RESEARCH PLAN

A. Project Title

Full title: Evaluating acoustics for squid assessment in the Bering Sea
Short title: Squid acoustics

B. Proposal Summary

An assessment of squid density and distribution has not been conducted in the Bering Sea Aleutian Island (BSAI) ecosystem despite the importance of squid in marine mammal diets and potential competition between marine mammals and commercial fisheries. Squid are difficult to assess with conventional trawling and acoustics provides an alternate approach, surveying large distances over short time periods and snapshots of organisms throughout the water column. Our project will evaluate the potential of acoustic technology to assess Bering Sea squid. We will examine methods used to characterize acoustic energy from squid assemblages in the horseshoe region near Unimak Island. Candidate assemblages will be characterized (size, shape, location) with adaptive transects. We will evaluate the influence of light levels and behavior on squid characterization and assessment by surveying during day, crepuscular periods, and at night. A systematic survey with high resolution transects will evaluate horizontal distribution and patchiness of squid aggregations. To verify identity of squid, we will deploy a midwater or bottom trawl. Collected specimens will provide life history information for BSAI squid. We will calculate an index of squid density based on our systematic acoustic data and a catch per unit effort (CPUE) from our trawl catches. With the National Marine Fisheries Service (NMFS), we will compare these values with reported squid bycatch from the commercial walleye pollock fishery. In partnership with the University of Washington's Burke Museum, we will develop a teacher's kit or squid module to highlight North Pacific squid species.

C. Project Responsiveness to NPRB Research Priorities or Identified Project Needs

Our study addresses research priority ***2.c.i.*** *Stock assessment and life history of squid and sharks.* We will assess the potential for the use of acoustic technology to assess squid abundance. Our study will evaluate approaches used to acoustically characterize squid, conduct a preliminary systematic survey of squid in an area where squid are traditionally caught, and collect information on Bering Sea squid life history.

D. Project Design and Conceptual Approach

Introduction

Squid are an important, but poorly understood component of the BSAI ecosystem. Even though eighteen species of squid have been identified in the Bering Sea (Sinclair et al. 1999), little effort has focused on understanding their density distribution or life history. Squid populations are generally volatile, with recruitment and individual growth strongly tied to environmental conditions such as temperature (Rodhouse 2001, Forsythe 2004). For that reason, squid populations may respond rapidly to ENSO events or climate change (Forsythe 2004, Pecl and Jackson 2004). As squid are important in the diets of marine mammals such as northern fur seals and Steller sea lions (Sinclair and Zeppelin 2002, Ohizumi et al. 2003, Ream 2005) and represent significant bycatch in the Bering Sea walleye pollock fishery, gaps in squid life history and distribution data limit our ability to effectively manage squid stocks.

Although no directed squid fishery currently exists in Alaskan waters, both Japan and Korea have previously trawled for squid (Gaichas et al. 2004). Squid are currently fished in the Bering Sea outside of U.S. waters by Russia. The Russian fleet had a commercial catch quota of 141,000 mt in 2005 (Alaska

Pacific University 2006). In comparison, American or joint venture vessels captured 1,411 mt of squid in the BSAI ecosystem in 2006 through direct and indirect trawling (NMFS 2006a). The walleye pollock (*Theragra chalcogramma*) fishery accounts for approximately 98% of all squid captures in U.S. waters (Gaichas et al. 2004). Worldwide increases in demand for squid, coupled with declining production of squid in other areas, has increased export values for U.S. squid (FAO Fisheries Department 2005, U.S.D.A. 2005). The NMFS has acknowledged the possible rapid development of a directed squid fishery in the BSAI ecosystem (Gaichas 2005).

