska waters has reduced since the late 1990s and 2000s, mirroring patterns observed in fisheries-independent indices (Matta et al. 2022).

Management and conservation

Management of the catch of Pacific sleeper sharks is limited to a few regions within their distribution. In federal waters of Alaska, the overfishing status of Pacific sleeper sharks is assessed and the catch is managed as part of multi-species shark stock complexes within each of the two main management areas: the Bering Sea/Aleutian Islands and the Gulf of Alaska. Harvest control rules for Alaska groundfish are set using a descending six-tier system corresponding to the amount of data available for a given stock (NPFMC 2020). Little information exists to support single-species stock assessments for Pacific sleeper shark or most of the other component species within the shark stock complexes, placing them in the lowest tiers, in which the status of the stock cannot be determined. For example, the Gulf of Alaska Pacific spiny dogfish stock falls into Tier-5 of the North Pacific Fishery Management Council's harvest control rule structure because their biomass estimate from trawl surveys is considered reliable. Harvest limits of Tier-5 species are partially estimated based on fishery-independent trawl survey biomass estimates (NPFMC 2020). In contrast, fishery-independent surveys are inadequate to generate estimates of abundance for the remaining species of the shark complexes (including Pacific sleeper sharks), due to either their distribution or catchability, and they are therefore considered Tier-6, the most data-limited tier category. Harvest limits for these Tier-6 species are estimated based on historical catch. The current management strategy is to set the maximum harvest limits for the shark complexes in each management area based on the aggregate of the individual species' harvest limits or as a single harvest limit estimated for the complex as a whole; thus, there is no species-specific management for any of the shark species in Alaska waters. This approach assumes that maintaining historical catch levels is sustainable, will not result in overfishing, and that all species within the complex are equally vulnerable. Generally, shark catches in Alaska waters have stayed well under the maximum amount allowed (Tribuzio et al. 2022). However, this method for setting harvest limits ignores any biological information and is associated with a high risk of overfishing (Carruthers et al. 2014). Furthermore, it is important to note that Pacific sleeper sharks appear to have declined in abundance during the period when Tier-6 assessment methods have been used (Fig. 2). Assessment methods applicable to data-limited stocks are currently being explored to better manage Pacific sleeper sharks in Alaska (Tribuzio et al. 2022), including incorporating accessory information into harvest specifications, demographic-based population models that incorporate movement analysis, and plausible estimates of life history parameters (Tribuzio and Kruse 2011; Free et al. 2017; Pantazi et al. 2020; Dureuil et al. 2021). As Pacific sleeper sharks have been identified as among the most vulnerable to overfishing of all managed stocks in Alaska waters due to their likely low productivity (Ormseth and Spencer 2011), such research into alternative management methods is timely.

Research into the use of electronic monitoring (EM) video data to improve Pacific sleeper shark catch estimates in Alaska waters is ongoing (C. A. Tribuzio and K. R. Fuller, personal communication). These projects aim to develop machine learning tools to identify and size-grade Pacific sleeper sharks in recorded video, thereby making the video review process more efficient while providing previously unavailable size data to refine estimates of total catch. This information will be especially useful to improve catch estimates in longline fisheries, where sharks are incidentally caught but not necessarily landed.

Pacific sleeper sharks do not appear to be formally assessed elsewhere, though biological and demographic data are collected through various scientific survey and fisheries research platforms in other parts of their range. In British Columbia, their conservation status has not been assessed and is currently unknown. Additionally, no stock assessment process has been completed and there is little known about their population, distribution, and abundance. When possible, data on Pacific sleeper shark encounters are collected during fisheries-independent surveys; however, individuals are not generally sampled or sexed. In 2011, the US West Coast management region made a change requiring that the groundfish fishery monitor 100% of discards, resulting in improved data (Jannot et al. 2021). Still, Pacific sleeper sharks do not qualify as a managed species under any of the Pacific Fishery Management Council fishery management plans.

Because they can be perceived as a nuisance due to their tendency towards longline depredation and entanglement in fishing gear, directing fishing on Pacific sleeper sharks has been proposed to reduce negative impacts on other groundfish fisheries (Orlov 2017). The majority of the catch throughout its range is immature, and due to its likely life history attributes of slow growth, long generation time, and low overall productivity, it is highly improbable that a sustainable fishery for this species could be established (Smith et al. 1998; Simpfendorfer and Kyne 2009; Tribuzio and Kruse 2011; Au et al. 2015; Matta et al. 2022). Furthermore, the IUCN status of the Pacific sleeper shark recently changed from Data Deficient to Near Threatened in large part due to possible population declines in portions of their range (Rigby et al. 2021), and the North Pacific Fishery Management Council's Scientific and Statistical Committee noted conservation concerns in its most recent review of the stock assessment (SSC 2022). Given these concerns, a conservative management approach is warranted pending better understanding of this species.

Future studies/conclusions

This review demonstrates that there are many areas in which our understanding of Pacific sleeper shark biology and ecology could be improved, particularly regarding habitat use and life history. These knowledge deficits should be the focus of future research for improving the assessment and management of this potentially long-lived and vulnerable species. There are a number of ongoing studies to fill research gaps, including longevity estimation, bioenergetics, movement, reproduction, and advancing stock assessments of Pacific sleeper sharks in Alaska waters. Catch estimates, a main factor in determining harvest limits in stock assessments in the Bering Sea/Aleutian Islands and Gulf of Alaska federal management regions, have been much improved over the past decade thanks to the teamwork of scientists and fishery managers. Advanced computing methods such as machine learning are being used to process electronic monitoring video data and to further improve estimates of catch, particularly in fisheries sectors that have not been historically well-observed. Researchers are currently working towards refining estimates of maturity and estimating movements from a blend of survey data, tag information, and baited cameras. The pilot project described herein to determine estimates of age from eye lens radiocarbon has been fully funded, with the objective of providing estimates of life history parameters including growth and natural mortality that are critical for improving stock assessment. Until more information becomes available, a precautionary approach to its management is warranted throughout its range.

