Research, Biology, and Management of Sharks and Grenadiers in Alaska

by
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Figure 1. Three main species of shark encountered in Alaska waters. From top left, clockwise: sport-caught spiny dogfish, scientist deploying a satellite tag on a sleeper shark, spaghetti-tagged salmon shark. Photos by Gordon Kruse (University of Alaska Fairbanks), Dean Courtney, and Dave Clausen.

Sharks and grenadiers in Alaska are two taxonomically unrelated groups of fishes that are interconnected by management and ecological commonalities. Although neither group is targeted by commercial fisheries in Alaska, both types of fishes are incidentally caught in considerable numbers in both longline and trawl fisheries. Recently, there has been increased interest in these species because of their ecological importance: grenadiers are the most abundant fish at surveyed depths on the continental slope, and sharks are predators at the top of the food chain. The increased interest has also been sparked by these species' potential susceptibility to overfishing due to their slow growth and late maturity. The following article summarizes the biology and management of sharks and grenadiers in Alaska and discusses current shark and grenadier research conducted by scientists at the Alaska Fisheries Science Center's (AFSC) Auke Bay Laboratories (ABL).

SHARK BACKGROUND

Nine species of sharks occur in Alaska waters (Table 1). Here we focus on the three shark species most commonly encountered in commercial fisheries and research surveys in Alaska (Fig. 1): spiny dogfish (*Squalus acanthias*), Pacific sleeper shark (*Somniosus pacificus*), and salmon shark (*Lamna ditropis*). In AFSC trawl surveys, spiny dogfish account for the vast majority of the catch in numbers, but sleeper sharks and sometimes salmon sharks can constitute more than half of the catch in weight due to their larger size (Table 2, Fig. 2). The catch of sharks and areas of greatest catches vary by year. For instance, in 2005 the catch of spiny dogfish in the Gulf of Alaska trawl survey was spread out along the continental shelf, with the highest catch near Kodiak Island and Southeast Alaska; however, in 2007 the highest catch was between Prince William Sound and Southeast Alaska (Fig. 3).

Spiny dogfish are among the oldest and slowest growing of all shark species. They live to more than 100 years, only grow to about 1.3 m, and don't reach sexual maturity until about 34 years of age. The species also has one of the slowest reproductive cycles; gestation takes about 20-22 months, with an average of about nine pups born each cycle. Spiny dogfish bear live young (aplacental viviparous), which are nourished through a yolk sac in utero. Female spiny dogfish may also skip a year between pregnancies, further decreasing the species' reproductive rate.

The biology of sleeper sharks is largely a mystery. They are a large (up to 7 m), deepwater species (to depths of 2,000 m) and are difficult to study because so few boats are capable of landing them. Sleeper sharks are more commonly encountered at higher latitudes because they utilize shallower depths than they do at more southerly latitudes. Longevity and age at maturity for this species is unknown. However, as part of the same family as spiny dogfish, sleeper sharks are assumed to share some of the same characteristics, such as maturity at a large size relative to their maximum size. Similar to spiny dogfish, sleeper sharks bear live young but unlike spiny dogfish may have as many as 300 pups per reproductive cycle.

The salmon shark is quite different from the other two species. The salmon shark is a member of the family Lamnidae, which includes great white, porbeagle, and mako sharks. This family of sharks is known for fast swimming speeds and endothermic capabilities (i.e., "warm blooded"). The salmon shark can maintain a constant body temperature up to 20°C warmer than the surrounding water temperature. Salmon sharks are not as long-lived as spiny dogfish, only living to about 20 years and maturing at 8-10 years. Like dogfish and sleeper sharks, salmon sharks also bear

Table 1. List of all shark species recorded in Gulf of Alaska waters.

Common name	Scientific name
Pacific sleeper shark	*Somniosus pacificus*
Spiny dogfish	*Squalus acanthias*
Salmon shark	*Lamna ditropis*
Blue shark	*Prionace glauca*
Great white shark	*Carcharodon carcharias*
Basking shark	*Ceterhinus maximus*
Thresher shark	*Alopias vulpinus*
Bluntnose sixgill shark	*Hexanchus griseus*
Brown cat shark	*Apristurus brunneus*

live young but utilize a unique form of embryonic nourishment known as "oophagy." Pups start gestation with an external yolk sac, but also during pregnancy the female ovulates unfertilized eggs for the young to feed on after the yolk sac is absorbed (Fig. 4). Fecundity in this species is low, about 4-5 pups per litter, and females may skip years between pregnancies.

SHARK RESEARCH AT AUKE BAY LABORATORIES

A number of research projects on spiny dogfish and sleeper sharks are under way at Auke Bay Laboratories. The goals of these projects, conducted in collaboration with the University of Alaska Fairbanks (UAF) and the University of Washington (UW), are to describe the abundance, ecological role, and habitat use of spiny dogfish and sleeper sharks in Alaska. Spiny dogfish have been collected from a number of AFSC, Alaska Department of Fish and Game, and UAF/UW research cruises. Catch information and samples from the cruises are used to study the life history, feeding ecology, demographics, age, and growth of spiny dogfish. Laboratory analyses of stable isotopes from theses samples will be used to determine what trophic level spiny dogfish are in the ecosystem. Current sleeper shark research, done in cooperation with the UAF, examines AFSC survey catch, sleeper shark movement, and the species' trophic level to better understand the sleeper shark's ecological role in Alaska.

Shark Tagging Studies

The movements and habitat use of spiny dogfish and sleeper sharks are being studied with the use of several tag types**:** visual tags, satellite tags, sonic tags, and archival tags. Visual tags, either spaghetti or plastic disk types, do not record data but provide information on the general movement of an animal from when and where the animal was tagged and subsequently recaptured. Satellite tags record depth and temperature, among other data, and are programmed to release after a specific duration. The tags float to the surface and transmit their data to satellites, which in turn transmit that data to the AFSC**.** Archival tags are similar to satellite tags in that they record depth and temperature, but unlike satellite tags, archival tags are surgically implanted requiring the fish be recaptured before the data can be retrieved. Sonic tags emit a unique signal which is picked up by either a network of submerged hydrophones or a boat-mounted hydrophone. Sonic tags transmit data such as depth and location whenever the tagged animal is within range of the hydrophone.