The ability of managers to set catch and bycatch rates for squid in the BSAI is hampered by the lack of quantitative stock information. No comprehensive survey of squid has been undertaken in the Bering Sea and "there is no reliable biomass estimate for squids, either in aggregate or by species, for any year in any (area) at this time" (Gaichas et al. 2004). For that reason, squid overfishing level (OFL), acceptable biological catch (ABC), and the resultant total allowable catch (TAC) are based on the catch history of squid between 1978 and 1995 (NPFMC 2005). This approach does not incorporate trends in abundance or biomass over time (Gaichas et al. 2004), and cannot compensate for interannual variability in squid recruitment (Agnew et al. 2000). This averaging approach provides no information on the spatial or temporal effects of fishery (by)catch on species-specific recruitment or within key marine mammal foraging areas.

In 2006, squid catches by the walleye pollock fleet surpassed the 1,084 mt TAC. As a result, NMFS prohibited retention of squid in the BSAI beginning in July (NMFS 2006b, NMFS 2006c). The combination of a > 500 mt squid bycatch in a single week (NMFS 2006a) and the threat of restrictions during the walleye pollock B season that would result if the OFL limit of 2,620 mt was exceeded (NMFS 2006c), industry cooperatives voluntarily shifted fishing operations out of the Unimak Pass/horseshoe region. This decision circumvented pollock fishery closure due to squid bycatch but forced the fleet to travel in excess of 300 nmi out of the usual fishing grounds during July and August. The combination of high bycatch in 2006, deficiencies in setting squid TAC levels, possible development of a directed squid fishery, and potential conflict between fisheries and marine mammals, all emphasize the need for a comprehensive assessment of Bering Sea squid stocks (Gaichas et al. 2004).

Assessing squid stocks is a complex task, and only a few assessments in the world have used fisheries-independent data. Periodic estimates of squid abundance and distribution have been performed using research bottom trawl surveys in the northwest Atlantic (Hendrickson et al. 2002). Japanese stocks have been measured using a combination of research and commercial fishery jigging data (Murata 1989, Kawabata 2005). Assessment of squid abundance or biomass using acoustic technology has occurred off the coast of Oregon (Starr 1985), around the Falkland Islands (Goss et al. 2001), and in Japan (Kawabata 2005). Acoustics has also been used to observe and map aggregations of spawning squid in South Africa (Sauer et al. 1992, Roberts et al. 2002). Data from acoustic surveys are considered to be a reliable direct estimator of squid stock abundance (Starr and Thorne 1998, Goss et al. 2001, Kawabata 2005).

In contrast to squid assessments, the use of acoustics to assess abundance of pelagic fish stocks is widespread. The ability of acoustic surveys to continuously survey large areas over short time periods provides a comprehensive snapshot of a population that is not possible to collect using other direct sampling technologies. Acoustics have been proposed as a strategy for the assessment of squid in the Bering Sea (Gaichas et al. 2004, Gaichas 2005). But to our knowledge, no dedicated project has been or is planned to assess the utility of acoustics for squid assessment in the Bering Sea by the NMFS.

Background

Acoustic echosounders send short (e.g. 0.2 msec - 1.0 msec), repetitive (e.g. 3 pulses s^{-1}) pulses of high frequency sound (e.g. 12 kHz - 420 kHz) into the water column in a narrow, directed beam. With each acoustic pulse, the entire water column is sampled at high resolution. When the sound wave encounters a density different from the surrounding water (e.g. fish swimbladder or squid), an echo is reflected back and is received at the transducer. This echo provides quantitative measures of target location, size, and abundance. Data from multiple pulses are used to construct continuous maps of target densities and sizes.

Echosounders operating at frequencies between 38 - 120 kHz are typically used for meso- and bathypelagic acoustic-based population assessments. Within that range, the lowest frequency (38 kHz) is able to detect larger targets such as fish while higher frequencies (120 kHz) are used in the identification of organisms such as euphausiids or fish without swimbladders (Figure 1). By determining the dependence on frequency for the intensity of scattering, frequency-dependent backscatter can be used directly or the differences between frequencies can be used to identify species. This approach is known as “frequency differencing” and is commonly used to discriminate species during acoustic surveys (e.g. Kloser et al. 2002). Return signals from all frequencies can be used to characterize aquatic organism distribution patterns in two ways: integrated energy, called volume backscatter, measures the total acoustic energy per unit volume being reflected from individual organisms or assemblages; target strength measures the intensity of returned energy from single animals (targets) and is used to measure target sizes. Measurements from free-swimming animals are referred to as “*in situ* target strengths.” Both volume backscatter and target strength measurements provide information on distribution and abundance and will be used in our study.

