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Cooperative Multispecies Acoustic Surveys in the Aleutian Islands

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ABSTRACT

In Alaska, commercial fisheries have been implicated in the slow recovery of the endangered Western stock of Steller sea lions (*Eumetopias jubatus*; hereafter, W-SSL). To address this issue the Aleutian Islands walleye pollock (*Gadus chalcogrammus*; hereafter, pollock) fishery was closed in 1999. Although the fishery was reopened in 2005 to accommodate development of an economically struggling Aleutian Islands community, W-SSL critical habitat in the Aleutian Islands remained closed to pollock fishing. From 2006 through 2008, fishery biologists with the Alaska Fisheries Science Center (AFSC) in conjunction with an Alaska Native regional corporation, fish processors, and fishers explored the technical feasibility of conducting small-scale multispecies cooperative acoustic surveys in the Aleutian Islands. The surveys were meant to provide spatially and temporally relevant estimates of groundfish biomass to set acceptable biological catch levels for a pollock fishery within one day's transit from the community, including areas inside W-SSL critical habitat. This was intended as a means to open W-SSL critical habitat to the developing pollock fishery while reducing the probability of adverse interactions between the fishery and W-SSL stock. The surveys were designed by AFSC biologists but conducted by fishers on board commercial fishing vessels using scientifically calibrated echosounders. Biological data collected from the concurrent fishery were used to characterize acoustic backscatter. This report discusses the development of these surveys, the technical feasibility of conducting scientific grade surveys on board fishing vessels, the use of fishery data to supplement the acoustic surveys, and evaluates the uncertainty around estimates obtained in this manner.

CONTENTS

INTRODUCTION

From 2006 through 2008 a series of studies was completed to evaluate the technical feasibility of conducting multispecies acoustic surveys using scientifically calibrated commercial echosounders on board commercial fishing vessels in the Aleutian Islands. These studies were meant to be a pathway to the development of a temporally and spatially responsive cooperative management system for walleye pollock (*Gadus chalcogrammus*; hereafter, pollock) fishery within critical habitat designated for the endangered western stock of Steller sea lion (*Eumetopias jubatus;* hereafter, W-SSL) in the central Aleutian Islands. In 1999 the North Pacific Fishery Management Council (NPFMC) closed the Aleutian Islands area to directed pollock fishing to help the recovery of the W-SSL population (Barbeaux et al. 2015). In 2005, to accommodate an Adak Island-based pollock fishery, the NPFMC opened waters in the Aleutian Islands to directed pollock fishing. This was in response to the 2004 allocation of Aleutian Islands pollock quota to the Aleut Corporation (an Alaska Native regional corporation), intended to spur development of a commercial fishery for this economically disadvantaged community (Madden 2008). However, because of considerable uncertainty on the effects of commercial pollock fishing in this area on W-SSL recovery, waters inside W-SSL critical habitat remained closed.

In 2005 the Aleut Corporation allowed two catcher-processor trawl vessels to fish for Aleutian Islands pollock resulting in an economic failure with only 109 metric tons (t) of the 15,500 t quota harvested by the fishery (Barbeaux et al. 2015). The failure of the fishery was in part due to the majority of pollock habitat in the Aleutian Islands area near Adak Island being closed to pollock fishing (Fig. 1). A further complicating factor for this fishery is that pollock and Pacific ocean perch (*Sebastes alutus*; hereafter, POP) overlap in spatial distribution in the

Aleutian Islands. In 2005, POP bycatch in the Aleutian Islands pollock fishery exceeded 50% of the total catch (Barbeaux et al. 2015). The 2005 Aleutian Islands pollock fishery was voluntarily halted by the fishing industry because they could not find fishable concentrations of pollock and in part because of high POP bycatch in areas remaining open to pollock fishing. Surveying near Adak Island is expensive due to its remoteness. The island is 389 nautical miles (nmi; 720 km) west of the major fishing port of Dutch Harbor, Alaska, and 1,042 nmi (1,930 km) southwest of Anchorage, Alaska. Although the area surrounding Adak Island has been surveyed triennially or biennially using bottom trawls by the Alaska Fisheries Science Center (AFSC) during the summer since 1991 (von Szalay et al. 2011), a bottom trawl is not the best tool for assessing pelagic or semi-pelagic fish populations. Further, in order for the Aleutian Islands pollock fishery to be profitable, it must be conducted on pre-spawning aggregations in mid- to late March so summer surveys may not provide information relevant to winter fisheries. Furthermore, pollock distribution in the neighboring eastern Bering Sea is known to shift seasonally between diffuse summer feeding aggregations and dense winter spawning aggregations (Kotwicki et al. 2005) and therefore summer surveys would not adequately estimate impacts of a winter fishery on pollock populations or winter W-SSL forage densities. Prior to the studies presented here, few data existed to inform management on possible local impacts of a winter pollock fishery in the Aleutian Islands region.