Author contributions

MM reviewed literature, analyzed data, and conceived of and drafted the original manuscript; CT, LD, and AA compiled and analyzed data and contributed to the manuscript; KF and GD edited the original draft and contributed additional text. All authors read, edited, and approved the manuscript.

Data availability

Much of the data for this review are from published studies, referenced throughout the document. Data from Alaska are from a variety of sources: fisheries data are available from the NOAA Alaska Regional Office and the Department of Fisheries and Oceans, Canada (DFO); survey data are from the NOAA Alaska Fisheries Science Center, the Alaska Department of Fish and Game, and DFO; at-sea observer data are from the North Pacific Observer Program; opportunistic reports are from fishers and other researchers. Size data from the US West Coast and British Columbia are from the International Pacific Halibut Commission, DFO, and the At-Sea Hake Observer Program (NOAA Northwest Fisheries Science Center). Non-confidential data and code used to create figures (R Core Team 2021) are available at https://github.com/BethMatta-NOAA/sleeper-shark-review.

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Figures

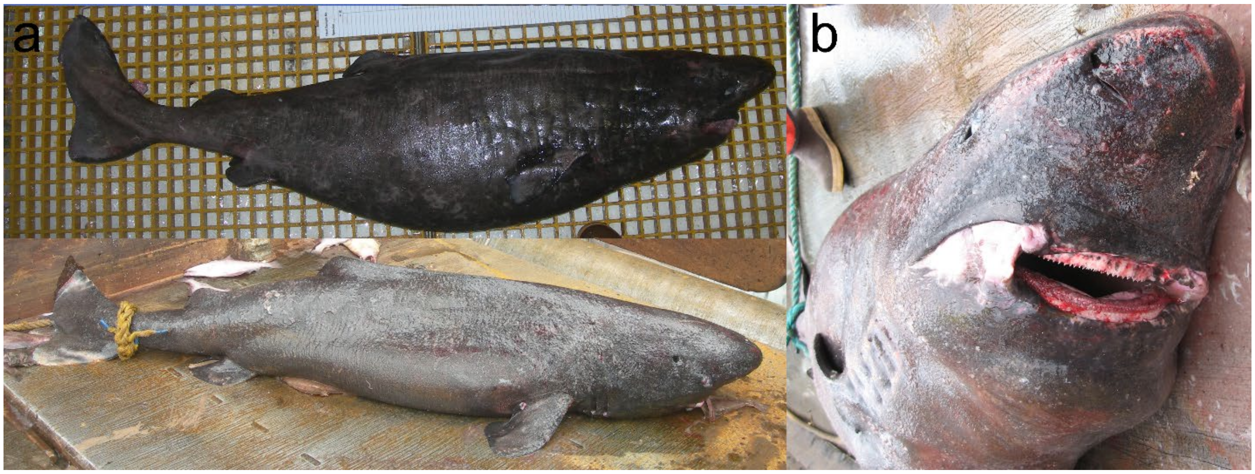

Fig. 1 The Pacific sleeper shark *Somniosus pacificus*. All individuals pictured are immature and under 200 cm total length. a) Two individuals showing variation in coloration. b) Pacific sleeper sharks have relatively small mouths and teeth.