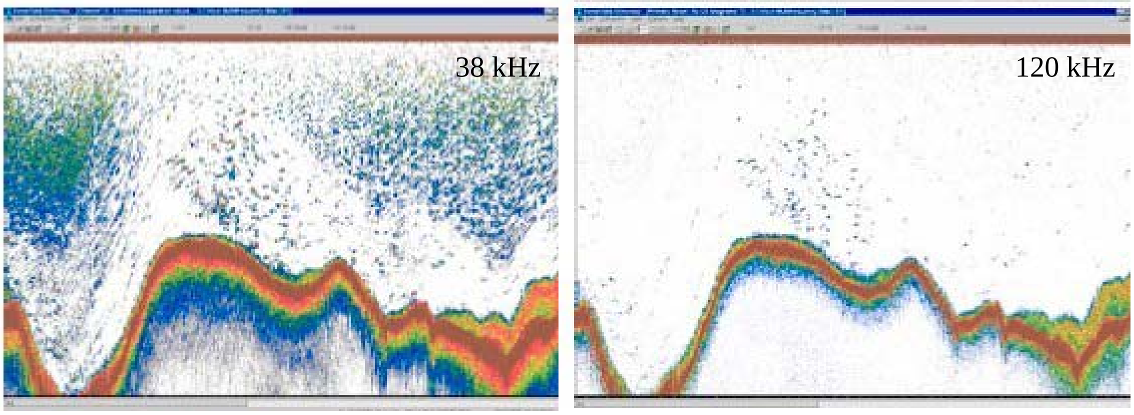

Figure 1. Echograms (depth vs distance) from 38 (left panel) and 120 (right) kHz echosounders. The 38 kHz echogram shows small swimbladdered fish and 120 kHz echogram shows fish without swimbladdders. Taken from Simmonds and MacLennan (2005).

Equipment

Our laboratory is currently equipped with state-of-the-art Simrad EK-60 splitbeam echosounders operating at 38 and 120 kHz. We are requesting funds to purchase a Simrad EK-60 70 kHz echosounder to provide an intermediate frequency for our survey. Although squid are detectable at these frequencies (Goss et al. 2001, Kawabata 2005), a 70 kHz intermediate frequency will provide an additional frequency that can collect data to several hundred metres depth and be used as a direct comparison to the 38 kHz echosounder (Goss et al. 2001, Bower and Ichii 2005). As the depth range of echosounder signals is related to both frequency and input power, 120 kHz echosounders are restricted to a range of approximately 200 m. Since squid in the Bering Sea are often on the continental slope during the day (Sinclair and Stabeno 2002), they will not be detected at 120 kHz. Conversely, a 70 kHz unit would penetrate to depths of approximately 500 m and would detect squid aggregations on the slope. During a June 2005 acoustic survey on the slope near Unimak Pass, an assemblage that was observed on the 38 and 120 kHz echosounders during the day (Figure 2) and subsequently trawled, contained high numbers of squid and Pacific ocean perch (*Sebastes alutus*).