After the failed 2005 fishing season, AFSC scientists began working with the Aleut Corporation, local fish processors, and fishers to explore alternative data sources and management systems. One alternative cooperative management systems envisioned relied on seasonally and spatially explicit multispecies quotas generated from small-scale acoustic surveys to manage a pollock fishery within W-SSL critical habitat in the central Aleutian Islands. This was seen as a possible means to reopen W-SSL critical habitat to pollock fishing while reducing the probability of adverse interactions between the fishery and W-SSL populations. The surveys would be conducted by commercial fishers and survey biomass estimates reviewed by AFSC acoustic technicians. A fishery would be allowed based on setting multispecies biomass quotas for an area in consideration of local W-SSL forage requirements. For such a cooperative management system to succeed: 1) commercial fishing vessels must be able to collect high-quality acoustic data during late February to late March when high winds and rough sea states prevail, 2) pelagic fish biomass in proposed fishing zones must remain stable for the duration of the fishery or seasonal fluctuations in biomass be understood, 3) uncertainty and potential bias in pelagic fish biomass estimates must be understood and taken into account when setting area-specific multispecies biomass quotas, 4) a method for determining an acceptable catch level that accounts for the foraging requirements of local W-SSL populations and allows for their recovery under the U.S. Endangered Species Act (e.g., ecosystem-based fishery management (EBFM); Pikitch et al. 2004), and 5) the real costs of cooperative surveys would need to be less than potential profits from the fishery.

From 2006 through 2008 a series of studies (Aleutian Islands Cooperative Acoustic Survey Studies; hereafter, AICASS) were conducted in an attempt to address technical issues surrounding the proposed cooperative management system (issues 1-3 above). Commercial echosounders have been used extensively for conducting systematic surveys (Kloser et al. 2000, Kloser et al. 2001, O'Driscoll and Macaulay 2005) and for collecting high-quality acoustic data where dedicated surveys were not feasible (Melvin et al. 2000, Barbeaux et al. 2013, Barbeaux et al. 2014). O'Driscoll and Macaulay (2005) provide a thorough overview of the use of calibrated commercial acoustic systems from commercial fishing vessels in scientific pursuits and Karp (2007) has provided basic guidance for their use in scientific applications. The challenge for AICASS was to determine if it was possible to perform reliable multispecies acoustic surveys from commercial fishing vessels during winter in the Aleutian Islands where weather conditions are often severe, pelagic fish distributions are thought to be ephemeral with substantial seasonal and diel migration (Barbeaux et al. 2012), and verification trawling could be limited due to W-SSL concerns. This report describes these studies and investigates implications of their results with regards to technical feasibility, the use of fishery data to supplement acoustic surveys in lieu of verification trawls, and uncertainty around estimates obtained using these methods. Beyond implications for this individual case, this study provides a useful exploration of methodologies that could be applied to management of pelagic resources in other sensitive habitats where resources are limited and partnerships with industry and other stakeholders possible.

