INVESTIGATION OF BYCATCH AND THE ECOLOGY OF SHARKS IN THE BERING SEA

ABSTRACT

The proposed project investigates the demography and trophic ecology of salmon sharks and Pacific sleeper sharks caught as bycatch in Bering Sea pollock fisheries. Salmon sharks and Pacific sleeper sharks are caught as bycatch at levels between 200 and 1,400 metric tons annually. It is not known if the shark population in Bering Sea can sustain these levels of removal. Very little is known about the life history of these sharks in the Bering Sea or about their role in the ecosystem as top level predators. The PIs propose to use a suite of mathematical population and ecological models to characterize the bycatch of sharks in the Bering Sea pollock fishery and quantify the potential impacts of bycatch on the population. Current information from the Gulf of Alaska on sharks suggests that only segments of the salmon shark population migrate in and out of Alaskan waters and that Pacific sleeper shark have a relatively small home range. This data suggests that the impacts of bycatch may not be consistent among life history stage, sexes, or species. The PIs propose to collect archived data regarding shark population structure and commercial bycatch. In addition the PIs propose to collect data aboard commercial pollock at-sea processors to estimate demographic, reproductive, and diet variables. Considerable support has been offered by the pollock industry, in particular by the At-Sea Processors, to adequately assess the potential impacts of shark bycatch so that informed mitigation efforts can be implemented. The outcome of this study will be an integrated understanding of ecosystem function and likely consequences of the removal of such levels of shark biomass in the Bering Sea.

BACKGROUND AND RELEVANCE TO PCCRC RESEARCH PRIORITIES

PCCRC research priority 3b) focuses on “improving knowledge and education relating to the assessment of important non-target species stocks” such as large sharks. As such, the PIs propose to assess the importance of shark bycatch and to address the feasibility of using commercial ships of opportunity to collect meaningful data regarding bycatch rates, life history, and feeding ecology of sharks in the Bering Sea. Our underlying hypothesis is that bycatch is an ecosystem level phenomenon that can be controlled, if not eliminated, and that there are consequences associated with large scale perturbations of the ecosystem, such as bycatch. Further, it remains to be determined whether these perturbations are indeed significant. Of the several North Pacific elasmobranch species (sharks and skates), this proposal focuses on salmon sharks (*Lamna ditropis*) and Pacific sleeper sharks (*Somniosus pacificus*), two of the largest fish species in the North Pacific Ocean.

The PIs propose a modest three year study to mine the appropriate data from traditional ecological knowledge of fishermen, NMFS observer databases, NMFS survey databases, and International Pacific Halibut Commission (IPHC) databases for shark abundance and bycatch information. While some of this data has already been collected for the North Pacific Fisheries Management Council (NPFMC; Courtney et al. 2005) the quality of the data and the uncertainty in the estimates of abundance and bycatch are not clear. These data will be used to provide the best possible information about the Bering Sea bycatch of sharks prior to the beginning of field work. The field work will provide the first data directed at modeling the salmon and Pacific sleeper shark dynamics in the Bering Sea. The objectives of this proposal would not be attainable with the proposed budget without industry assistance on-board their ships. As a consequence, the data collected over a three year project will stand alone as a valuable source of information contributing to the overall goal of understanding bycatch implications.

The PIs will also pursue additional funding to carry out a more costly and extensive project to address shark bycatch by proposals to the North Pacific Research Board and Alaska Sea Grant. This work would allow greater temporal and spatial coverage in the Bering Sea and also provide a better database for modeling life history parameters. The current study will focus on a single sector (pollock at-sea processors) of the commercial fishing fleet in the Bering Sea while additional efforts to get funding from other sources will focus on other fisheries that work in different areas and times. Shark diets collected from a broader habitat are likely to encounter additional prey items such as marine mammal parts. While the current budget does not support DNA analysis of these parts to species the additional projects to be proposed will include identification of pinnipeds and cetaceans. Recent studies in the Gulf of Alaska found little evidence for Pacific sleeper sharks depredation on Steller sea lions (Sigler et al. 2006). Additional funds will also be used to use satellite tags to study the migration and movement patterns of salmon and Pacific sleeper sharks. These data are critical to understanding the true extent of the shark populations in the North Pacific and the associated impact of bycatch.

To sustain commercial fisheries in the North Pacific Ocean and Bering Sea, the interactions of targeted species with other non-targeted species, especially long lived, slow growing, low fecund species such as sharks, must be quantified. The Principal Investigators on this proposal intend to develop a multiyear program to quantify these important interactions. With the help of the commercial fishing industry, data will be collected to adequately assess the role of sharks in the Bering Sea ecosystem so that potential risks associated with bycatch of these species can be determined. Although usually studied separately, demography of an apex predator and their ecological role will be studied concurrently in part because of the high costs of obtaining samples. As a result, the impact of bycatch on the Bering Sea shark population as well as the broader impact upon the Bering Sea ecosystem of the large scale removal of sharks will be studied. The relevance of this research program to the goals of the PCCRC, specifically those related to the pollock fishery, is high.

Is shark bycatch an issue?

Vessels associated with the At Sea Processors in Seattle, Washington have noted a potential increase in shark bycatch during pollock and sablefish Bering Sea fisheries (personal communications; Dr. Edward Richardson and Dr. Kevin Duffy, Executive Director of At Sea Processors). Shark biomass estimates from the National Marine Fisheries Service (NMFS) bottom trawl survey and bycatch estimates from the NMFS observer database have also increased through the early 2000's (Figures 1-3; Courtney et al. 2005). Although data is limited, bottom trawl data collected by the NMFS indicates that total shark biomass (dominated by salmon, Pacific sleeper and dogfish sharks) increased in the 1990's to a peak in 2002 of 6,000 and 25,000 mt on the eastern Bering Sea shelf and slope, respectively (Figure 1; Courtney et al. 2005).