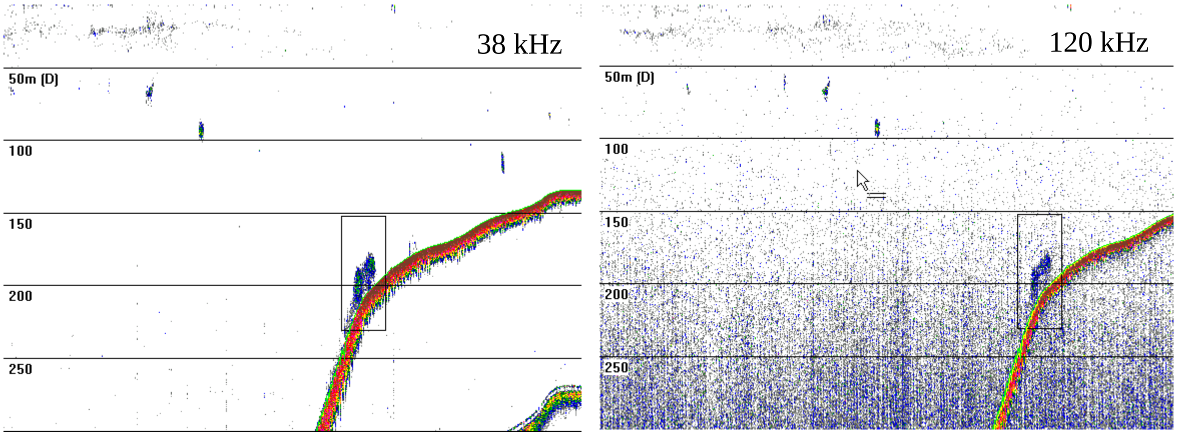

Figure 2. Echograms from Bering Sea slope survey in June 2005. Midwater trawl of this aggregation captured squid and Pacific ocean perch. Thresholds differed between the two images (-85 dB for 120 kHz and -65 dB for 38 kHz) to better show the aggregation. Note increased noise and loss of signal at ~200 m on 120 kHz echosounder.

Conducting our survey with 38, 70, and 120 kHz echosounders will allow us to characterize squid on the 38 and 70 kHz systems during the day, on the 38, 70, and 120 kHz systems at night, and on the 38, 70 and possibly the 120 kHz unit (depending on squid vertical migration patterns) during crepuscular periods. This suite of frequencies will allow us to test the efficiency of frequencies and frequency differencing to characterize squid. All echosounders will be calibrated with a tungsten carbide calibration sphere before or during our survey using procedures outlined in Foote et al. (1987).

Objectives

Our project will evaluate the potential of acoustic methods to assess squid in the BSAI ecosystem. We will investigate how to characterize acoustic backscatter from squid and will test our analytic techniques in a regional abundance assessment. By collecting specimens to identify organisms detected by the echosounders, we will also contribute to squid species distribution and life history information in the BSAI.

Our specific project objectives are to:

1. acoustically characterize squid assemblage size, shape, and target strength of individual animals during day
2. determine the influence of squid crepuscular and night movement/behavior on acoustic detectability and characterization
3. evaluate horizontal distribution and patchiness of squid schools
4. collect squid samples for species composition and life history information
5. compare an index of squid density based on acoustic measurements with squid bycatch from the walleye pollock commercial fishery
6. develop a public school outreach education program on Bering Sea squids in conjunction with the Education Department at the University of Washington’s Burke Museum of Natural History and Culture

Sampling and analytic strategies

General approach

Our sampling will be conducted along the shelf break in the horseshoe region near Unimak Island (Figure 3). Squid bycatch by the walleye pollock fleet has been consistently high during the B-season (June-

October) from at least 2000 to 2006. We will begin our survey in Area 1 (Figure 3) and if animals are not detected, we will shift survey efforts to Area 2. The survey will run over 14 days in late-August or September 2007, the period when large aggregations of squid are found feeding and spawning on the Bering Sea shelf break (Gaichas 2005, Elaina Jorgensen, Alaska Fisheries Science Center, personal communication). The exact survey dates will depend on fishing activity and the availability of fishing vessels for charter.

An example schematic of our sampling design is presented in Figure 3. Over the shelf break, we will survey systematic transects perpendicular to depth isobaths (Figure 3 right panel). This approach equalizes sampling effort among depths and minimizes bias due to assemblage trends in depth (Simmonds and MacLennan 2005). Between systematic transects we will also conduct a high resolution systematic survey (Figure 3 right panel B) to investigate horizontal variation in squid distribution. In addition to systematic transects, we will conduct short adaptive transects (Conners and Schwager 2002) to obtain high-resolution acoustic samples of specific assemblages (Figure 3 right panel C). Stationary data will be collected above squid assemblages during crepuscular and night periods (Figure 3 right panel D).