METHODS

2006 Aleutian Islands Cooperative Acoustic Survey Study

The initial AICASS was conducted in 2006 to investigate distribution of pelagic and near bottom fish in the central Aleutians Islands in areas accessible to catcher vessels delivering to Adak Island (Barbeaux and Fraser 2009). A secondary objective of the 2006 study was to examine the spatial distribution of fish aggregations to determine optimum transect spacing for future surveys. The Aleut Corporation agreed to allocate pollock quota for the study and fishers involved in the study were allowed to harvest up to 1,000 t of groundfish in the study area. Acoustic data collections and trawling to verify acoustic backscatter were conducted by the 23 m fixed-pitch, propeller driven commercial fishing vessel FV *Muir Milach* equipped with a hull-mounted SIMRAD ES60 38 kHz echosounder and an Aleutian Wing Trawl (AWT). The only modification to the commercial trawl gear was the installation of a 0.38 inch (0.95 cm) mesh codend net liner to capture smaller organisms. Standard sphere acoustic system calibrations were conducted prior to and after the surveys (38.1 mm tungsten carbide sphere; Foote [1987]) and vessel self-radiated noise was tested (Barbeaux and Fraser 2009) to evaluate acoustic system performance.

Six acoustic surveys were conducted from 21 February to 21 March 2006 between 174.3° W and 175.3° W longitude on the north side of the Aleutian Islands (Barbeaux and Fraser 2009). Three surveys were within a designated large survey area (180 nmi^2; 618 km^2) west of Atka Island North Cape W-SSL haulout and three small-scale surveys were conducted over the highest densities of pollock within the large survey area (Fig. 2). The larger surveys had transects running north-south spaced at 1.5 nmi (2.78 km). This was generally perpendicular to the predominantly east-west bathymetry. Two small-scale surveys (72 nmi^2; 247 km^2) were conducted spaced at 1.0 nmi (1.85 km) with transects running north-south and one small-scale survey (9 nmi^2; 30.9 km^2) was conducted spaced at 0.5 nmi (0.93 km) with transects running east-west. Surveys were conducted during both day and night to investigate diel migration. Trawl tows were conducted during surveys to identify acoustic sign. Temperature, oxygen, and conductivity at depth were collected throughout the survey period and area using a Seabird SBE19 CTD. Between surveys the vessel was allowed to fish until it reached capacity (~165 t; Barbeaux and Fraser 2009).

2007 and 2008 Aleutian Islands Cooperative Acoustic Survey Studies

The 2007 and 2008 AICASS were conducted to assess temporal and spatial distributional constancy of mid-water fish concentrations throughout the entire area of interest to commercial fishers delivering to Adak Island. The 2007 and 2008 studies were conducted between 172° W and 179° W longitude on the north side of the central Aleutians Islands (1,595 nmi^2; 5,478 km^2; Fig. 1). Three acoustic surveys were conducted on board the *Muir Milach*: 14-21 March 2007, 13-20 April 2007, and 23 - 27 March 2008. The NOAA ship *Oscar Dyson*, a state-of-the-art noise-quieted acoustic research vessel commissioned in 2005, conducted one survey from 16 to 29 February 2008. The *Oscar Dyson* was equipped with SIMRAD EK60 echosounders and 18 kHz, 38 kHz, 70 kHz, 120 kHz, and 200 kHz transducers. Verification trawls during the *Muir Milach* surveys were conducted as in 2006, and during the survey conducted by the *Oscar Dyson* using a 30/26 AWT (Honkalehto et al. 2009). The four surveys were conducted as a series of parallel transects running north-south, approximately perpendicular to the shelf break with an initial random start location (Fig. 3). In deference to results from the 2006 survey (see below) and available survey time, transects were spaced at 2.5 nmi (4.6 km). To control for spatial heterogeneity in survey estimates, all surveys followed the same transects. Transect lengths were to 2.5 nmi (4.6 km) shoreward of the 200 m isobath or the 50 m isobath, and offshore 5 nmi (9.3 km) of the 200 m isobath or until fish echosign was not observed, whichever was greater. Because fish were only observed to be associated with the shelf break in Survey 1, the design was altered. In Surveys 2 through 4, transects were ended off shelf once fish were no longer observed regardless of distance from the 200 m isobath. This reduced the surveyed area for Survey 2 by 44%. In 2008 the 13 easternmost transects surveyed in 2007 were not surveyed due to time constraints reducing the survey area for Surveys 3 and 4 by an additional 15%. The acoustic systems were calibrated and self-radiated vessel noise checked as in the 2006 study. Temperature, oxygen, and salinity at depth were collected at regular intervals using a Seabird SBE19 CTD.