Estimated bycatch rates of sharks in the Bering Sea from a combination of observer and NMFS catch data increased from a total of 400 mt in 1997 to 1400 mt in 2002 (Figure 2; Gaichas 2001, 2002, Courtney et al. 2005). Pacific sleeper shark bycatch dominated the total with a peak of 800 mt followed by salmon sharks with a total of 50 mt, both in 2002 (Figure 2; Courtney et al. 2005). Between 1997 and 2002, both species of shark were caught incidental to fisheries in 11 of 17 Bering Sea and Aleutian Island statistical and reporting areas, however, 77% of Pacific sleeper shark and 74% of salmon shark bycatch was focused in 2 areas in particular (517 and 521, Boldt et al. 2003). The majority (87%) of the salmon shark bycatch occurred during the pollock trawls in 1997-2001 while the Pacific sleeper shark bycatch occurred during the pacific cod longline (30%), pollock trawl (26%), and turbot longline (17%) fisheries (Courtney et al. 2004).

Generally, as the total shark biomass in the Bering Sea increases, the bycatch rate also increases (Figure 3; Courtney et al. 2005) suggesting that understanding the trophic relationships, migration patterns, and life history characteristics of these species is important to understanding ***when*** they will interact with commercial fisheries in the Bering Sea. To determine ***what*** the relative impact of these bycatch trends is will require a quantitative assessment of what life history stage of shark is being caught and the relative importance of each shark to the Bering Sea Ecosystem. This has not been directly studied in the Bering Sea.

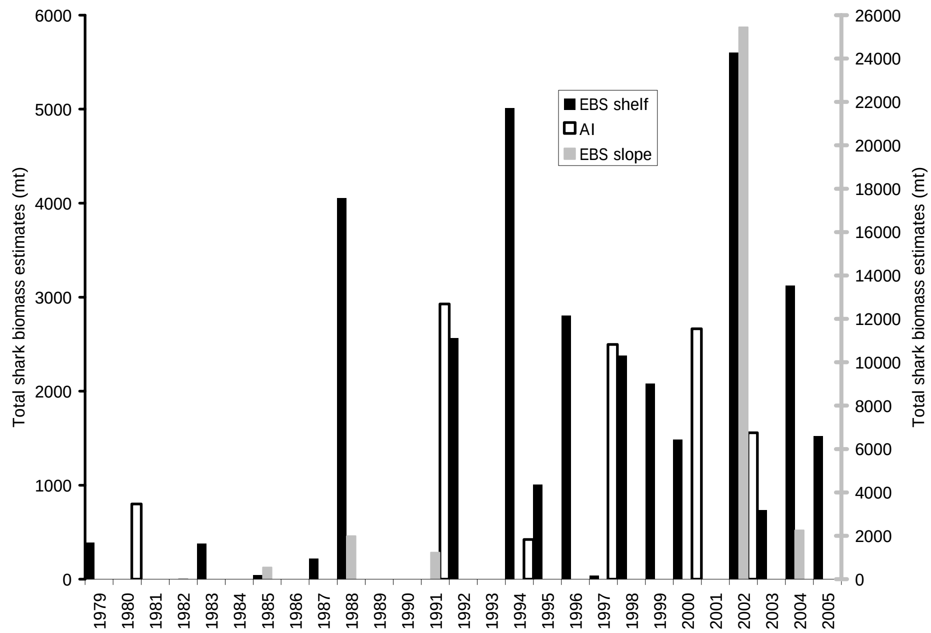

Figure 1. Total shark biomass (mt) estimated for the Eastern Bering Sea slope, Eastern Bering Sea shelf, and the Aleutian Islands based on NMFS bottom trawl surveys. Data are directly from Table 12 in Courtney et al. 2005. Note that data was not collected in all years and does not reflect a zero value. Grey bars (EBS slope) correspond to the right y-axis.

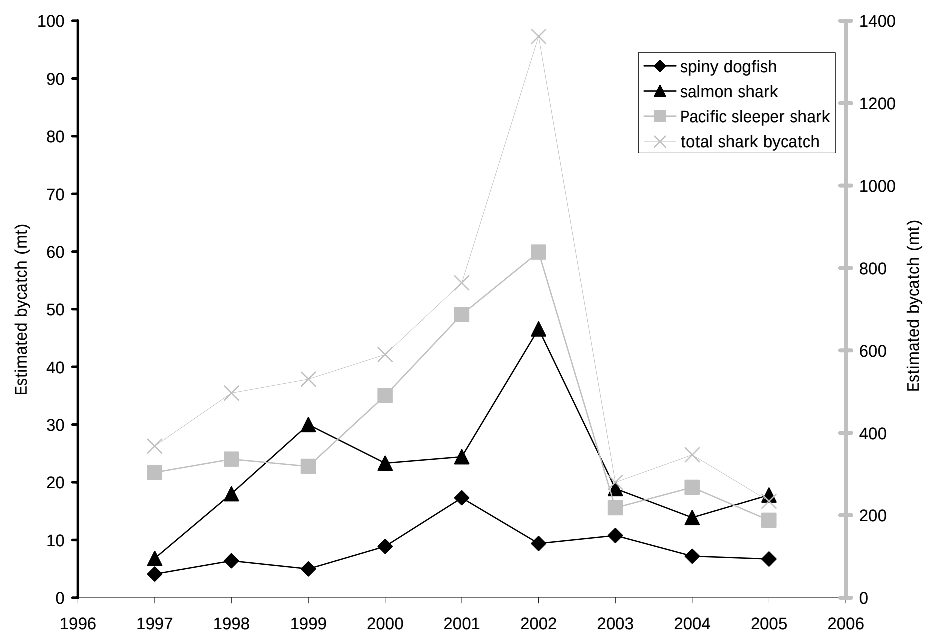

Figure 2. Estimated shark bycatch (mt) in the Eastern Bering Sea and the Aleutian Islands based on NMFS observed fishery catches. Data are directly from Table 3 in Courtney et al. 2005. Note that data was estimated differently in 1997-2002 than from 2003-2005.