During 2004-2007, 617 visual, 167 archival, and 1 satellite tag were deployed on spiny dogfish; of this tagging effort, data from 2 archival tags and 1 satellite tag have been recovered. Detailed data from the tags are being analyzed, but preliminary location data from these tags suggest that spiny dogfish are highly migratory; the median distance travelled by the two archivally tagged spiny dogfish was 1,568 km over 265 days, and the satellite-tagged spiny dogfish travelled 753 km in just 66 days. In 2004, 24 sleeper sharks were sonic-tagged in Southeast Alaska. Thirteen tags successfully transmitted data within 1 month of tagging and showed that sleeper sharks moved very little in that time period; they moved an average of 6 km a day and migrated vertically throughout the day.

Spiny Dogfish Age and Growth

The spiny dogfish, as its name suggests, has hard enamel-covered spines anterior to each dorsal fin. The spines are used in determining age. Each year as the animal grows the spine grows and enamel is laid down. When the animal is growing fast (summer) the enamel is thinner, and when growing slow (winter) the enamel is thicker. This creates an annular or banding pattern where each pair of light and dark bands represents 1 year. These spines can easily be aged and measured using only a low-powered microscope by counting the number of band pairs present on the spine. Scientists at ABL have found that for unworn spines, growth follows a predictable linear pattern as the animal grows (Fig. 5). One problem with using external structures such as spines for ageing fish is that the spines tend to be broken or the tips worn and the number of worn band pairs must be estimated. By plotting the number of band pairs against the size of the unworn spine, the number of worn band pairs can be estimated for the remaining spines. A comparison of the growth patterns of dogfish spines in British Columbia and Gulf of Alaska indicated that there can be regional differences.

Spiny Dogfish Population Demographics

Population demography is the mathematical modeling of abundance and spatial distribution and how these features change over time through the processes of birth, migration, and death. This type of analysis

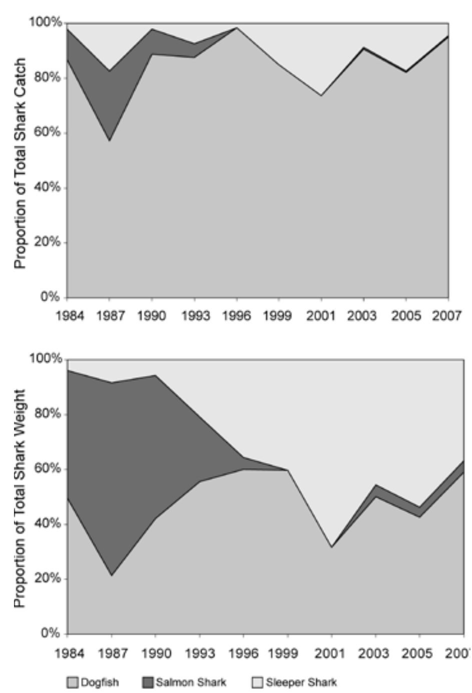


Figure 2. Proportion of shark catch for each of the three primary species of shark caught during the AFSC bottom trawl survey. The top panel is the proportion of total catch for each species in numbers and the bottom is the proportion of total weight caught for each species.

Table 2. Summary of shark catches (in numbers and weight) during the AFSC bottom trawl survey (1984-2007).

	Catch numbers			Weight (kg)		
	Salmon shark	Spiny dogfish	Sleeper shark	Salmon shark	Spiny dogfish	Sleeper shark
1984	5	39	1	672	715	57
1987	16	36	11	2,334	715	281
1990	13	126	3	1,559	1,257	172
1993	9	154	13	1,000	2,361	886
1996	1	681	11	116	1,632	972
1999	0	96	17	0	1,724	1,167
2001	0	56	20	0	943	2,038
2003	2	327	32	342	3,927	3,579
2005	1	137	29	180	2,091	2,629
2007	2	341	16	250	3,627	2,267
Total	49	1,993	18	6,453	18,992	14,048

can provide critical information about a population's ability to tolerate fishing pressures. For the spiny dogfish demographic analysis, ABL scientists are considering using a stage-based model with five stages rather than a strictly age-structured model. The stage-based model categories correspond to biologically significant life stages: neonates, juveniles, subadults, pregnant adults, and nonpregnant adults. This model is based on the idea that some stages may take longer than others. Results of this analysis will provide information such as population growth rate, natural mortality, and tolerances to fishing pressure. The population growth rate indicates how fast the population will grow or shrink at a given level of fishing pressure and life history traits (survival and fecundity). Early results suggest that the population of spiny dogfish in the Gulf of Alaska may only be able to tolerate very low levels of fishing mortality (less than 5%), and that the population growth rate is among the lowest for all studied shark species. Thus far, we have not included the migratory character of spiny dogfish; however, it is possible that Gulf of Alaska dogfish are part of a larger North Pacific population. Inclusion of migration will enable us to more realistically evaluate the ability of Gulf of Alaska dogfish to recover from fishing.

Spiny Dogfish Relative Abundance Trends

There are no directed fisheries or surveys for sharks in Alaska marine waters; consequently, abundance estimation is limited to indirect methods. In a collaborative project between the AFSC and UW, catch rates of spiny dogfish from many sources were modeled to estimate abundance. Catch rates from the International Pacific Halibut Commission annual longline survey, the AFSC sablefish longline survey, and the North Pacific Observer Program (commercial fishery data) from 1979 to 2005 were reconciled into one model to estimate total dogfish catch and relative abundance trends. The catch model showed periodic increases in catches but did not show an overall trend of increasing or decreasing catch over the entire time period. Scientists determined from this study that though spiny dogfish are not currently overfished, the potential for overfishing is high due to the slow growth and late maturation of dogfish and the relatively high bycatch in Alaskan fisheries.