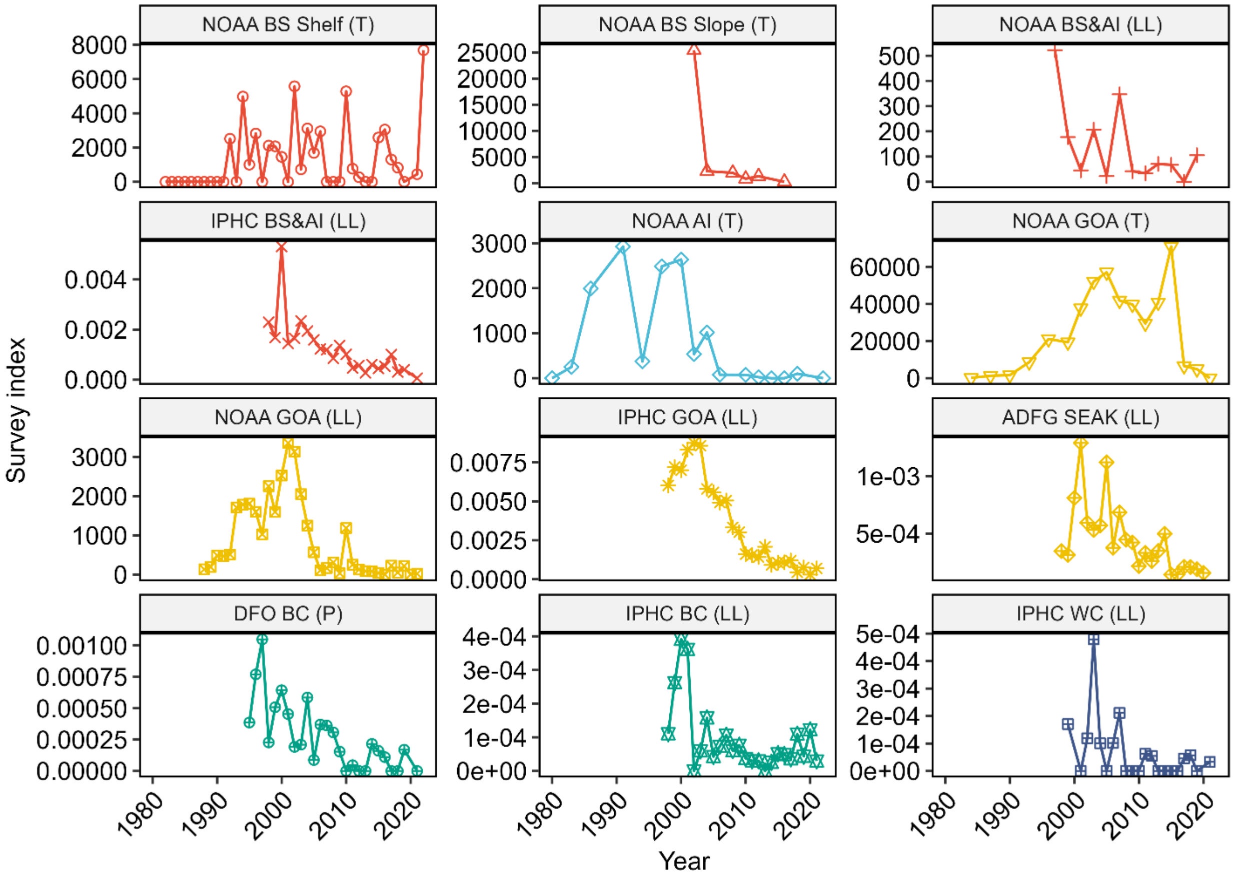

Fig. 2 Indices of abundance of Pacific sleeper shark *Somniosus pacificus* abundance. Fisheries-independent trawl (T), longline (LL), and pot (P) surveys operated by federal and state agencies (NOAA: National Oceanic and Atmospheric Administration Fisheries; IPHC: International Pacific Halibut Commission; ADFG: Alaska Department of Fish and Game; DFO: Department of Fisheries and Oceans, Canada) within large management areas in the eastern North Pacific Ocean (color-coded by region; BS: Bering Sea; AI: Aleutian Islands; GOA: Gulf of Alaska; SEAK: Southeast Alaska; BC: British Columbia; WC: United States West Coast). Units of measurement differ across surveys (NOAA T: biomass; NOAA LL: relative population numbers; IPHC LL, ADFG LL, and DFO P: catch per unit effort)

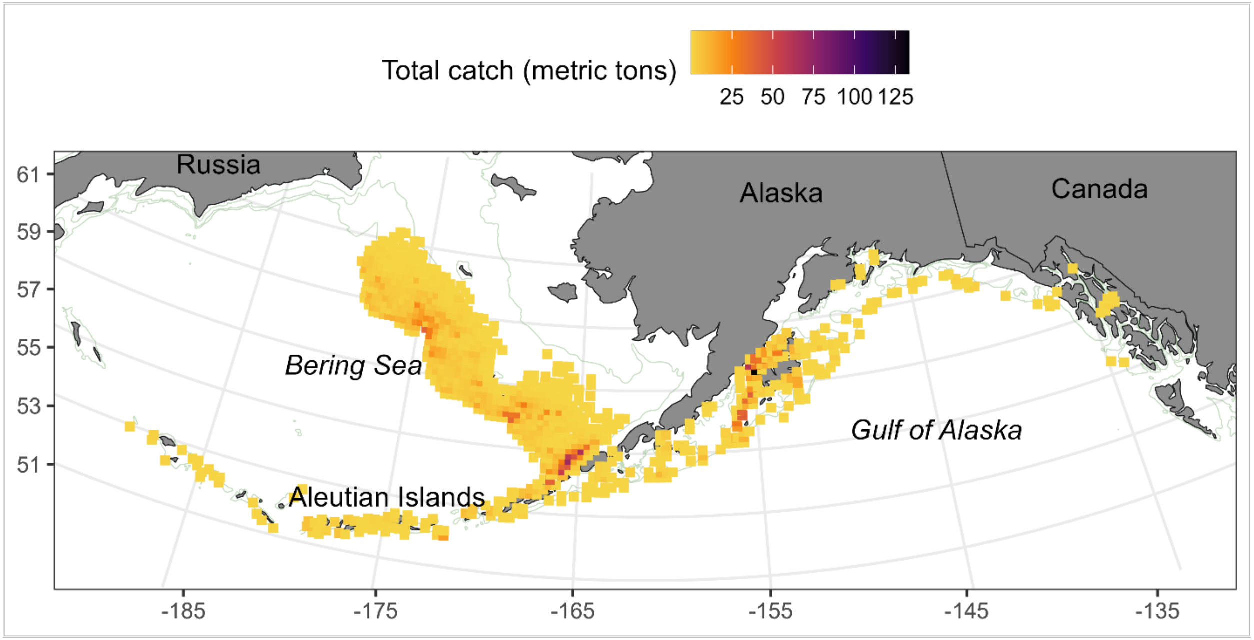

Fig. 3 Total weight of Pacific sleeper sharks *Somniosus pacificus* caught in commercial fisheries in Alaska waters from 1997-2021. Data are aggregated within 400 km^2 grid cells to preserve confidentiality of fisheries participants (retrieved from https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map on August 8, 2022)