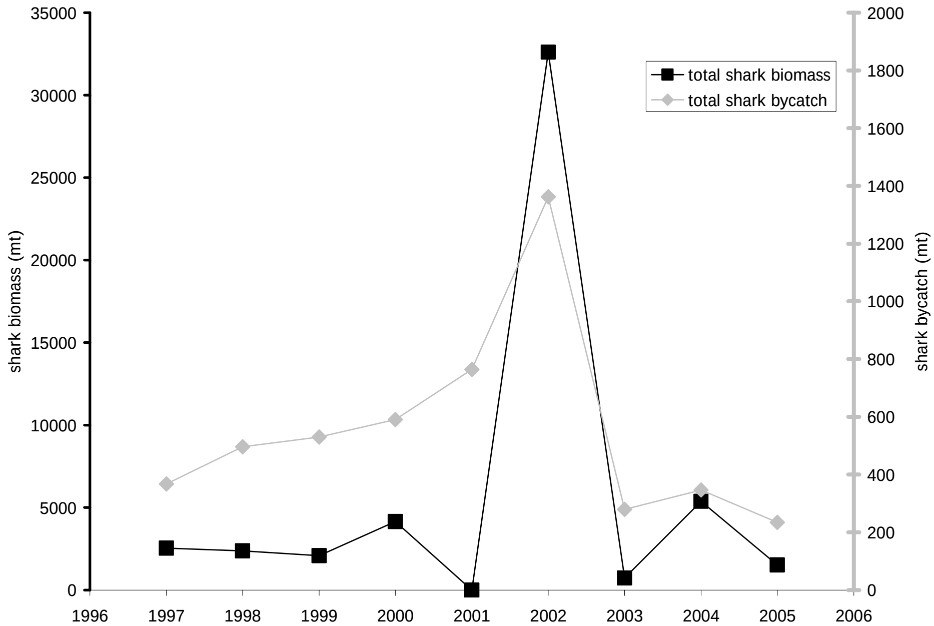

Figure 3. Total shark biomass (mt) estimated for the Eastern Bering Sea slope, Eastern Bering Sea shelf, and the Aleutian Islands based on NMFS bottom trawl surveys. Data are directly from Tables 3 and 12 in Courtney et al. 2005. Note that bycatch data was estimated differently in 1997-2002 than from 2003-2005. Also note that bottom trawl data was not collected in all years from all regions of the Bering Sea and Aleutian Islands so this represents only an index of biomass.

Shark bycatch importance to management and industry

The north Pacific Fisheries Management Council (NPFMC) has initiated discussions to amend current Fishery Management Plans to include criteria for managing non-targeted species. The goal of the non-target management would be to protect them from overfishing. One of the groups under consideration is "sharks". The Council notes that most of the non-target species are not well surveyed and are data poor with respect to life history. The creation of such management groups would necessitate focused efforts to fill in the gaps on life history, stock, and trophic information to manage and mitigate bycatch of species such as sharks.

The Alaska pollock fishery is currently certified by the Marine Stewardship Council by conforming to rigorous environmental standards for sustainable and well-managed fisheries. To maintain certification, the industry must meet conditions related to the impacts of the fishery on essential fish habitat, biodiversity, and functional relationships with endangered, threatened, or icon species. Gathering data on the potential impacts of pollock fisheries on large shark populations in the Bering Sea is one step towards addressing these conditions and assuring an environmentally sound sustainable fishery.

Shark Biology: salmon shark

The three main shark species caught in Alaska waters are salmon sharks, Pacific sleeper sharks, and spiny dogfish. This proposed study focuses on the 2 largest species, salmon and Pacific sleeper sharks. The salmon shark ranges in open and coastal pelagic zones from the Koreas, north to the Bering Sea, and south to Mexico (Compagno 1984). Male and female salmon sharks in the eastern North Pacific (Kodiak Island to southern California; n=182) have been aged to 17 and 20 years, respectively (Goldman and Musik 2006). This study suggested that eastern North Pacific salmon sharks had faster growth rates, time to sexual maturity and greater weight at length than western North Pacific salmon sharks (Nagasawa 1998). In general, salmon sharks approach 3 meters in length and can weigh over 150 kg, however, females are known to be larger than males at the same age. More information on this sexual dimorphism is required before adequately estimating population abundance and demographic parameters. Salmon sharks have been found to migrate over long distances during the winter between Alaska (Gulf of Alaska and Bering Sea) to the oceanic transition zone and to southern California including open ocean migrations as far south as Hawaii (22°N) (Hulbert et al. 2005, Weng et al. 2005). Female salmon sharks remain relatively local during the summer and then migrate south from Prince William Sound in the winter (Hulbert et al. 2005, Weng et al. 2005). Subadults migrated as far south as Los Angeles, CA (1000 km west) while adults remained in the Gulf of Alaska. Males have not been sampled in Prince William Sound but have been found in the Bering Sea and dominate the sex ratio in the western north Pacific (Blagoderov 1994, Nagasawa 1998). More information is required on male salmon shark movements in the eastern North Pacific and on both male and female movements in the Bering Sea before seasonal abundance estimates can be accurately estimated.