In 2007 the Aleut Corporation allocated pollock quota for the purposes of this study and a harvest of up to 3,000 t of groundfish were allowed within the study area, including within W-SSL critical habitat. Commercial fishing was only allowed in an area after completion of survey transects. The 2008 study was fully funded through a North Pacific Research Board grant (NPRP Project 730; Logerwell et al. [2009]) and no commercial fishing was conducted as part of the study.

Data Processing

Data were processed using Echoview V 3.1, a fisheries acoustic data processing application. Although the multiple frequencies available on the *Oscar Dyson* aided species identification and bottom delineation, only 38 kHz data were used for quantitative estimates. For all surveys the sounder detected bottom based on a SIMRAD proprietary algorithm which was reviewed and corrected when necessary. The algorithm tended to misidentify bottom in areas of high relief or where high densities of fish were near bottom. Regions of pollock, POP, and other species, most notably the deep scattering layer primarily made up of myctophids, were identified in the backscatter. The deep-scattering layer was easily discernible from pollock and POP in echograms as backscatter returns were substantially lower. Because this layer was composed of species that were not substantial bycatch and of no interest to fishers as targets, it was excluded from further analyses. Pollock and POP backscatter were scaled to biomass using biological data collected in verification tows. These data included proportion of each species by number, fork length, maturity, and weight-at-length (Barbeaux and Fraser 2009, Logerwell et al. 2009). Numbers of pollock and POP were estimated following methods for mixed-species acoustic surveys described by Simmonds and MacLennan (2005) in which backscatter was proportioned based on the composition in the nearest verification trawls and species specific target strength

(TS). The pollock target-strength model used for initial biomass estimates was TS = $20\log_{10}L-66$, where TS is target strength (dB re m^2) and L is mean fork length in centimeters (Traynor and Williamson 1983, Traynor 1996). As no target-strength studies have been published for POP, the POP target-strength model used for initial survey estimates was TS = $20\log_{10}L-67.5$ based on a generic target-strength relationship for physoclist fishes (Foote 1987).

Data Analysis

Acoustic Data Quality

Acoustic data quality on board the commercial fishing vessel was assessed for acoustic system stability and vessel suitability. Over the 3-year study period, acoustic system stability was assessed through multiple on-axis calibrations using a 38.1 mm diameter tungsten carbide calibration sphere and applying standard sphere calibration techniques (Foote et al. 1986, Simmonds and MacLennan 2005).

Two primary concerns for acoustic data quality beyond system calibration were self-radiated vessel noise and bubble wash-down. Although this interference cannot easily be controlled on a commercial fishing vessel, self-radiated vessel noise can be measured prior to a survey to determine vessel choice and survey effort can be limited to conditions where the effects of bubble wash-down are limited. For vessels not specifically designed as acoustic sampling platforms the signal-to-noise ratio in acoustic data can be dominated by self-radiated noise (Mitson 1995). Self- radiated high frequency noise is generated by motor vibrations in the hull and hydrodynamic effects such as water flow noise past the hull, and propeller-related turbulence (Simmonds and MacLennan 2005). This type of high-frequency noise can degrade acoustic signals when the noise intersects with the frequency of the acoustic survey. A vessel self-radiated noise test as described by Barbeaux and Fraser (2009) was used to assess the noise characteristics of the vessel at the survey frequency and to help determine the optimum survey speed where vessel-generated noise did not interfere with survey operations. To monitor self-radiated noise throughout the study the transducer was occasionally switched to passive mode between transects to evaluate vessel noise levels (Barbeaux and Fraser 2009).

Bubble wash-down occurs when air bubbles are forced under the hull and move over the face of a transducer. The high impedance contrast between sea water and air results in heavy attenuation of both the outgoing and incoming signals. This can greatly reduce signal strength, biasing density estimates, or fully block the signal. For vessels with hull-mounted transducers, bubble wash-down is common and inevitable at heavier sea states. To assess the effects of bubble wash-down, missing acoustic samples were defined as deviations in the transmit pulse S_V (dB re 1 m^{-1}) greater than ±1% of the mean from each survey. The number of missing acoustic samples was counted for the 2007 and 2008 studies. Dominant wind direction and daily average wind velocity were obtained from the NOAA weather station ADKA 2 on Adak Island (NDBC 2014). A binomial logit linear regression model (Venables and Ripley 2002) was used to quantify the relationship between the proportion of missed samples per day, sampling vessel, and wind conditions.