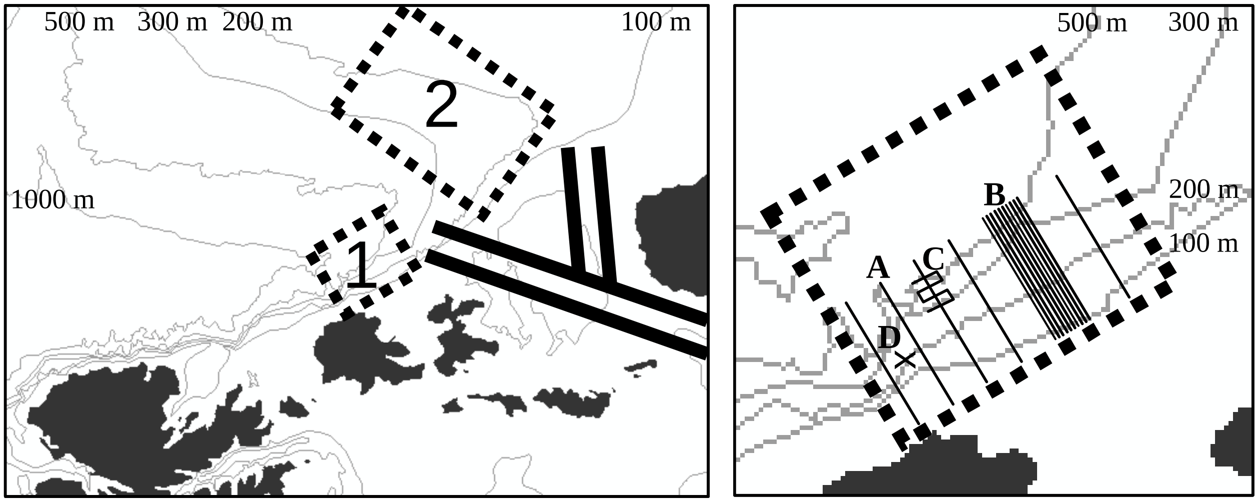

Figure 3. Location of study areas in the horseshoe region near Unimak Island (left panel) and an example survey design in Area 1 (right panel) showing systematic transects (A), high resolution systematic transects (B), adaptive transects (C), and an example stationary site (D).

Objective 1 - Acoustic characterization of squid

Using all frequencies, we will collect data following systematic transects until a pattern that may or may not be squid is observed on the echosounder. At that time, the target assemblage will be approximately described by height, location, and depth of water. We will break from our systematic transect and conduct a high-resolution adaptive survey (Figure 3) to characterize the full horizontal extent of the assemblage. We will use these characterizations to identify patterns associated with species or groups (i.e., squid versus fish) during sampling.

To identify assemblage constituents, we will deploy a midwater or bottom trawl. Environmental conditions (conductivity, temperature, salinity) will be measured at each gear deployment site using a Conductivity-Temperature-Depth (CTD) recorder. After sampling the assemblage, we will return to our survey break point and resume mapping, measuring, and identifying the constituents of other patterns observed on the echosounder.

We will use frequency-dependent intensities to determine which frequency, or combination of frequencies, most clearly identifies observed assemblages that were confirmed to be squid through trawl catches. Once we have selected the optimal combination of frequencies, we will characterize squid assemblages using metrics that quantify shape, size, density within the assemblage (minimum, maximum, mean, and variance), distance off bottom, location, and water depth.

Objective 2 - Squid crepuscular and night behavior

Squid assemblage vertical migration during crepuscular/night periods (Goss et al. 2001) can affect acoustic characterization and assessment. For our crepuscular/night observations, we will select assemblages that were verified as squid during our daytime systematic transects and maintain station above the aggregation (Figure 3) with echosounders running. We will begin collecting acoustic data 1 hour before sunset and continue collecting through civil twilight, nautical twilight, and into the night. If acoustic observations are made during a morning crepuscular period, we will begin collecting data 1 hour before nautical twilight. Ambient light levels will be recorded throughout acoustic collections using a portable ambient light logger. The horizontal extent of the dispersed squid assemblage at night will be characterized with short adaptive transects (Figure 3) after the stationary data collections. Trawling will verify species composition and size for comparison with target strength measurements.