Data on size, sex, and maturity of salmon sharks intercepted by commercial fisheries are not currently available in the Bering Sea. Modeling the standing stock of salmon sharks for predictive purposes becomes particularly uncertain without further information about the fraction of the females that migrate, whether all that do migrate are pregnant, and whether males migrate. There is further uncertainty as to whether shark sizes and ages are different in the Bering Sea than in Prince William Sound.

Shark Biology: Pacific sleeper shark

The Pacific sleeper shark ranges on the continental shelves and slopes from Japan, north to the Bering Sea and south to Mexico (Compagno 1984). Pacific sleeper sharks grow to about 7 m and weigh over 400 kg (Compagno 1984). Pacific sleeper sharks tagged (n=48) in the Gulf of Alaska were found to migrate relatively short distances of 100 km (76%) and 500 km (8%) within a year (Hulbert et al. 2006). Movement patterns of sonically tagged Pacific sleeper sharks in Glacier Bay National Park were also minimal (Hooge and Taggart, submitted). Given the apparent minor movements of Pacific sleeper sharks, demographic and diet data currently available for Pacific sleeper sharks in the Gulf of Alaska may not be applicable to Pacific sleeper sharks caught in the Bering Sea. In addition, more information is required about the potential movement differences between sexes.

Data on size, sex and maturity of Pacific sleeper shark intercepted by commercial fisheries are not currently available in the Bering Sea. Modeling the standing stock of Pacific sleeper sharks for predictive purposes becomes particularly uncertain without some reproductive information, especially without guidance about the reproductive output and possible relationships to the size structure and abundance of the population. There is further uncertainty as to whether shark sizes and age and sex distributions are different in the Bering Sea in comparison to the data available from the Gulf of Alaska.

Shark trophic ecology

Predation plays an important role in structuring and regulating prey populations in an ecosystem. Top level consumers may determine the fate of all populations in an ecosystem (Carpenter et al. 1985). Control of a system, by a top level predator, has been illustrated for relatively simple freshwater systems (Carpenter et al. 1985). Such control has been difficult to clearly illustrate in larger, more complex marine ecosystems (Link 2002). The Georges Bank fish community in the Northwest Atlantic is described as a predator controlled ecosystem (Tsou and Collie 2001). This system has undergone dramatic changes in community structure due to the over-exploitation of valuable, top level fish predators (Fogarty and Murawski 1998). The system is now dominated by elasmobranchs (sharks and skates) and other lower valued piscivores (Collie and Delong 1999). Predation by these piscivorous species is the most dominant source of mortality on pre-recruit fishes in the Georges Bank fish community (Collie and Delong 1999, Overholtz et al. 1999, Tsou and Collie 2001). Predation on the early life stages of marine fish may contribute to the extensive fluctuations seen in some stocks (Bailey and Houde 1989, Bax 1998). In the Georges Bank ecosystem, the dominance of the piscivorous fish species in the system may be altering the rate of recovery of the valuable groundfish species (Fogarty and Murawski 1998). Understanding how species interact, through competition and predation, is valuable for managers in predicting long term trends in multispecies fisheries (Tsou and Collie 2001).

Large shark species are known to be important apex predators which can affect the community structure of complex ecosystems (Link 2002). Furthermore, it has been suggested that sharks may be fundamental to the maintenance and stability of marine communities, fulfilling the role of keystone predators (Hinman 1998). In addition to their characteristic position within their food webs, sharks exhibit a number of other distinct life history traits that require consideration. Sharks exhibit K-selected life history strategies, characterized by slow growth, delayed onset of sexual maturity, low fecundity and natural mortality, and greater longevity than that experienced by teleosts (Holden 1974 and 1977, Hoenig and Gruber 1990, Walker 1998). These life history characteristics, in combination with heavy exploitation rates, have led to rapid stock declines and fishery failures worldwide (Compagno 1990, Hoff and Musick 1990, Castro et al. 1999).

Shark populations have been receiving a great deal of attention due to their relative trophic position and the effects of fishing on their populations (Kitchell et al. 2002). In 1994, the member countries of the Convention of International Trade in Endangered Species of Wild Flora and Fauna (CITES) mandated a review of the status and trade in sharks (Stevens et al. 2000). The United Nations Food and Agriculture Organization International Plan of Action for Shark Conservation and Management in 1999 suggested that national shark fishery management plans be in place by 2001. This goal continues to be a priority for the organization and many of its member countries (Cavanaugh and Fowler 2004) as the threat faced by many shark species continues to grow in step with the lucrative market for shark products. Therefore, it is important to understand the trophic status of sharks in the Bering Sea and address the impact that commercial pressure may *or* may not impose on the salmon shark and Pacific sleeper shark populations.