Inter-transect Distance

An objective of the 2006 study was to evaluate the spatial distribution of fish aggregations in the survey area to assess the effect of inter-transect distances on biomass estimates and relative estimation error. We chose two simulation methods to assess the effects of changing the inter-transect distance on the relative estimation error and biomass estimates. For both methods, an inverse distance weighting procedure using the “idw” function from the “gstat v1.0-21” R package (Pebesma 2004, Pebesma et al. 2015) was used to simulate fish distribution at 0.1 nmi (0.185 km) resolution for each survey with the number of nearest samples set at four for all simulations. These values were summed to obtain the “actual simulated biomass”. The simulated fish distributions were re-sampled with 10 random starting points for inter-transect distances of 0.5 nmi (0.93 km) to 5 nmi (9.26 km) at 0.5 nmi intervals resulting in 100 simulated surveys for each survey.

For the first method, transitive 1-dimensional (1-d) linear variogram models (Petitgas 1993, Williamson and Traynor 1996, Walline 2007) using “RGeostats v10.0.8” R package (Renard et al. 2014, R Core Team 2013) were fit to each of the 100 simulated surveys and the relative estimation error and resulting biomass estimated for each (P. Petitgas. Pers. commun., 2014. IFREMER, Nantes, France). The 1-d geostatistical relative estimation error (CV_{geo}) was defined here as the 1-d transitive standard error divided by the total biomass estimate. Percent bias in the biomass estimates was calculated as the surveyed simulated total biomass estimate minus the actual simulated survey biomass divided by the actual simulated survey biomass.

For the second method a fixed block-bootstrap (Hall et al. 1995) with 10,000 samples, as implemented in the “tsboot” function of the “boot v1.3-13” R package (Canty and Ripley 2014), was taken for each of the 100 simulated surveys. The bootstrapped relative estimation error (CV_{boot}) was calculated as the bootstrapped standard error of the biomass estimate over the bootstrapped survey biomass estimate. The appropriate bootstrap block size for each of the 100 simulated surveys was determined using the “b.star**”** function in the “np v0.60-2” R package (Politis and White 2004, Hayfield and Racine 2014). Parallel processing with the “snowfall v1.84-6” R package (Knaus 2013) was used to speed the iterative procedures. Bias in the biomass estimates for each simulation was calculated as the mean bootstrapped total biomass estimate minus the actual simulated survey biomass divided by the actual simulated survey biomass.

Biomass Stability Within the Study Area

An important requirement for setting overall biomass limits based on cooperative acoustic surveys was that acoustic biomass estimates were representative of the underlying biomass for at least the duration of the fishery. For the 2007 and 2008 AICASS the study area was surveyed twice to evaluate within-season temporal variation in fish distribution. A visual examination of the distribution of fish within the survey area was conducted by plotting cumulative proportions of total biomass by transect from west to east for each survey. The similarity of these distributions was statistically evaluated using Kolmogorov-Smirnov goodness-of-fit tests (Zar 1999) with Holm's correction for multiple tests (Holm 1979) for all survey combinations.

Testing Species and Size Composition Assumptions

Uncertainty in standard acoustic survey biomass estimates is largely due to heterogeneity in fish distribution and variance in target strength and species identification (Rose et al. 2000, Demer 2004, O'Driscoll 2004, Woillez et al. 2009). Species and size composition data are generally obtained through verification trawls conducted during surveys. However, in W-SSL critical habitat, protection measures would require limits on trawling activity prior to assessing biomass estimates in any management system proposed following this study, likely increasing the level of uncertainty and bias in biomass estimates. In the expanded uncertainty analysis, five possible contributors to uncertainty in survey biomass estimates were investigated: size composition, system calibration, target-strength models, inter-transect spacing, and species composition. This is not a full accounting of survey uncertainty, but rather an expanded investigation into those factors that were thought to be major contributors and could be investigated using available data.