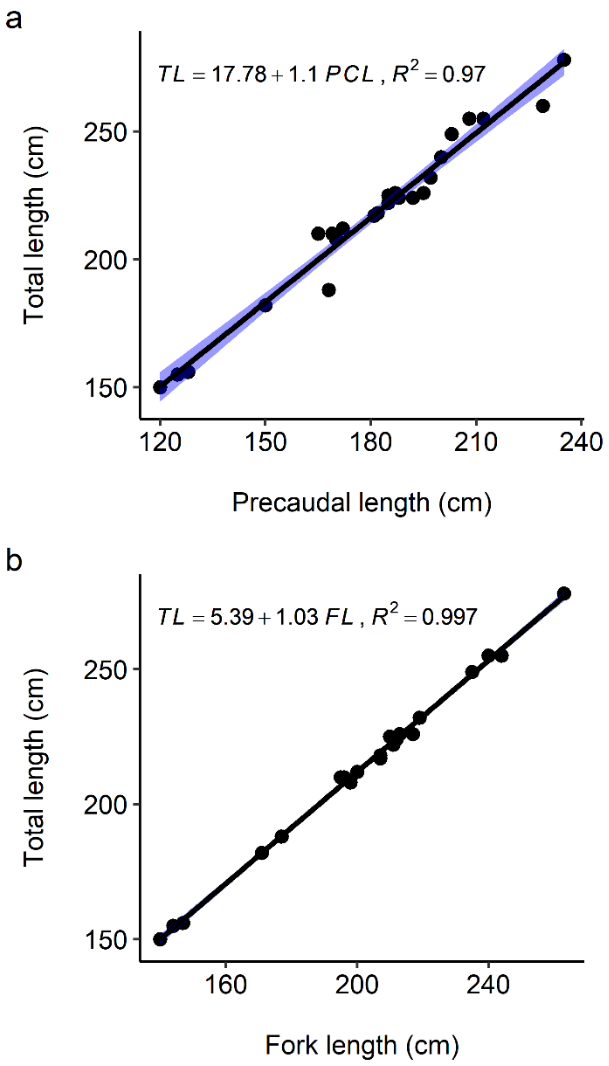

Fig. 4 Length-length relationships of Pacific sleeper sharks *Somniosus pacificus*. Linear regressions between total length (TL) and a) precaudal length (PCL, n=24) and b) fork length (FL, n=21). Blue shading indicates 95% confidence regions. Data collected by Hulbert et al. (2006)

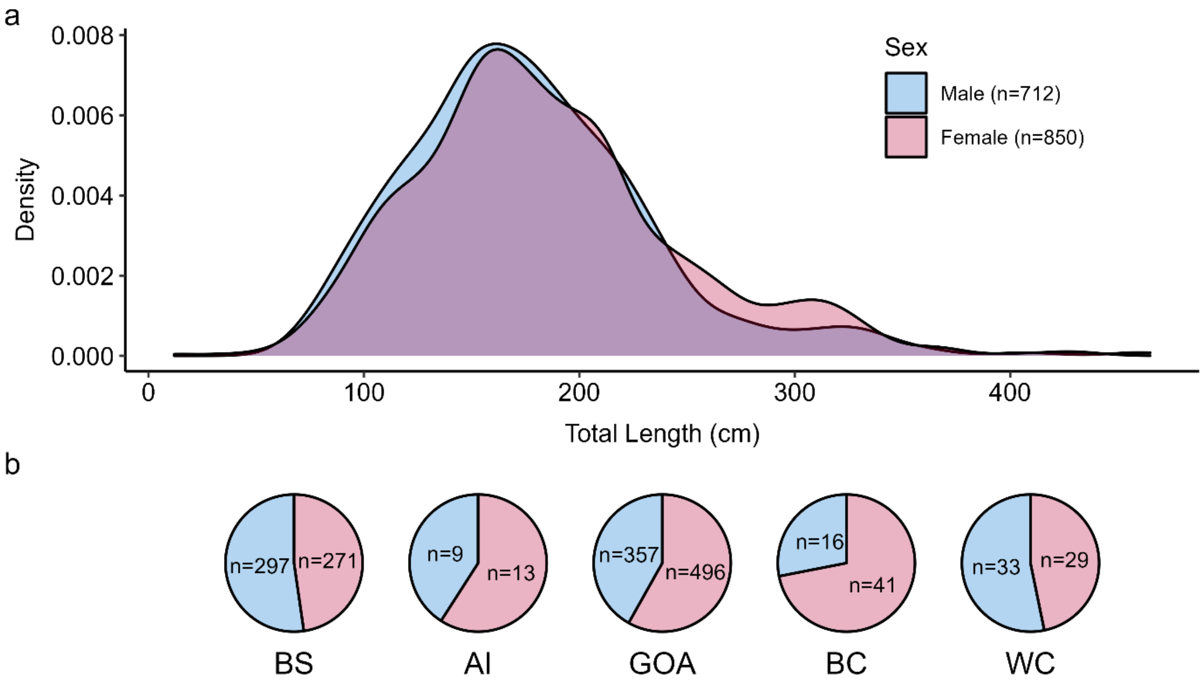

Fig. 5 Size and sex information for Pacific sleeper sharks *Somniosus pacificus* caught along the west coast of North America (Bering Sea to Baja California). a) Length distributions of landed and measured males and females. b) Sex ratios of lengthed Pacific sleeper sharks caught within management regions (BS: Bering Sea, AI: Aleutian Islands, GOA: Gulf of Alaska, BC: British Columbia, WC: US West Coast). Sample sizes indicated by *n*