The trophic status of Salmon and Pacific sleeper sharks is not well documented in the Bering Sea, however, ecosystem models based on diet and life history patterns suggest that the role of sharks in the Bering is important (Jurado-Molina and Livingston 2002; Jurado-Molina et al. 2004; Jurado-Molina et al. 2005; Figure 4). Figure 4 represents a Bering Sea food web from Jurado-Molina and Livingston (2002) that has been adapted to include sharks showing sharks role as an apex predator of important commercially fished species. Salmon shark diets in the Gulf of Alaska (n=51) are dominated by four salmon species in June and July during the peak of the salmon return to spawning streams as well as sablefish, gadids, herring, rockfish, and squid in Prince William Sound (Hulbert et al. 2005). Vertical movements of Pacific sleeper sharks suggest that feeding may occur pelagically as well as demersally (Hulbert et al. 2006). Pacific sleeper sharks feed on teleosts (including tuna, salmon, gadids, grenadier, and flounders), other sharks, cephalopods, crustaceans, marine mammals, and carrion (Compagno 1984, Ebert et al. 1987, Orlov and Moiseev 1999, Yang and Page 1999). Pacific sleeper shark diets in the Gulf of Alaska (n=198) are comprised of diverse taxa including teleosts (mostly salmon), cephalopods, and marine mammals (frequency of occurrence = 15%) (Sigler et al. 2006). Larger sharks consumed a greater amount of teleosts and marine mammals. Cephalopods were seasonally most important in the diets during May. Marine mammals found in the stomach contents included grey whale (*Eschrichtius robustus*) and harbor seal (*Phoca vitulina*) neither of which was known to be predated or scavenged. Given the diverse diets and lack of diet data in the Bering Sea for both species, directed diets studies are necessary to adequately determine the potential ecosystem affects of sharks being removed due to bycatch.

OBJECTIVES/HYPOTHESES

The goal of this study will be to investigate bycatch and assess the trophic status of Pacific sleeper and salmon sharks in Bering Sea commercial fisheries. Our underlying hypothesis is that bycatch is an ecosystem level phenomenon that can be controlled, if not eliminated, and that there are consequences associated with large scale perturbations of the ecosystem, such as bycatch. Further, it remains to be determined whether these perturbations are indeed significant.

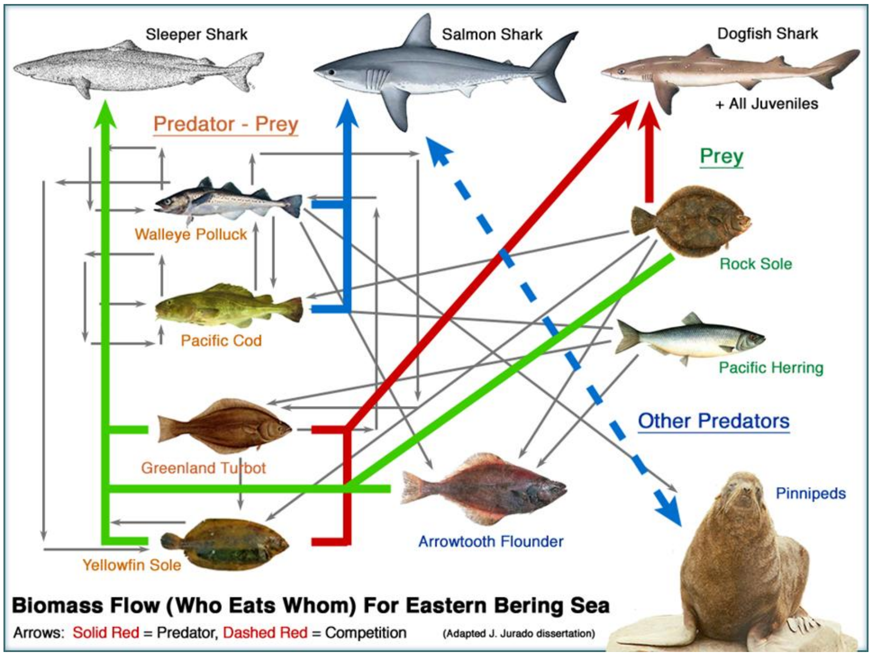

Figure 4. Depiction of biomass flow in the eastern Bering Sea. Inclusion of the three sharks species is a modification of Figure 1 in Jurado-Molina and Livingston (2002).

The objectives include:

- Characterization of the shark bycatch from multiple sources including but not limited to commercial fishing groups, NMFS, observer database, and the IPHC survey. This will include an analysis of appropriate methods for estimating bycatch in shark data limited databases.
- Characterization of the shark bycatch onboard the at-sea processors fishing pollock in 2007-2009.
- Collection of demographic parameters (vital rates including reproduction and survival) to support mathematical population projections.
- Identification of the diet composition of shark bycatch to support estimation of the trophic level of sharks based on species, size, and sex.
- Discuss the implication and impacts for the amount of bycatch that would result from changes in the spatial and temporal fishing patterns by the pollock at-sea processors in the Bering Sea.
- Discuss policy implication for adequate management for sustainable pollock fisheries and conservation of shark species in the north Pacific.

METHODS/ANLAYSES

Data Base Collections

The NMFS, IPHC, observer program, and the at-sea processors will be contacted to gain access to relevant shark bycatch data, while taking into consideration proprietary information. The databases that the NMFS and the industry have accumulated over the years will be central. While these databases do not contain any of the detailed information needed in the analyses described, they will present a time series of an index that will provide indications of trends and spatial-temporal dependencies. This data would be subject to immediate evaluation and statistical analysis to learn as much as possible to facilitate the most efficient field sampling possible.

a. It is anticipated that analysis of such data will reveal seasonal or spatial patterns of bycatch that were not otherwise apparent.
b. The patterns of bycatch will be considered in terms of changes in other species abundance and climate variability (PDO, temperature, and sea ice) in the Bering Sea.

c. To the extent made possible by the structure and consistency of the data, general linear and additive modeling of the data will be applied to obtain information about interdependencies in space and time and components of variance.

Field Data Collection

Data will be collected on board at-sea processor vessels during the pollock fisheries in the Bering Sea during 3 separate cruises coinciding with pollock spawning, summer, and winter aggregations in 2007-2009. Three years of data are necessary to ensure that our sample size is large enough to accomplish our objectives on board commercially operating vessels. In addition, interannual differences in bycatch rate will be related to environmental and spatial variables to address potential fishing practices that reduce future shark bycatch. Dr. Kevin Duffy with the At Sea Processors in Seattle, Washington has demonstrated the value that the industry places on understanding shark bycatch by offering to cover the expenses of transporting scientists to and from his vessels from Dutch Harbor, providing accommodations while on board the vessel, and providing personnel to assist data collection on other vessels that do not have scientists aboard. Scientists will run training sessions for personnel on multiple vessels to collect samples for life history and trophic information from bycatch when scientific crew are not on board. No live sharks will be handled or sacrificed in this study.