Sleeper Shark Relative Abundance Trends

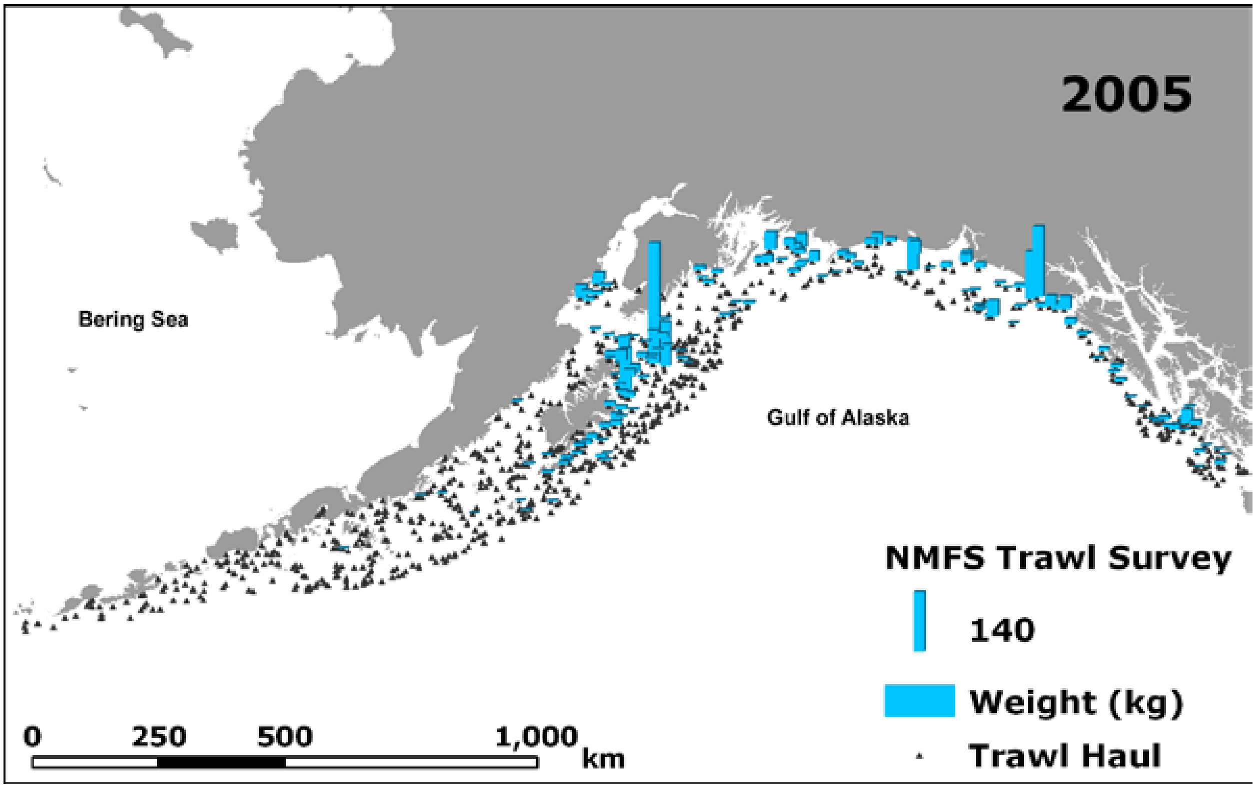
As with spiny dogfish, abundance estimation of sleeper sharks is limited to indirect methods due to the lack of directed survey and fishery data. Catch of sleeper sharks in the AFSC sablefish longline surveys from 1979 to 2003 was analyzed to assess trends in sleeper shark relative abundance. Based on the surveys, sleeper shark abundance increased in the eastern Bering Sea during 1988–94 and in the Gulf of Alaska during 1989–2003, but decreased in the Gulf of Alaska in 1997. The increasing trend in the Gulf of Alaska was driven entirely by one region, Shelikof Trough, where most (54%) sleeper sharks were captured. Whether increasing trends in the survey data represent an actual increase in the abundance of sleeper sharks at the population level or just reflect changes in local densities is unknown.

MANAGEMENT OF SHARK CATCH

Most shark fisheries worldwide are considered overfished or in danger of becoming overfished. On the U.S. East Coast a targeted fishery for spiny dogfish developed in the late 1980s and was declared overfished in 1998. Consequently, on the East Coast there are restrictions on the catch of spiny dogfish, which can affect other fisheries that incidentally catch them. Conversely, on the West Coast there has been a targeted fishery for spiny dogfish for over a century, and only in recent years has abundance become a concern.

In the Gulf of Alaska, there are no targeted fisheries for sharks of any kind in Federally-managed waters, and in state waters some sportfishing charters target salmon sharks. In Alaska state waters, sport fishing regulations limit fishermen to one shark per day and two per year. Commercially, in state waters, retention of dogfish is only allowed for set-net and longline fishermen in Yakutat Bay and through a special permit for other fisheries. There is interest in developing a market for Gulf of Alaska spiny dogfish, and fish processing plants in Kodiak and Yakutat Bay have purchased them. Globally, the species is highly valued for a number of products: vitamin A (from the liver oil), skin, fillets, belly flaps, fins, and eggs. In comparison, there is no demand for sleeper shark products, and a target fishery is unlikely to develop. Although salmon sharks are tasty, the market in Alaska is a tourist based catch-and-release fishery.

Federally, sharks are managed as part of the "Other Species Complex," along with such species as squid, octopus, and sculpins. Regulations allow fishing operations to retain up to 5% of their total catch as "Other Species." Accurately accounting for the incidental catch of sharks in commercial fisheries can be difficult. In Federal fisheries, vessels greater than 60 ft in length must carry an observer for at least part of the time, so an estimate of the numbers of sharks caught by those vessels exists. Vessels under 60 ft are not required to carry an observer, and limited information is available on the amount of shark catch on these vessels. Catch is also unaccounted for in many state fisheries, such as the salmon set-net fisheries where there can be very high catches of spiny dogfish in the summer. This incidental catch has been reported (anecdotally) to be as high as tens of thousands of dogfish in 1 day, requiring the