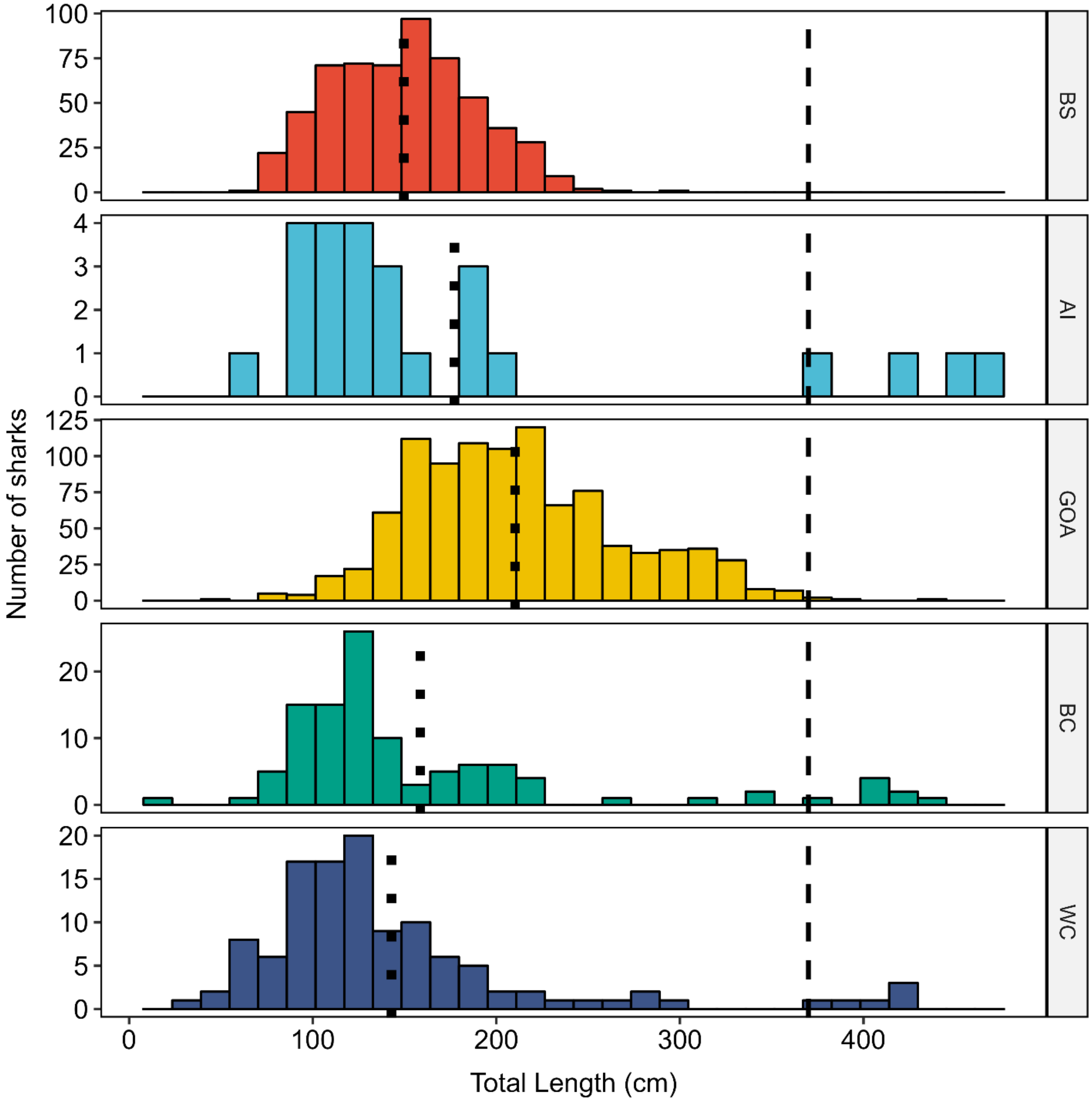

Fig. 6 Length distributions of landed and measured Pacific sleeper sharks *Somniosus pacificus* along the west coast of North America. Dotted lines indicate mean size in each region (BS: Bering Sea, n=584; AI: Aleutian Islands, n=25; GOA: Gulf of Alaska, n=982; BC: British Columbia, n=109; WC: US West Coast, n=117). Dashed line is the length at maturity of 370 cm total length estimated by Ebert et al. (1987)