The following data will be collected from sharks caught during commercial operations by scientific personnel:

- Life history: length, weight, vertebrae samples for future age determination study.
- Demography: sex, reproductive status, maturity stage
- Trophic status: stomach contents, muscle for isotopes

The following data will be collected from dead sharks caught during commercial operations when scientific personnel are not present:

- Life history: length, weight, vertebrae samples for future age determination study.
- Demography: sex
- Trophic status: muscle for isotopes
- Pictures of each shark will be taken to help assess length, reproductive status and maturity stage.

The PIs will also collaborate with NMFS and other researchers in the Bering Sea to help collect data important for ongoing Bering Sea research. This includes but is not limited to collecting water samples for the Bering Ecosystem Study (BEST; Dr. George hunt). The PIs will make sure other PIs funded through the NPRB Bering Sea Integrated Research Plan and BEST programs are aware of our efforts and ability to collect addition samples during our cruises.

Laboratory Analysis

<u>Population demography: Reproductive biology, genetics, and age</u>

Although a full stock assessment of sharks in the Bering Sea is part of a larger project proposed to be funded by multiple sources, data will be collected from each shark to apportion that part of the stock impacted by bycatch. Reproductive tracts of all sharks sampled will be collected and transported to Seattle. The timing of first reproduction and the number of pups will be determined as a function of size and/or age.

Genetic samples will also be taken to address questions of parentage. Given the potential long range migration of salmon sharks and the local movement patterns of Pacific sleeper sharks, identification of distinct stocks among the western vs. eastern North Pacific, Gulf of Alaska, and Bering Sea will be important.

Whereas it is possible to carry out length based stock assessment modeling, the variances of estimators that result are much greater than when stock assessment modeling is based on age (Lai and

Gallucci, 1985; Gallucci et al. 1995). Thus, effort will be made to do at least a preliminary age determination of both shark species from cartilage along the spine to build an age - length key. While some efforts have been successful with salmon sharks (Goldman and Musick 2006), no progress with Pacific sleeper sharks has been made. Our age determination methods will focus on the use of a scanning electron microscope (SEM) as well as light microscopes with stained samples.

<u>Trophic Ecology: Stomach contents and stable isotopes</u>

Stomachs will be removed from cloth bags and excess liquid will be blotted off with a paper towel. Each stomach will be weighed (0.01g) before and after removing the contents to estimate content weight. A determination of stomach fullness and digestion stage will also be recorded for each specimen. The following stomach fullness indices will be used: 1 - empty, 2 - 25% full, 3 - 50% full, 4 - 75% full, and 5 - 100% full based on a stretched stomach estimating maximum capacity. Indices for digestion stage will be: 0 - pristine, no digestion, 1 - mostly pristine, 2 - mostly digested, 3 - fully digested. Empty stomachs will be assumed to be real although potential regurgitation during capture may bias this value. Observation of any regurgitation while the sample is brought on board will be noted and incorporated into the analysis. The stomach contents will be gently rinsed with distilled water over the sieve to rinse off formalin residue. Prey organisms will be separated, counted, and identified to the most practical taxonomic level. This will include identification of teleosts, invertebrates, and marine mammal tissue. Marine mammal tissue will be frozen for future analysis when funds are available for DNA testing. Whole fish specimens will be measured (1.0 cm) and weighed (0.01g). An attempt to identify digested fish prey will be made by using otolith and other bony structures. Data from all specimens will be recorded and later entered into a database.

Stable isotope analysis is a useful way to determine trophic position. Multiple stable isotopes of carbon and nitrogen occur naturally in the environment. The natural proportions of ^{12}C and ^{13}C are 98.9 % and 1.1 %, respectively; those of ^{14}N and ^{15}N are 99.64 % and 0.36 %, respectively. During chemical and metabolic processes, however, the isotopic ratios change in a process called fractionation. It is fractionation that allows the isotopic ratios to be useful in ecological studies. During metabolic processes, the heavier isotope is preferentially retained which slightly increases the isotopic ratio of the tissue (DeNiro and Epstein 1978; Tieszen 1978). Isotopic ratios of carbon (C) and nitrogen (N) are expressed as $\delta^{13}C$ and $\delta^{15}N$, which is the difference between the $^{13}C/^{12}C$ or $^{15}N/^{14}N$ ratios of the sample and a standard and are expressed in parts per thousand (‰). The ratios are calculated by the equation:

$$\delta^{13}C \text{ or } \delta^{15}N = [(R_{sample} - R_{standard}) / R_{standard}] * 10^3$$

where R is the ratio $\delta^{13}C$ or $\delta^{15}N$, the standard for carbon is an isotopic equivalent to the Chicago Pee Dee belemnite ratios (Craig 1957), and the standard for nitrogen is atmospheric nitrogen (Rau et al. 1992). Samples showing increased concentrations of the ^{13}C or ^{15}N are termed “heavy” or “enriched” whereas those with lower concentrations are termed “light” or “depleted”.

Carbon isotopes have been used to study food webs in ecological studies (Fry and Sherr 1984). Predator tissues bear signature $^{13}C/^{12}C$ ratios that are directly related to those of their prey and have been shown to transfer in a predictable manner (Peterson and Fry 1987). $^{13}C/^{12}C$ ratios are often used as a sign of a consumer’s primary prey items as enrichment of $\delta^{13}C$ between trophic levels is limited to 0-1‰ (DeNiro and Epstein 1978; Peterson and Fry 1987; Hobson and Welch 1992).