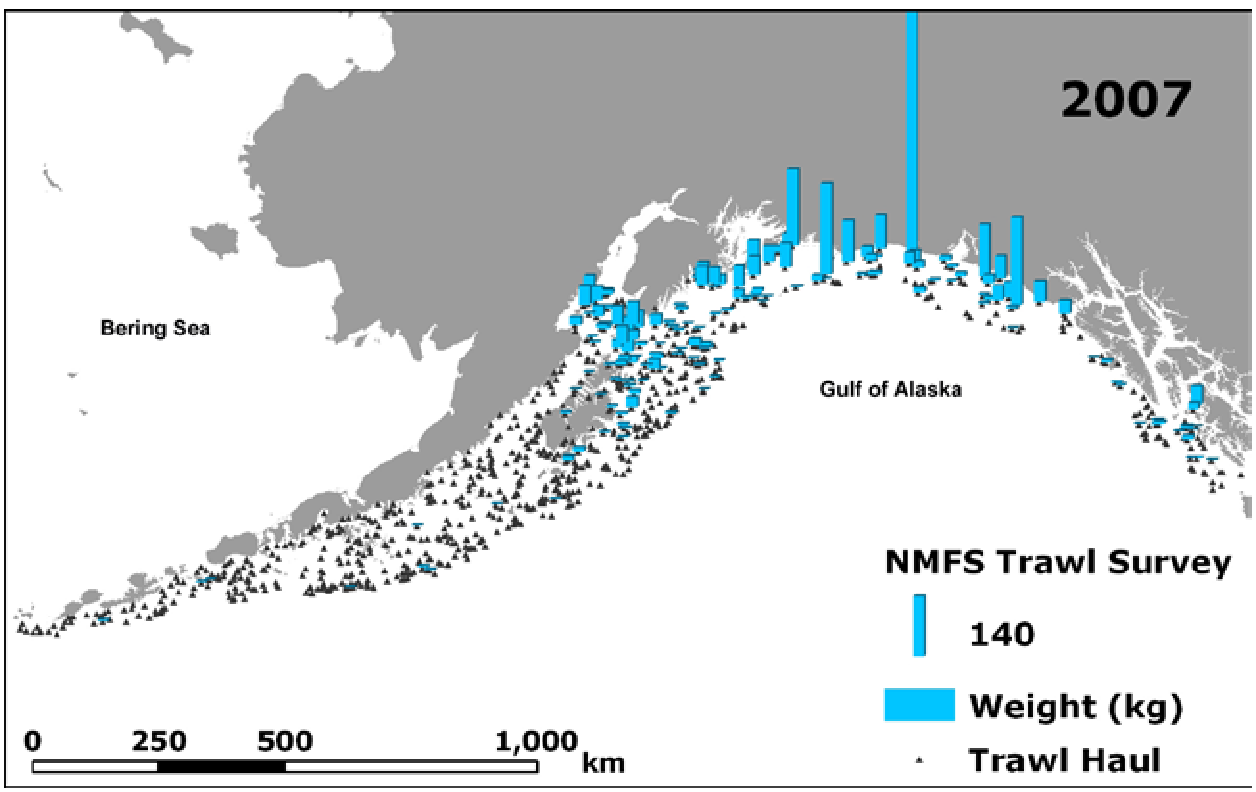


Figure 3. Total weight of dogfish caught (kg) during the 2005 and 2007 Gulf of Alaska bottom trawl survey. Triangles represent each haul with no dogfish caught, bars represent hauls with dogfish caught. The height of the bar is scaled to the weight in kilograms of dogfish caught, with the legend example bar being 140 kg.

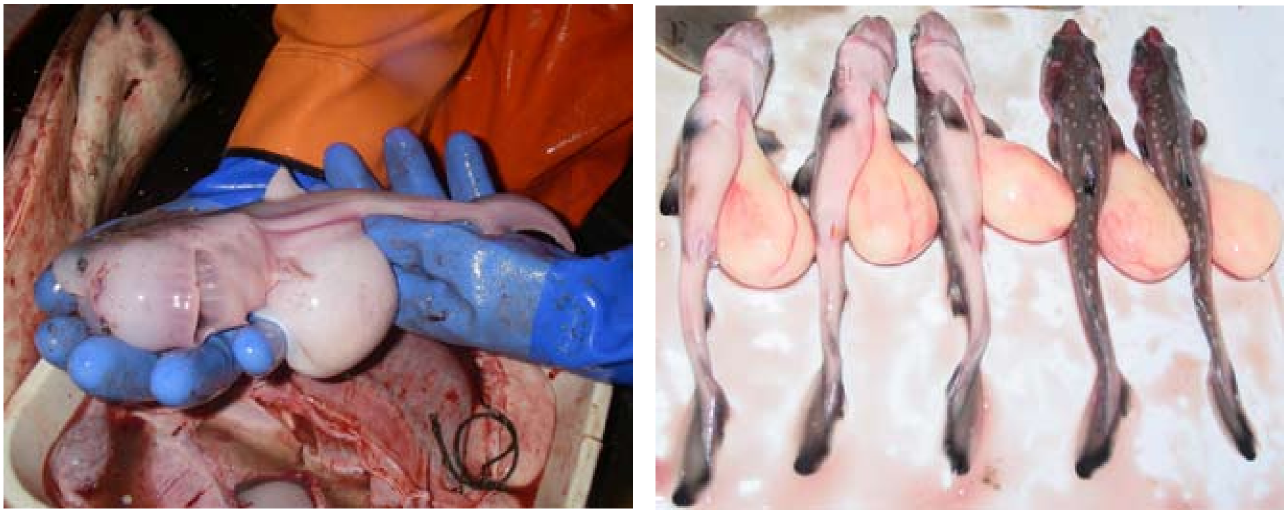


Figure 4. The left panel shows a salmon shark pup, about halfway through gestation. (Collected by Robert Foy, Kodiak Laboratory/Alaska Fisheries Science Center during a University of Alaska Fairbanks research survey). Note the distended belly and large head for eating unfertilized eggs. In comparison, the right panel shows spiny dogfish pups approximately three-quarters through gestation. They still have an external yolk sac, but are very similar in proportion to grown dogfish. Photos by Robert Foy and Cindy Tribuzio.

fishermen to abandon their nets, resulting in very high mortality rates of sharks.