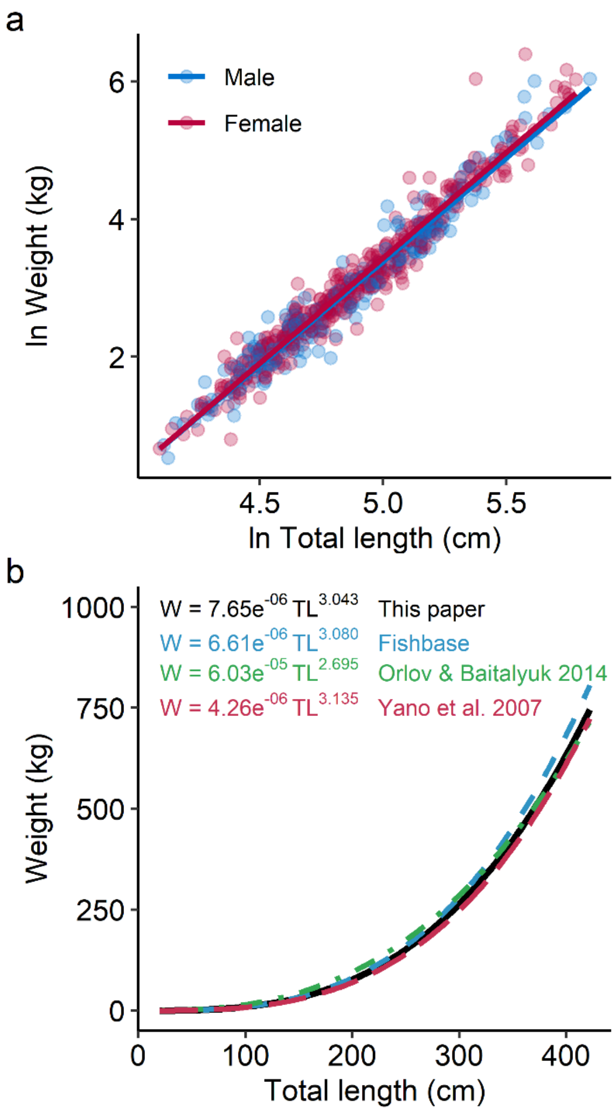

Fig. 7 Length-weight relationships of Pacific sleeper sharks *Somniosus pacificus*. a) Relationship between natural log-transformed length and weight for males (n=230) and females (n=367) collected from Alaska waters. An analysis of covariance determined no significant effect of sex on weight. b) Fitted length-weight relationship from the present paper (both sexes combined, back-transformed to original scale) in comparison with published relationships for Pacific sleeper sharks from Yano et al. (2007), Orlov and Baitalyuk (2014), and www.fishbase.se

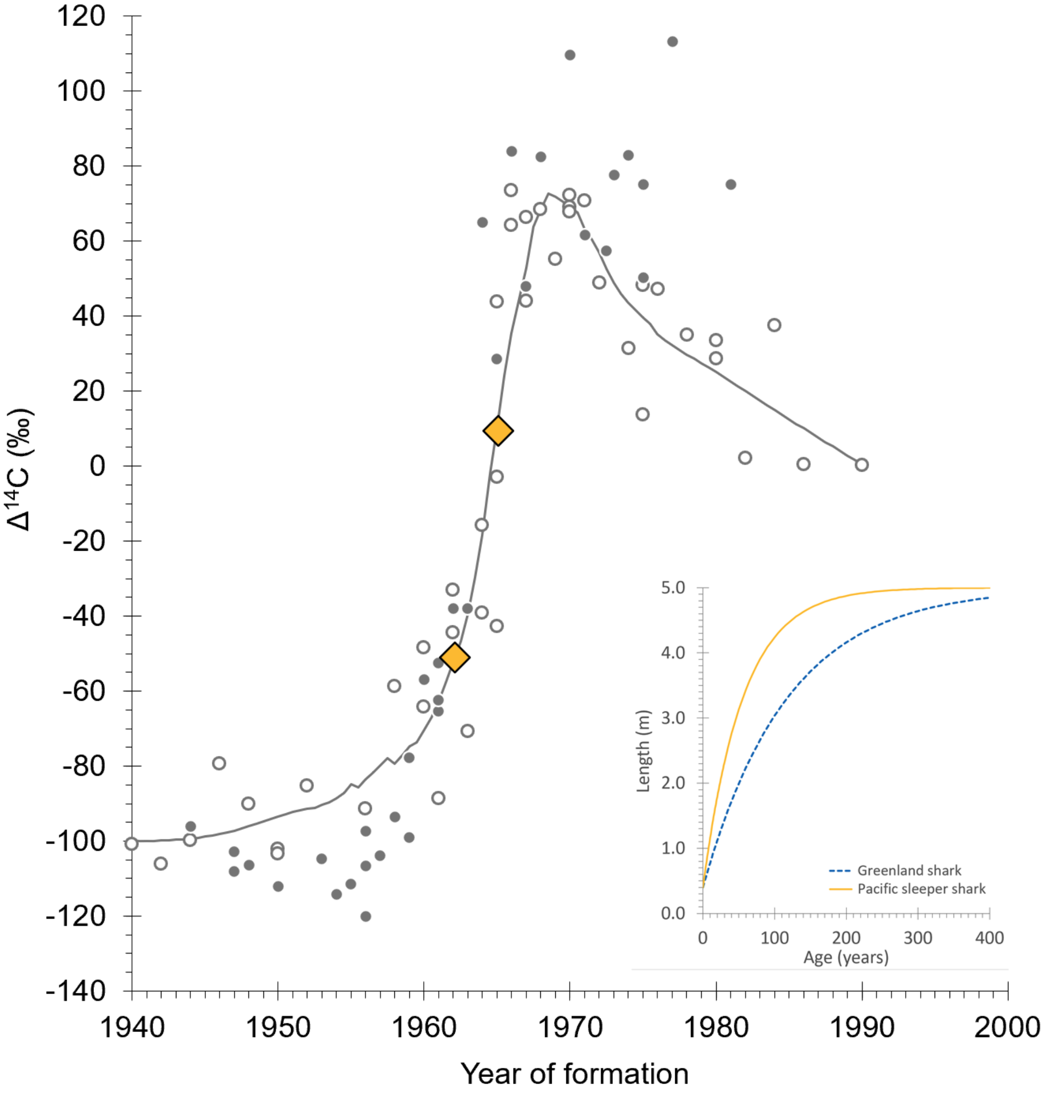

Fig. 8 Eye lens core radiocarbon ($\Delta^{14}C$) values (yellow diamonds) from a pilot study on a 3.1 m Pacific sleeper shark *Somniosus pacificus* that are aligned with regional chronologies to estimate a birth year. The specimen was collected in 2011 and each eye lens core (formed during pre-natal development) provided a diagnostic radiocarbon value ($\Delta^{14}C = 9.4$ and -51.1‰) that can be attributed to a formation date (birth year) between 1962 and 1965. Note that while the $\Delta^{14}C$ values from cores of the same individual differ, likely due to imprecision in the lens core extraction method, they still indicate a small range of potential birth years. Hence, this specimen was at most ~50 years of age and had a consequent growth rate (k) two times greater than Greenland shark *Somniosus microcephalus* (k ~0.018 *cf.* 0.009; see inset hypothetical growth curves). The bomb radiocarbon chronologies used as temporal references were from yelloweye

rockfish *Sebastes ruberrimus* (open circles) and Pacific halibut *Hippoglossus stenolepis* (solid circles) from the northeast Pacific Ocean (Kerr et al. 2004; Piner and Wischniowski 2004)