In contrast, nitrogen isotope fractionations become more enriched with increasing trophic levels (Owens 1987). Therefore, nitrogen stable isotope ratios ($^{15}N/^{14}N$) are useful as a predictor of actual trophic level as $\delta^{15}N$ shows an increase of 3-4 ‰ with increasing trophic level (Peterson and Fry 1987; Post 2002). This disparity in nitrogen isotope fractionation occurs because the consumer’s metabolic processes preferentially utilize the lighter isotope (Rau et al. 1983; Minagawa and Wada 1984; Rau et al. 1992) where fractionations greater than 2 ‰ arise during metabolic processes within an organism (Parker 1964; van der Merwe 1982; Fry and Sherr 1984).

While the use of stable isotopes does have certain limitations, including a lack of known trophic fractionations as well as the assumptions involved in analysis (Estrada et al. 2003), it also has distinct advantages over traditional diet measures. Stable isotope analysis provides information that represents assimilated and not merely ingested prey and the isotopic ratios present in consumer tissue are indicative of long-term diet (Peterson and Fry 1987). Consequently, stable isotope analysis serves as a complementary method to stomach content surveys.

The stable isotope ratios of carbon and nitrogen for the individual salmon and Pacific sleeper shark tissues will be determined from a sample of the dry, lipid free protein remaining following lipid extraction. The protein will be finely ground in a coffee grinder before analysis. A 1 to 2 mg aliquot will be analyzed using a Europa Continuous Flow Isotope Ratio Mass Spectrometry System (CF-IRMS) to determine the $\delta^{13}C$ and $\delta^{15}N$ values.

Population Demography

A full assessment of the sharks in the Bering Sea must await additional funding from one of the sources named above. However, the critical first step toward an assessment will be taken with the funding from this proposed project. In particular, the demographic data such as fecundity, size of first reproduction, size specific survival, etc. will permit initial population projections and analytical evaluations of the status of the population (Cortes 1996). A demographic analysis built around a Leslie projection matrix will be used to carry out risk analysis of the population declining below pre-assigned levels (Silva and Gallucci submitted).

The risk analyses are constructed in the context of traditional methodology where instantaneous rates of mortality (such as bycatch mortality) are employed. For a possibly depleted population, traditional methodology may not be adequate so the “reproductive potential lost” due to bycatch will be applied (Gallucci et al. 2006). Elasticity analysis (Heppel et al. 1999) is another method that will be used to evaluate population health similar to what has been applied to the blue shark (Silva and Gallucci submitted). This analysis is sensitive to population decline under low harvest rates where the juvenile segment of the population is harvested. These three methods build upon the Leslie projection matrix yet overcome issues of a stable age distribution and fixed vital rates.

Estimation of abundance in heterogenous environments can be approached in several ways including catch per unit effort from pollock trawling survey (count per area swept) or longlines (count per number of hooks). However, realistic abundance estimates of salmon and Pacific sleeper sharks depend on knowledge of possible sex specific seasonal movements (Hulbert et al. 2005). This proposed study will provide critical data about the sex and life history stages caught in the commercial fishery. That data is necessary to design a project with adequate sample sizes, spatial and temporal coverage to estimate population abundance.

The bottom line to these analyses is the interpretation of the results bridging the mathematics and the shark populations. The Pacific sleeper sharks may exhibit primarily local movement patterns and thus re-colonization may take a long time. However, salmon sharks in the Bering Sea may be linked to the segment of the population that migrates south to the oceanic transition zone Understanding the distribution of ages and sexes in the Bering Sea for both species is a central part of the interpretation.

Implications for policy

There are at least two elements of concern in an evaluation of shark bycatch in the Bering Sea. The first concern is the loss of biomass and reproductive potential and the increase in the probability of extinction of a shark population. The second concern is the impact on the food web in the Bering Sea caused by the removal of a fraction of apex predators. Demographic analyses and trophic analyses proposed in this study will be used to address these two concerns respectively. If either case is evaluated as a risk when combined with ecological knowledge, it may be sufficient grounds for NGO expressions of concern to justify further limitations being placed upon the fishery. These may take the form of limitations on locations, seasons, and gear.

A major product of this management project in the Bering Sea is a contribution to the development of a program to facilitate bycatch reduction of these sharks. It is planned that at the conclusion of this project industry can be advised with respect to some of the practical aspects of its fishing practices and the consequences in terms of bycatch of large sharks.

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TIMELINE

2007-2008												
2007	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**
Data collection	**X**				**X**			**X**				
Diet analysis		**X**				**X**			**X**			
Isotope analysis		**X**	**X**			**X**	**X**		**X**	**X**		
Statistical Estimation		**X**	**X**	**X**		**X**	**X**	**X**		**X**	**X**	**X**
Mathematical modeling		**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**	
Annual report												**X**
Presentation at annual meeting							**X**					
2008-2009												
	J	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**
Data collection	**X**				**X**			**X**				
Diet analysis		**X**				**X**			**X**			
Isotope analysis		**X**	**X**			**X**	**X**		**X**	**X**		
Statistical Estimation		**X**	**X**	**X**		**X**	**X**	**X**		**X**	**X**	**X**
Mathematical modeling		**X**	**X**	**X**		**X**	**X**	**X**		**X**	**X**	**X**
Annual report												**X**
Presentation at annual meeting							**X**					
2009-2010												
	J	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**
Data collection	**X**				**X**			**X**				
Diet analysis		**X**				**X**			**X**			
Isotope analysis		**X**	**X**			**X**	**X**		**X**	**X**		
Statistical Estimation		**X**	**X**	**X**		**X**	**X**	**X**		**X**	**X**	**X**
Mathematical modeling		**X**	**X**	**X**		**X**	**X**	**X**		**X**	**X**	**X**
Presentation at annual meeting							**X**					
Final Report and thesis draft												**X**