GRENADIER BACKGROUND

At least seven species of grenadier are known to occur in Alaska waters, but only three are commonly found at depths shallow enough to be encountered in commercial fishing operations or in fish surveys: giant grenadier (*Albatrossia pectoralis*), Pacific grenadier (*Coryphaenoides acrolepis*), and popeye grenadier (*Coryphaenoides cinereus*). Of these, giant grenadier has the shallowest depth distribution and the largest biomass, and hence is by far the most frequently caught grenadier in Alaska. Because of this importance, we focus here on giant grenadier.

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur worldwide in all oceans. Also known as “rattails,” they are especially abundant in waters of the continental slope, but some species are found at abyssal depths. Giant grenadier is a continental slope species that ranges from northern Baja California, Mexico, around the arc of the North Pacific Ocean to northern Honshu, Japan. The fish also extends north in the Bering Sea to approximately lat. 62ºN and is found in the Sea of Okhotsk. In addition, giant grenadier have been caught on at least nine seamounts in the Gulf of Alaska and on at least five seamounts in the Emperor Seamount chain of the North Pacific. Giant grenadier are reported to have a depth range of 140–2,189 m, although the fish are usually found in depths greater than 300 m.

A unique characteristic of the giant grenadier is its large size (Fig. 6). The family Macrouridae is quite speciose with well over 300 species worldwide. Giant grenadier is the largest in size of all these species. Total length is reported to exceed 150 cm. Largest known weight of an individual is 41.8 kg, based on a specimen sampled in a trawl survey of the eastern Bering Sea.

Despite the abundance of giant grenadier in Alaska, there is little information on its commercial catch, biology, distribution and abundance, and population characteristics in Alaska. Only two published studies have included data on the biology of Alaskan giant grenadier as part of larger studies on this species in the North Pacific Ocean, and one of these was based on data collected over 40 years ago. Additional information on giant grenadier in Alaska waters is scattered in various survey reports and in survey and fishery databases.

All species of grenadier in Alaska are presently considered “nonspecified species” by the North Pacific Fishery Management Council (NPFMC), which is responsible for setting groundfish quotas in Federal waters in Alaska. This means that grenadiers have not been included in any of the NPFMC fishery management plans and that there have been no limitations on catch or retention, no reporting requirements, and no official tracking of grenadier catch by management. However, in 2005 the NPFMC began examining a proposal that would modify the existing management struc-

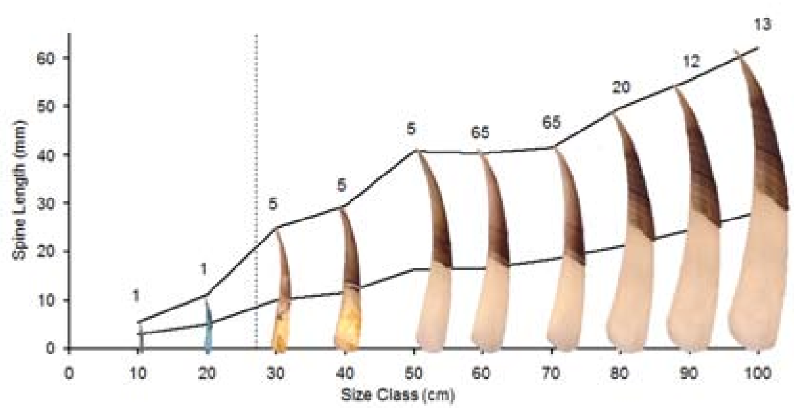


Figure 5. Relationship between dogfish size and average second dorsal spine length, for unworn spines. The top line is the total spine length and bottom line is the base length. Numbers represent the sample size for each 10 cm size bin. The dotted vertical line is the approximate size at birth for spiny dogfish.

ture to include grenadiers in the management plans. If this proposal is adopted, the NPFMC would then need to establish levels of overfishing (OFL), acceptable biological catch (ABC), and total allowable catch (TAC) for grenadiers in Federal waters of Alaska. The possibility that giant grenadiers may soon be part of the groundfish management structure in Alaska was a major reason that ABL began research on this species in 2005. In addition, research on giant grenadier is especially needed at this time due to the recent emphasis in fishery science on an ecosystem approach to management, and the fact that giant grenadier are so abundant on the slope that they are an extremely important component of the ecosystem.

Recent research at ABL on giant grenadier includes analysis of data on giant grenadier from fisheries and survey databases to estimate catch levels, abundance, and appropriate harvest levels, as well as field and laboratory research to determine important population parameters such as maturity, growth, and mortality. Also, in situ observations of giant grenadier and other grenadiers have been made from a deep-sea submersible.

Figure 6. A large giant grenadier caught during the annual AFSC longline survey in Alaska. Photo Auke Bay Laboratories.

GIANT GRENADIER RESEARCH AT AUKE BAY LABORATORIES

Commercial Catch

Virtually all the catch of giant grenadier in Alaska has been taken incidentally in fisheries directed at other species, particularly sablefish and Greenland turbot. All the giant grenadier catch is discarded, and the discard mortality rate is 100% because the pressure difference experienced by the fish when they are brought to the surface invariably causes death. As mentioned, no official catch statistics exist for grenadiers in Alaska because they are considered "nonspecified" species by the NPFMC. However, catches for giant grenadier have been estimated for the years 1997-2006 (Table 3). These estimates are based largely on data collected by the AFSC's Fisheries Monitoring and Analysis Division, which places observers aboard commercial fishing vessels through its North Pacific Groundfish Observer Program. Alaska-wide annual catch estimates of giant grenadier have averaged 16,000 metric tons (t), with about 11,000 t taken in the Gulf of Alaska; 3,000 t in the eastern Bering Sea; and 2,000 t in the Aleutian Islands. Of particular importance is the relatively large catch of 11,000 t in the Gulf of Alaska, mostly taken by the sablefish longline fishery which operates on the continental slope of the Gulf. This catch represents one of the largest bycatch amounts for any species in the area.