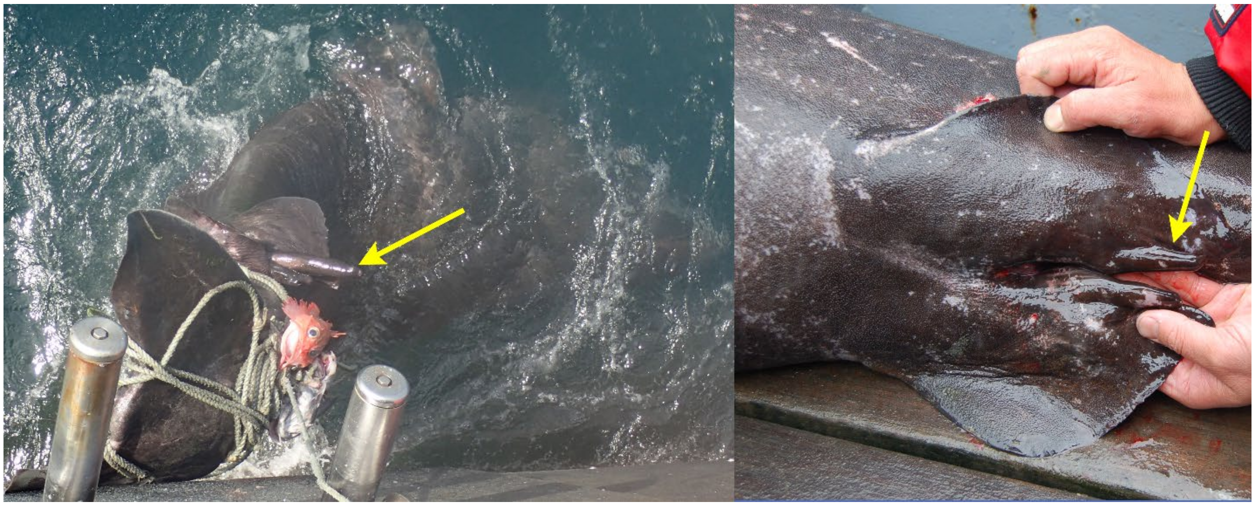

Fig. 9 Male Pacific sleeper sharks *Somniosus pacificus* thought to be mature (left) and immature (right) based on examination of the claspers (indicated by yellow arrows)

Fig. 10 A necropsy of a Pacific sleeper shark *Somniosus pacificus* that washed ashore after an apparent predation event by killer whales *Orcinus orca* off the coast of southeast Alaska in March 2022. Tooth marks are evident on the flank and the throat was ripped out, resulting in the removal of the heart, tongue, and liver. Images from Tribuzio et al. (in prep).

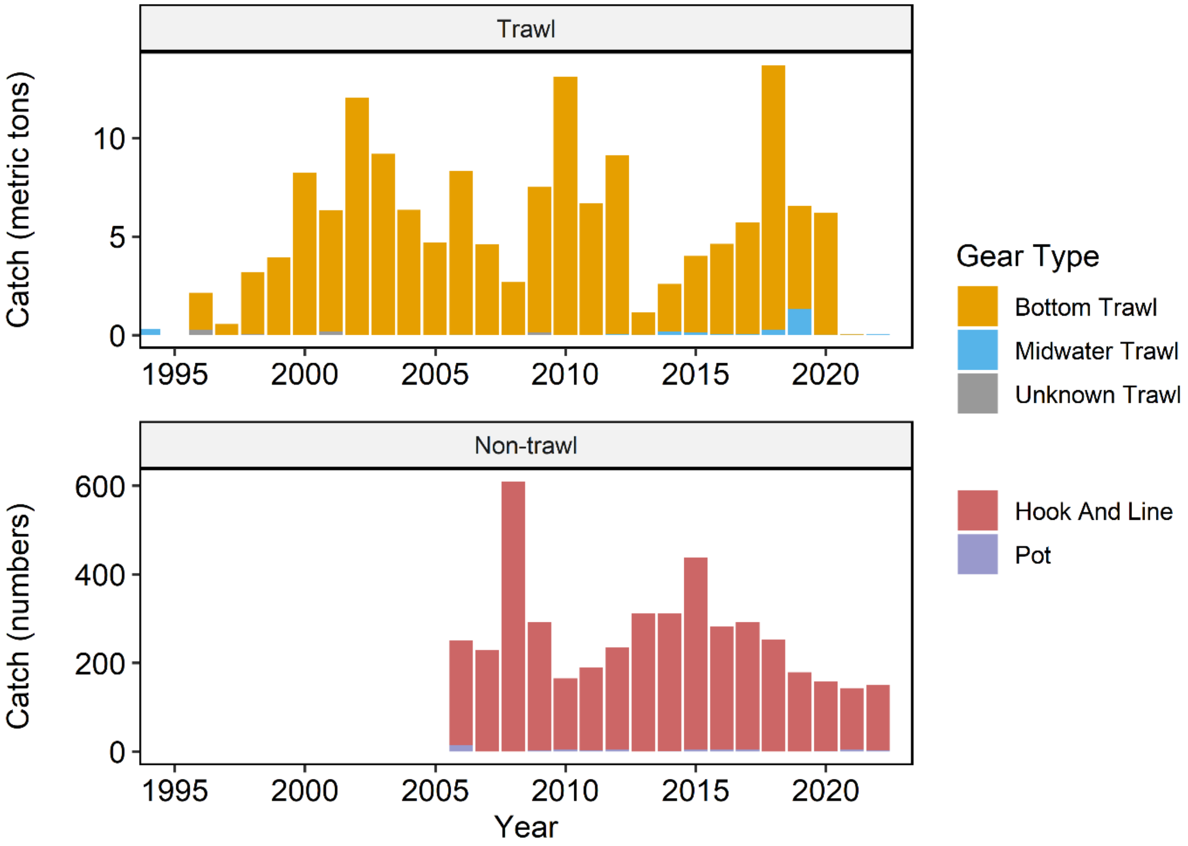

Fig. 11 Commercial catches (discards and landings) of Pacific sleeper sharks *Somniosus pacificus* in target groundfish fisheries in British Columbia waters. Catch in trawl fisheries is reported as total weight; catch in non-trawl fisheries is reported in numbers of sharks