PREVIOUS WORK FUNDED BY PCCRC

In 2004 Buck, C.L., Foy, R.J. and A.H. Haukenes were funded to study "Seasonal variation and metabolic performance of walleye pollock and the influence of water temperature". Our objectives for this study were to assess the physiological changes, metabolic rate, and swimming performance of pollock in two different temperatures. These objectives were tested in the Fall of 2004, Spring and Summer of 2006 on live pollock in the Kodiak Fisheries Research Center laboratories in Kodiak, Alaska. Final results indicating a greater impact of cold temperatures on the respiration and condition of pollock are being prepared for a final report and publication.

In 2000 Foy, R.J. and K.W. Wynne were funded to study "The quality of commercial fish species in Steller sea lion habitat units." The goal of this project was to determine the quality of fish species and energy density of fish available to Steller sea lions. Significant seasonal and interannual variability in the lipid and protein content of key sea lion prey species were found. These data have been used in numerous models related to predator-prey interactions in the Kodiak area (e.g. Buchheister, A., M. T. Wilson, R. J. Foy, and D. A. Beauchamp. 2006. Seasonal and geographic variation in condition of juvenile walleye pollock in the Western Gulf of Alaska. Transactions of the American Fisheries Society. 135:897-907.)

BUDGET JUSTIFICATION

We request 1 month of support Dr. Foy in each year to help set up the project design and to oversee the field collections and trophic assessment of sharks caught during this project. Dr. Foy has extensive experience with trophic ecology studies including diet and isotope methods. He has also worked with the commercial industry on a number of occasions to collect fisheries data. Eight months of a technician's time are requested to participate in sample collection, preparation, and laboratory processing at the Fishery Industrial Technology Center in Kodiak, Alaska. Dr. Foy will oversee 1 graduate student at the University of Alaska Fairbanks in years 2 and 3 of the project to assess the diets and trophic position (using stable isotopes) of sharks caught in the Bering Sea pollock fishery. Staff benefits are applied according to UAF's benefit rates for FY07 negotiated with the Office of Naval Research (ONR). A copy of the rate proposal is available at: http://www.alaska.edu/controller/cost-analysis/downloads /Negotiated/FY07_SB_Neg.pdf. Beginning in FY08 additional student healthcare costs are estimated to be $500 per semester.

We also request 3 trips for the PI and a technician or student from Kodiak to Dutch Harbor form field collections and fishery personnel training. A trip for the PI to collaborate with Co-PI in Seattle during years 2 and 3 of the project. A trip to the annual PCCRC meeting in Anchorage is scheduled for each year.

Supplies include raingear and miscellaneous sampling gear and a laptop computer in each of the first two years to be used for data entry on the back deck of the commercial trawler.

Services include Isotope analysis charges at the University of Alaska Fairbanks Isotope Facility. Also, publication, shipping, and communication charges are included. An additional service includes a subcontract to the University of Washington. Dr. Vince Gallucci and his student are being subcontracted to assess the population projections and the reproduction models at the University of Washington. Dr. Gallucci's experience with mathematical modeling and elasmobranch biology is critical to the success of this project. Drs. Foy and Gallucci will continue to collaborate as co PIs on additional proposed studies as outlined in the Background and Relevance section above (please see attached statement of work and budget for the University of Washington below).

Facilities and Administrative (F&A) Costs are not included in this budget per the Announcement of Availablity of Funds.

Industry Support

The contributions to be made by the At Sea Processors in Seattle, Washington are an enormous cost savings in the service category of the budget. The support to transport scientists to and from vessels from Dutch Harbor, to provide accommodations while on board the vessel, and to provide personnel to assist data collection on other vessels that do not have scientists aboard is substantial. Without this support, a vessel would need to be chartered for approximately 10 days in each of three sampling periods. This equates to a significant project savings which does not include gear or personnel time donated by the vessels. This kind of industry support and collaboration with scientists is critical to assessing the impacts and mitigation of bycatch in Alaska's fisheries.

University of Washington Budget Justification and Statement of Work

The University of Washington subcontract is for investigating the population demography of salmon and Pacific sleeper sharks in the Bering Sea during 2007-2009. Specifically, the subcontract is to collect data and mathematical analyses of the demography of the sharks to estimate whether the populations are increasing or decreasing using the methods of reproductive potential removed, elasticity and risk analysis.

This subcontract budget reflects 1 week of PI time for research in the Bering Sea and to supervise the work of a graduate student. The budget also reflects graduate student salary for nine months and tuition costs for three quarters for three years. Shannon O'Brien (RA student) will carry out research on the demography of the two shark species. She is a coauthor on a 2006 *Science* article with Dr. Ramón Bonfil on the migration of Great White sharks between South Africa and Australia using satellite tags. She is experienced with collecting biological information from large sharks. The collection of data is the first year's major task, with the second and third years' tasks increasingly devoted to the mathematical modeling of shark demography. We request 1 week of support for Dr. Vince Gallucci to primarily supervise mathematical modeling of the three different age structure analyses and to oversee general aspects of the data collection. Dr. Gallucci has extensive experience and a significant number of publications addressing shark population demographic models as well as extensive experience in the field collection of shark demography data. Three trips are included from Seattle to Dutch Harbor to participate in field data collections.