Survey Information

Fishery-independent surveys of the continental slope off Alaska have been conducted since the late 1970s using both bottom trawls and longlines; these surveys provide much information on distribution and abundance of giant grenadier. Areawide biomass estimates are computed from the trawl surveys, whereas indices of abundance are computed from the longline surveys.

Bottom trawl surveys in the relatively deep continental slope waters inhabited by giant grenadier in Alaska have generally been too intermittent to determine abundance trends over time. However, results of recent eastern Bering Sea and Gulf of Alaska trawl surveys emphasize the great abundance and important ecological role of giant grenadier in Alaska waters. In both the 2002 and 2004 eastern Bering Sea slope trawl surveys, giant grenadier was by far the most abundant species and comprised about one-half the total biomass for all species at depths 200-1,000 m on the continental slope (Fig. 7). Similarly, in the 1999 and 2005 Gulf of Alaska surveys, giant grenadier was the most abundant slope species at depths 200-1,000 m and composed approximately one-third of the total biomass in this stratum.

Bottom trawl surveys in Alaska consistently indicate that female and male giant grenadier have different depth distributions, with females inhabiting shallower depths than males. For example, in the 2005 Gulf of Alaska trawl survey, females greatly predominated at depths less than 700 m, whereas males only became moderately abundant in the deepest stratum sampled, 700-1,000 m (Fig. 8). Although there has been no information on sex distribution of giant grenadier in the commercial fishery[1], the survey data indicate that the catch is overwhelmingly female because most of the commercial effort is in water less than 700 m. Disproportionate removal of females by the fishery may have important management implications, as it clearly reduces the spawning potential of the stocks and could put them at greater risk of overfishing if catches were sufficiently large.

In contrast to the intermittent time series of the trawl surveys, longline survey abundance data for giant grenadier has been available annually for the Gulf of Alaska slope since 1990. Since 1996, the longline survey has also sampled the Aleutian Islands and eastern Bering Sea slopes in alternating years. The primary purpose of these surveys is to assess abundance of sablefish, but giant grenadier are also caught in large numbers. The longline surveys in the Gulf of Alaska generally showed an increasing abundance trend for giant grenadier from 1992 to 1997 and then somewhat of a decrease in subsequent years. However, interpretation of abundance trends for giant grenadier in

[1] For the first time, observers on commercial vessels in 2007 began collecting data on sex distribution of giant grenadier in the catch, but these data have not been analyzed as of the date of this article.

Table 3. Estimated catch in metric tons (t) of giant grenadier in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska, 1997-2006.

	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska	Total
1997	2,964	2,887	12,029	17,881
1998	5,011	1,578	14,683	21,272
1999	4,505	2,883	11,388	18,776
2000	4,067	3,254	11,610	18,931
2001	2,294	1,460	9,685	13,439
2002	1,891	2,807	10,479	15,177
2003	2,853	3,556	12,321	18,730
2004	2,225	1,123	11,964	15,311
2005	2,581	1,676	7,190	11,447
2006	2,068	2,222	8,291	12,581
mean	3,046	2,345	10,964	16,355

Table 4. Giant grenadier mean catch rates (no. caught/100 hooks), by area, during AFSC longline surveys of the continental slope in Alaska, 1990-2006. Bering areas 3 and 4 are located on the slope northwest of the Pribilof Islands, and Bering areas 1 and 2 are located south of the Pribilof Islands. Data are not available for the NW and SW Aleutian Islands areas.

Area	Mean catch rate
Eastern Bering Sea	
Bering 4	19.1
Bering 3	23.9
Bering 2	8.6
Bering 1	1.3
Aleutian Islands	
NE Aleutians	20.2
SE Aleutians	25.6
Gulf of Alaska	
Shumagin	25.8
Chirikof	21.5
Kodiak	12.1
W Yakutat	6.3
E Yakutat	3.6
Southeastern	3.1

the longline surveys is difficult, especially because competition for hooks with sablefish may have an effect on catch rates. To address this possible problem, ABL is planning future research to account for the effect of competition between species in the longline survey. Longline survey catch rates consistently indicate that greatest abundance of giant grenadier in Alaska is in the western Gulf of Alaska, eastern Aleutian Islands, and in some areas of the Bering Sea (Table 4). The catch rates also provide evidence for the extreme abundance of giant grenadier in these areas. For example, in the southeast Aleutian Islands region and western Gulf of Alaska, giant grenadier were caught on more than 25% of the hooks that were set. In the Gulf of Alaska, there appears to be a definite decline in catch rates as one progresses from the west to the east. This is supported by trawl survey results, which also show giant grenadier are much less abundant in the eastern Gulf of Alaska.

Appropriate Harvest Levels for Giant Grenadier

Though there is no directed fishing for giant grenadier and the incidental catch appears relatively modest compared to the commercial catch of targeted species, giant grenadier may be especially susceptible to overfishing for a number of reasons. These include their discard mortality rate of 100%, the disproportionate catch of females (discussed previously), and the documented general vulnerability of many deep-sea fish species to overfishing because of their peculiar life history traits. These traits often include longevity, slow growth, low fecundity, late maturation, low metabolic rates, and not spawning in some years, all of which may be characteristic of giant grenadier.

An analysis was conducted to determine if overfishing has occurred for giant grenadier in Alaska. This analysis was based on using estimates of biomass and natural mortality (M) for giant grenadier to compute OFL and ABC. Results indicated that catches have been much less than the computed OFLs and ABCs, especially in the eastern Bering Sea and in the Aleutian Islands (Table 5). Therefore, the biomass of giant grenadier in Alaska appears to be sufficiently high to support the catches that have been taken. Higher catches could probably be taken in the eastern Bering Sea and the Aleutian Islands, but fishery managers may want to exercise caution if catches increase in the Gulf of Alaska or if a targeted fishery for giant grenadier develops in this area.