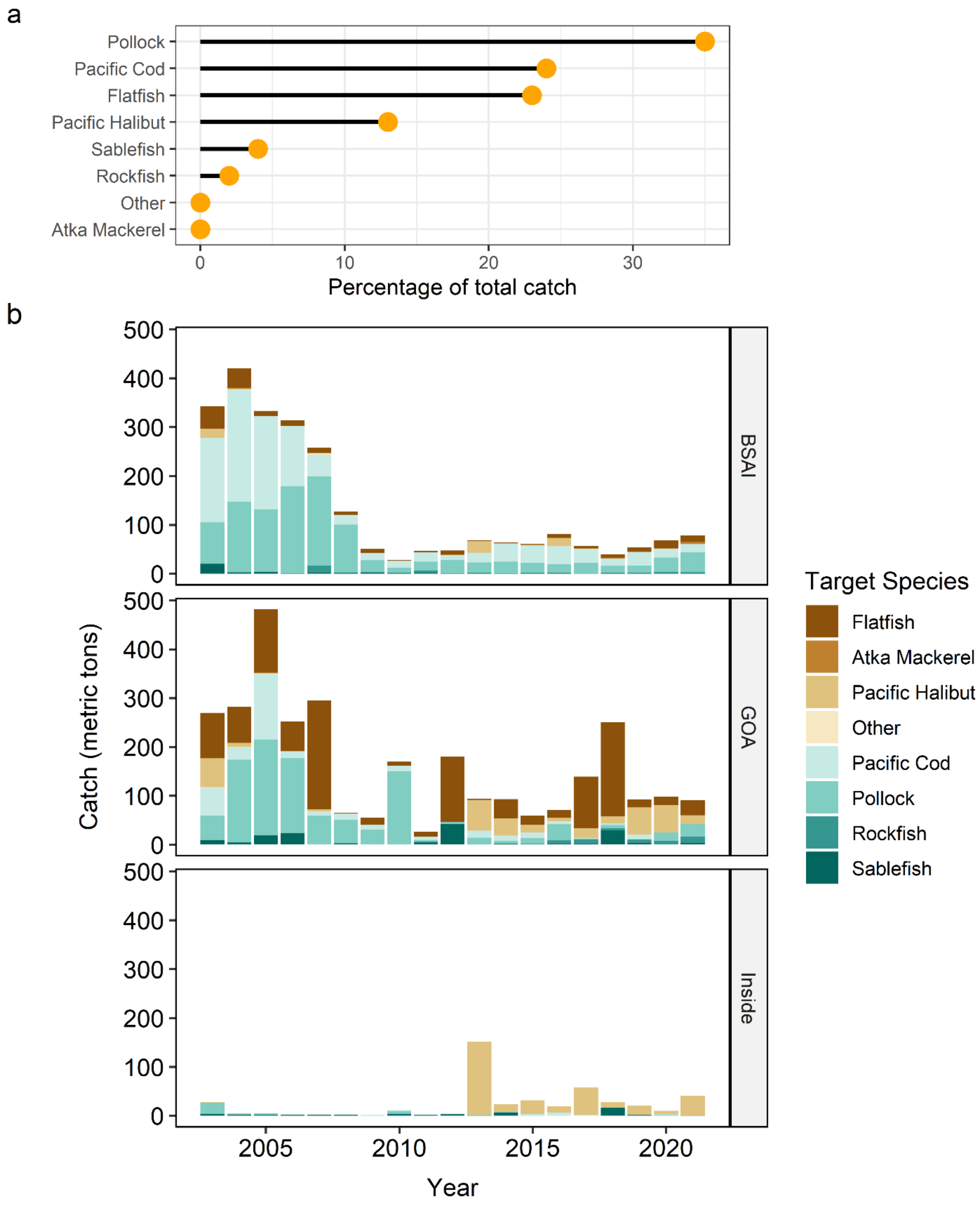

Fig. 12 Incidental catches of Pacific sleeper sharks *Somniosus pacificus* in targeted commercial fisheries in Alaska. a) Percentage of Pacific sleeper shark catch by weight in each target fishery (walleye pollock ("pollock") *Gadus chalcogrammus,* Pacific cod *Gadus macrocephalus*, mixed flatfish species Pleuronectidae, Pacific halibut *Hippoglossus stenolepis*, sablefish *Anoplopoma*

fimbria, mixed rockfish species Sebastidae, Atka mackerel *Pleurogrammus monopterygius*, and miscellaneous "other" groundfish species). b) Time series of sharks caught in target fisheries by area and management region (BSAI: Bering Sea/Aleutian Islands; GOA: Gulf of Alaska; Inside: waters 0-3 nautical miles from shore in Southeast Alaska and Prince William Sound) from 2003-2021. Note that the North Pacific Groundfish Observer Program restructured in 2013, resulting in increased coverage of inside waters. Data provided by the Alaska Regional Office Catch Accounting System