To investigate sensitivity of mid-water biomass estimates to these five factors we developed an approach similar to that of Rose et al. (2000) and O'Driscoll (2004) in which imprecision in system calibration, target strength to length relationship, inter-annual variability in size distribution, and spatial distribution were parameterized. For each uncertainty type, 10,000 draws from the respective distribution was taken and results applied to each of the surveys to obtain alternative biomass. To quantify the spatial uncertainty a fixed block-bootstrap was conducted, as described above for inter-transect distances, was taken for each of the 2007 and 2008 surveys.

To quantify combined uncertainty for all these sources a single draw from each of the respective uncertainty distributions was conducted and estimates applied to obtain an alternative transect biomass estimate for each survey. A single fixed-block bootstrap draw was performed of this simulated transect estimate as described above resulting in an alternative biomass estimate. This process was repeated for 10,000 draws to produce a probability distribution of the biomass estimate for all of the evaluated sources combined.

To test the sensitivity of biomass and uncertainty estimates to alternative species composition scenarios, the effects of changing the proportion of pollock by number was explored for proportions between 0 and 1.0 at a 0.05 resolution for each survey. Survey estimates were recalculated at each proportion and the expanded uncertainty re-sampling approach described above was repeated for 10,000 draws for each resolution.

System calibration uncertainty was estimated by averaging the variance of the calibration results for all four sphere calibrations conducted on board the *Muir Milach*.

Uncertainty in species target strength to length relationships was included in the evaluation. The pollock target strength (TS) to length (L) relationship of TS = 20 log (L) - 66 (SE = 0.6) (Traynor and Williamson 1983, Foote and Traynor 1988) was used. To capture uncertainty in the POP target-strength relationship all published *Sebastes* spp. Target-strength models (Table 1) were assumed equally plausible and selected through draws from a uniform distribution.

Length and weight data from the North Pacific Groundfish Observer database of commercial fishery catch (Cahalan et al. 2010) were used to develop distributions on pollock and POP size. Data were limited to catches from the north side of the central Aleutian Islands between 173° W and 179° W longitude for January through April 1991 to 2014. As there appeared to be an increasing trend in POP and pollock length for 1991-2005, only 2005-2014 data were used for the probability distribution. There were no pollock measurements collected in 2000 through 2003, 2006, 2008, 2011, or 2012 and no POP measurements collected in 1991 through 1996, 1998, and 1999. There were 777 pollock and 1,071 POP specimens with both length and weight collected. The annual mean length was calculated for each year and mean annual length and standard deviation of the annual means assumed to be normally distributed. A log-normal mixed-effects model (Zuur et al. 2009) was used to quantify the length to weight relationship and annual variability with length as a fixed effect and year as a random effect for both pollock and POP.

RESULTS

Acoustic Data Quality

The commercial fishing vessel used for acoustic data collection was an excellent platform for the rigors of the Aleutian Islands in the winter. The vessel was highly stable in the rough conditions experienced in the Bering Sea and North Pacific Ocean. Vessel noise levels remained below the 10:1 signal-to-noise ratio at engine speeds below 1,200 RPM (Fig. 4, top panel). This resulted in vessel speeds which averaged between 4 to 8 knots (7 to 15 kmH^{-1}) depending on tidal and weather conditions. The commercial acoustic system was found to be stable between 2006 and 2008 with < 0.1 dB difference among all standard sphere calibrations (Fig. 4, bottom panel).

The missing sample rate for the commercial fishing vessel was 4.4% across all three surveys, while during the initial 2008 survey the *Oscar Dyson* had a missing sample rate of 0.1%. Although the generalized linear binomial logit models of the *Muir Milach* data found both dominant wind direction and maximum daily wind speed to be significant factors in missing samples, these factors explained less than 2.7% of the deviance. For all surveys combined there were fewer missed samples for the commercial fishing vessel when winds blew from the south-western quarter, when surveying in the lee of the Aleutian Islands, and an increased probability of missed samples at increased maximum daily wind speeds. At all maximum daily wind speeds less than 15 knots (27.8 kmH^{-1}; the maximum at which data were collected) the missing sample rate remained below 10%.