The crepuscular behavior of squid will be monitored using change in assemblage center of depth, rate of change in depth center, increased observation of single individuals, and dispersion of backscatter out of the original assemblage center. We will correlate crepuscular changes in squid aggregations with ambient light levels. During squid assemblage dissipation, we will evaluate whether squid movement or school dispersion patterns are consistent and investigate whether dispersion patterns can be used to distinguish squid from fish.

We will use echoes from single animals (called targets) to estimate *in situ* target strengths (units dB) of individual squid. Estimates of mean target strength will be compared to *in situ* target strength estimates for *Loligo opalescens* (Cailliet and Vaughan 1983, Starr 1985) and with *ex situ* target strength estimates for *Todarodes pacificus* (Kawabata 2005). We will derive a target strength-to-mantle length relationship using *in situ* target strength and specimen lengths from trawl catches. This relationship will be compared to the empirical target strength-to-mantle length relationship of Kawabata (2005).

Objective 3 - Squid horizontal distribution

We will survey a grid of systematic transects (Figure 3) to evaluate the horizontal distribution of squid assemblages within our study area. The survey will be conducted during daylight hours. To obtain more detail on squid spatial distribution, we will also conduct sets of finely spaced transects (Figure 3) within our regular survey grid. The horizontal spacing of our high resolution transects will be approximately 1/10 that used during the systematic survey.

A horizontal bin size for our analyses will be determined using robust variograms (Cressie and Hawkins 1980) to evaluate the spatial relationship among animals within our data. Following the Nyquist sampling rule (Legendre and Legendre 1998), a horizontal bin size less than ½ the range of our variogram (Rivoirard et al. 2000) will be used to capture the spatial patterns observed in squid distribution. A variogram characterizes the spatial scale of the distribution by estimating the variance in density as a function of distance.

Using the horizontal data resolution, we will map the distribution of squid volume backscattering (Sv) observed along our systematic and high resolution transects. We will calculate an overall mean acoustic backscatter and variance estimate for our survey area.

We will also investigate the presence of spatial trends in our data due to location or water depth using generalized linear models (GLM). If spatial trends are identified in our data, they will be removed and residuals from our GLMs will be used in subsequent analyses. Robust variograms (Cressie and Hawkins

1980) will be used to model the horizontal spatial relationship among squid assemblages at the horizontal resolution of our data. Ordinary or universal kriging (Cressie 1991) will be used to interpolate predictions of squid distribution throughout our study area. Interpolated predictions of squid density will be used to estimate squid abundance within our survey area.

Objective 4 - Life history sampling

While identifying assemblage constituents (Objective 1, Objective 2), we will collect specimens of squid with a midwater or bottom trawl. These samples will be used to contribute to squid life history knowledge in the BSAI. All specimens will be identified to the lowest possible taxonomic group, weighed, measured, and assessed for reproductive status. Length-frequencies and length/weight relationships will be compiled for all sampled specimens. Data will be summarized by genus and/or species and, when possible, by age classes. Specimens will be frozen or preserved for archival purposes. We will also photograph catch composition using representative individuals. We will have a squid biologist from the University of Washington participate during the research cruise.

Objective 5 - Comparison with squid bycatch

We will compare four indices of squid density - two from our survey (acoustic density, midwater or bottom trawl CPUE) and two regional indices from commercial pollock bycatch (Unimak Pass/horseshoe CPUE, Bering Sea CPUE) estimates from the NMFS.

We will compare our acoustic estimates of squid density to sampling gear CPUE on portions of our systematic survey or adaptive acoustic transects. Using estimates of squid *in situ* target strength (Objective 2), we will scale our acoustic backscatter data (Objective 4) to density. Our midwater or bottom trawls will be converted to CPUE by dividing squid catch (kg) by the number of minutes that the gear fished. Using all estimates of density and CPUE, we will calculate a Pearson correlation coefficient (Legendre and Legendre 1998) and test whether acoustic density and trawl CPUE are correlated.