Field and Laboratory Studies on Giant Grenadier Maturity, Age, Growth, and Mortality

Because giant grenadier is not a commercially important species, there has been little research directed at its life history. Many aspects of the species' maturity, age, mortality, and growth are still unknown. To investigate the biology of giant grenadier in Alaska, scientists at ABL sampled giant grenadier during the summer AFSC sablefish longline surveys in 2004 and 2006. Ovaries were developmentally characterized at sea, and samples of otoliths and ovaries were taken for laboratory analyses. Back at the lab, otoliths were aged by the AFSC Age and Growth Program in Seattle, and portions of the ovaries were thin-sectioned and mounted on slides for a microscopic evaluation of ovarian development (Fig. 9). Fecundities were also calculated for samples that had late developed eggs.

In both years, giant grenadier ovaries were in all stages of development, which indicates that their spawning period is likely very long and could encompass much of the year. Because giant

Table 5. Computed overfishing levels (OFL) and acceptable biological catch (ABC) for giant grenadier in the eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA). For comparison, the mean estimated catch of giant grenadier for the years 1997-2006 is also shown. OFL, ABC, and mean catch are in metric tons (t).

Area	OFL	ABC	Mean catch
EBS	31,148	23,361	3,046
AI	39,731	29,798	2,345
GOA	27,852	20,889	10,964
Total	98,730	74,048	16,355

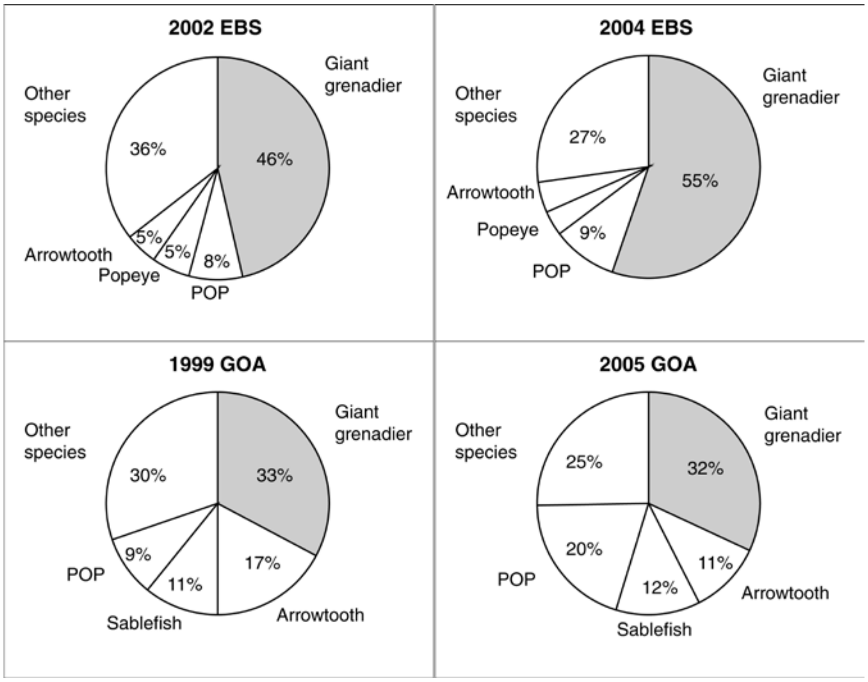


Figure 7. Biomass estimates (%) of species caught in recent bottom trawl surveys of the eastern Bering Sea (EBS) and Gulf of Alaska (GOA) continental slope at depths 200-1,000 m. (Arrowtooth = Arrowtooth flounder, POP = Pacific ocean perch, Popeye = Popeye grenadier).

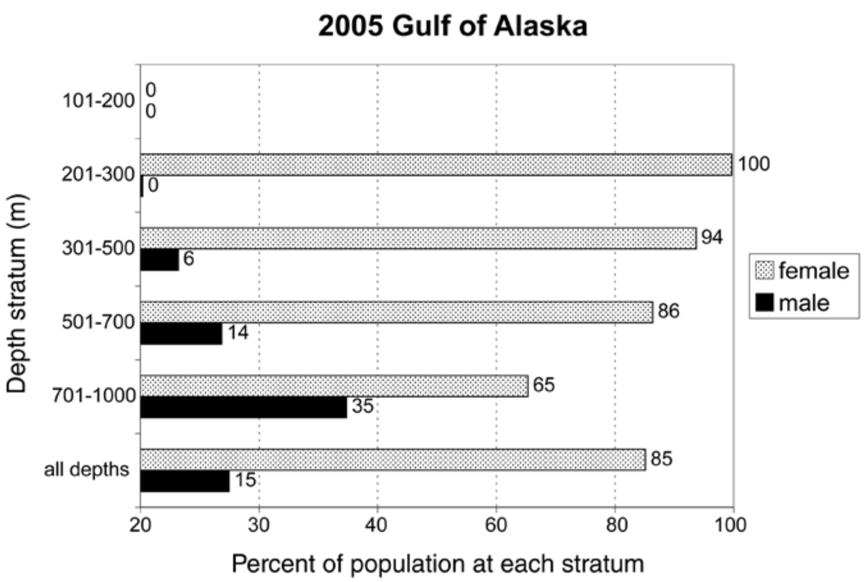


Figure 8. Sex distribution, by depth stratum, of the estimated population of giant grenadier in the 2005 bottom trawl survey of the Gulf of Alaska.

grenadier is a deepwater species, and there is little seasonality in deep waters, spawning and hatching time may not be restricted by environmental variables. Other studies have found that various species in the grenadier family also have a long spawning season. To pinpoint the spawning season of giant grenadier, year-round extensive sampling would be necessary.

Ages from otoliths indicated that the giant grenadier samples ranged from 14 to 58 years old. Relatively small giant grenadier are sometimes caught in trawl gear but are not caught on longline gear. However, very small giant grenadier are almost never captured in any fishing gear because their early life-stages are thought to be pelagic; it is unknown at what age or size the fish settle to the bottom of the ocean. The species likely lives even longer than 58 years because specimens much larger than the largest fish in our age samples have been caught on the AFSC longline survey. The age at which 50% of female giant grenadier mature was 24.9 years when a microscopic evaluation was used to stage ovaries and 21.7 years when visual staging at sea was used—a difference of 3.2 years (sample size = 292). This discrepancy can be attributed to the incorrect assignment of mature fish as immature in the at-sea stages. Total fecundity ranged from 35,000 to 231,000 oocytes (mean = 106,761, standard deviation = 58,687).

No ovary classification system can distinguish spent or resting from immature fish 100% of the time because the signs of spawning are ephemeral. Because ovarian walls can thicken after maturity is reached, we were able to successfully place 31% of ovaries with an unknown maturity status into the "immature" or "post-spawned" categories based on wall thickness measurements from the slides. Because there was some overlap in the wall thicknesses of immature and mature ovaries, there were some "unknown" ovaries that could not be placed into the immature or post-spawned category.

Scientists with the AFSC's Age and Growth Program found that the giant grenadier otoliths had three distinct shapes, which is not typical for most fish species. Some differences in the growth of giant grenadier were also noted between fish with different otolith shapes. The cause of the different otolith shapes is unclear, and AFSC scientists are still examining the possibility that giant grenadier are actually two or more species. Alternatively, otolith shape could differ by grenadier populations or by different life-history backgrounds. Research on validating the ageing of giant grenadier otoliths and the potential that giant grenadier are actually more than one species is currently being investigated by the Age and Growth Program.

In this study, natural and total mortality rates were estimated using several existing methods. Estimates of natural mortality ranged from 0.052 to 0.106 and estimates of total mortality were 0.047 and 0.149. The data indicate that giant grenadier are a long-lived, late-maturing species, with low natural mortality. Other species that also are late maturing and very long-lived, such as rockfish (*Sebastes* spp.),

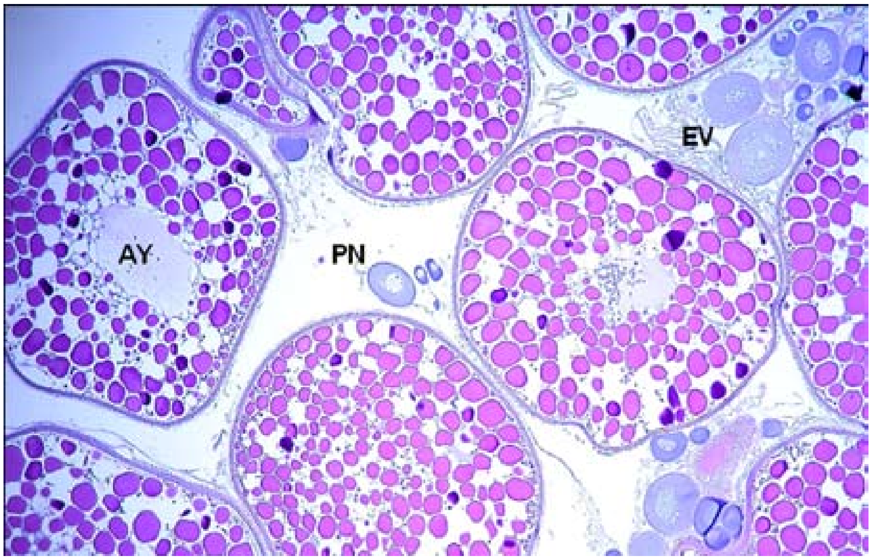


Figure 9. Micro-photograph of a thin-sectioned mature giant grenadier ovary with advanced yolked oocytes (AY, which are almost ready to be released as fully developed eggs), perinuclear oocytes (PN, which are very early developing), and early vacuole stage oocytes (EV, which are in the early stages of developing into a yolked oocyte). Photo by Cara Rodgveller.

Figure 10. Underwater video photograph taken from the ROV *Jason II* of what are believed to be two giant grenadier at a depth of 1,203 m in the Aleutian Islands. Photo by Doris Alcorn.

have similar estimates of M (0.02-0.09), so the estimates we found are reasonable.

Observations from a Deep-Sea Submersible

Underwater observations of grenadiers provide valuable data unattainable with trawl or longline sampling. For example, little is known about the life history and habitat of giant grenadier that live below the maximum sampling depths of our surveys (generally 1,000 m). Scientists at ABL are presently analyzing grenadier observations based on deep-sea video taken from the remotely operated vehicle (ROV) *Jason II* in the central Aleutian Islands in 2004 (Fig. 10). Video is being analyzed from seven dives in depths from 170 to 2,947 m. Thus far we have observed grenadiers from 8 cm to more than 100 cm total length and have observed grenadiers of vastly different sizes (and species) in close proximity-within 1 m of each other. Individuals greater than 80 cm total length can often be identified as giant grenadier based on their size and the depth where they were observed, but species identification from the video is less certain for smaller fish, which may include other species such as Pacific or popeye grenadier. This study will provide valuable information on grenadier depth distribution and associations between grenadiers and bottom habitat, as well as grenadier density estimates.

CONCLUSION

Though sharks and giant grenadier in Alaska are ecologically important and are incidentally caught in considerable numbers, considerable uncertainty remains about the biology and population dynamics of these fishes. Because of their ecological roles and their potential for overharvest, continued research on the biology and life history or sharks and giant grenadier is needed. Research projects at ABL have been directed at learning more about the age, growth, maturity, mortality, and abundance trends of these species. Research at ABL has also uncovered information on the demographics of spiny dogfish and movements of Pacific sleeper sharks.

Future ABL research on sharks will include close monitoring of catch and improving the reliability of catch estimates in commercial fisheries, as well as examining the movement patterns of both spiny dogfish and Pacific sleeper shark within the Gulf of Alaska and neighboring regions. Additionally, studies on spiny dogfish will focus on small spatial scales to investigate if there are geographic differences in biological characteristics. Future giant grenadier research will include a deepwater longline survey to examine the distribution and relative abundance of giant grenadier at depths deeper than 1,000 m, the maximum depth of the AFSC longline survey. An understanding of how hook competition between giant grenadier and sablefish on the longline survey affects giant grenadier catch rates is required to accurately assess trends in grenadier abundance. Validation of the ageing of giant grenadier will also be important for the confirmation of the maturity and growth work presented here.

Sharks and grenadier are both long-lived and slow-growing species that are not well understood. The goals of the research at ABL are to better understand the life-history, biology, abundance, and incidental catch, of these species, so that effective management decisions can be made.