We will work in conjunction with the Alaska Fisheries Science Center other species (which includes squid) assessment biologist, Olav Ormseth, to compare indices of squid density to commercial bycatch of squid. In a similar effort off the Sanriku coast, Japan, Kawabata (2005) found agreement between acoustic estimates of *Todarodes pacificus* and commercial purse seine CPUE. Fisheries Observers on Bering Sea commercial walleye pollock fishing vessels report squid bycatch CPUE by date and trawl location. We will calculate Pearson correlation coefficients (Legendre and Legendre 1998) to test whether our estimates of acoustic density and trawl CPUE are correlated with commercial walleye pollock CPUE of squid both within the Unimak Pass/horseshoe area and for the entire Bering Sea. See attached letter of support.

Objective 6 - Outreach Education

We will also work with the Education Department at the Burke Museum of Natural History and Culture at the University of Washington to develop a schools and public educational program that highlights Bering Sea squid and their role in the BSAI. During 2007, the Burke Museum will be hosting a giant squid exhibit that will provide an excellent forum and opportunity to showcase regional squid species. We will coordinate with Burke Museum staff prior to our survey to assess specimen needs and documentation (e.g., photo, video) that would be informative in an educational program. See attached letter of support.

E. Timelines and Milestones

We will conduct a 14-day survey of squid schools along the shelf break in the horseshoe region near Unimak Island in August or September 2007 (Table 1).

Table 1. Time budget for “Evaluating acoustics as a tool for squid assessment in the Bering Sea”

	Year 1												Year 2									
	2007							2008												2009		
Activity	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Cruise preparation	—	—	—																			
Survey cruise				—	—																	
Data Analysis						—	—	—	—	—	—											
Outreach Materials									—	—	—	—	—									
Manuscript Preparation											—	—	—									
NPRB annual meeting								—												—		

Products

We anticipate that our research will result in two primary publications in scientific journals: one on methods description (acoustic frequency-differencing and trawling) to acoustically discriminate squid and one on the distribution of squid along the BSAI shelf break with a comparison to commercial bycatch.

F. Project Management

Experience and Qualifications of Personnel

The Principle Investigator, Dr. John Horne, will have overall responsibility for the project. He will oversee the design and coordination of the survey, analyses of data, and the organization and writing of manuscripts. Dr. Horne has 20 years experience participating in and organizing research cruises, has used acoustic equipment in ecological applications since 1991, and has more than 30 publications on the acoustics and distribution of nekton species in freshwater and marine ecosystems. Dr. Horne has participated in eight NOAA-NMFS acoustic cruises in the Bering Sea and Gulf of Alaska.

Dr. Sandra Parker Stetter will participate in and coordinate sampling cruises, lead the analyses, co-author scientific publications, and coordinate the education/outreach component with the University of Washington Burke Museum of Natural History and Culture. Dr. Parker Stetter has participated in 16 acoustic and research cruises, including a Bering Sea cruise funded by NPRB, and has 6 publications in the fisheries acoustics and ecological literature. Please see attached CV (as ‘letter of support’).

David Barbee will organize cruise logistics and assist in analyses of acoustic, trawl, and catch data. Mr. Barbee has completed an undergraduate degree in Fisheries Science and has an additional 2 years of experience in fisheries acoustics and analyses.

Coordination and Collaboration

We will work in conjunction with the recently hired Alaska Fisheries Science Center other species biologist, Olav Ormseth (arriving late 2006), to compare our indices of squid acoustic density and trawl CPUE to walleye pollock commercial bycatch of squid. Please see attached letter of support from the outgoing other species biologist, Sarah Gaichas.

We will work with the Education Department at the University of Washington Burke Museum of Natural History and Culture to develop a public schools teacher kit or module that focuses on Bering Sea squid and their role in the BSAI. Please see attached letter of support.

G. Figures and Tables

Figures and tables are embedded in the text.

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