Inter-transect Spacing

The 2006 1.0 and 1.5 nmi spaced surveys had a 1-d geostatistical relative estimation error (CV_{geo}) ranging from 0.076 to 0.178 and a fixed block bootstrap relative estimation error (CV_{boot}) ranging from 0.163 to 0.328 (Table 2). For the IDW simulations both the CV_{geo} and CV_{boot} increase with increasing inter-transect distance for all 2006 surveys, however the 1-d geostatistical method has a much steeper slope with CV_{geo} much lower at smaller inter-transect distances and much higher at larger inter-transect distances than the fixed block bootstrap method (Fig. 5). In addition the variability around the estimate of CV_{geo} increases with increasing inter-transect spacing, while variability of the CV_{boot} estimate remained relatively stable. The biomass estimates from the sampled simulations were the sum of the samples and therefore were the same for both the 1-d geostatistical and fixed block bootstrap methods. Biomass estimates were biased low at inter-transect distances less than the native survey spacing of 1.5 nmi (2.8 km). At higher inter-transect distances the variability of the simulated survey biomass estimates increased with increasing inter-transect distances and there was a growing positive, albeit non-significant, bias in the estimates of total biomass.

In addition to survey estimation error, the cost of the surveys was an important consideration in deciding the appropriate inter-transect distance for the 2007 and 2008 surveys. Cost was defined here as the number of 16-hour days needed to survey the region of interest. The area to be surveyed in 2007 was estimated to be approximately 1,595 nmi^2 (5,478 km^2), 220 nmi (407 km) from east to west with a mean north to south transect length of 7.25 nmi (13.4 km). In 2006 the survey vessel travelled at 7 knots (13 kmH^{-1}) on average while surveying and 11 knots (20 kmH^{-1}) between transects. These values allowed us to fit a power curve to calculate the total number of 16 hour days, *D*, needed to survey the region at inter-transect distances, *r*, between

0.5 nmi (0.9 km) and 5 nmi (9.3 km) as $D_r = 15.959^{-0.859}$ with an R^2 of 0.998. Using this relationship and the resulting estimation errors from the simulation exercise described above a cost-benefit analysis was conducted for inter-transect distances. Figure 6 shows the distribution of CV_{geo} and CV_{boot} estimated for the simulated surveys and inter-transect distances by the estimated cost in days to survey the expanded 2007 survey area.

In 2007, 20 days were allocated by the vessel owners and the Aleut Corporation to complete the two surveys. This time frame included calibration before and after the survey, transport time to and from the survey area, time for verification trawls, and any days lost due to poor weather conditions. An estimation error of approximately 0.2 was thought to be acceptable for our purposes and therefore a minimum of seven active survey days were required to complete each survey. Using the estimates above, it was determined that the 2007 survey area could be surveyed in 7.26 days with an inter-transect distance of 2.5 nmi (4.6 km), resulting in an expected CV_{geo} of 0.16 and CV_{boot} of 0.22. This would leave 2.74 days for calibration and poor weather for each survey. In 2007 verification trawls were to be conducted by vessels other than the survey vessel and therefore were not expected to affect survey duration.

The initial 2007 survey had an inter-transect distance of 2.5 nmi (4.6 km) and took 8 days to complete, including one weather day. Survey 2 of 2007 was completed in 5 days, but is not comparable due to shortened transects, as offshore portions of transects were ended earlier than in the initial survey. A comparison of survey cost between years was not applicable due to reduced survey area in 2008. Within the area commonly surveyed across all surveys, the mean CV_{geo} was 0.16 and the CV_{boot} was 0.22, the same as the expected simulated values from the 2006 surveys.

Biomass Stability and Catch Within the Study Area

AICASS 2006

In the 2006 AICASS sizable aggregations of pollock were observed centered near the 300 m isobath along the shelf-break throughout the study area. However, pelagic fish (including both POP and pollock) biomass in the survey area declined by 62% (53% discounting removals) from the first to last survey for the same area, indicating that the 2006 survey area was not large enough to capture seasonal distributional shifts (Table 2). Pacific ocean perch (POP) were a small component of the 2006 AICASS catch, roughly 3% of the total commercial landings, and were not considered a significant component of the acoustic backscatter.

AICASS 2007 and 2008

In the 2007 and 2008 AICASS, pelagic fish aggregations were again found along the 300 m isobath with distinct areas of higher concentrations north of Kanaga Island and Atka Island (Fig. 3). The March 2007 survey (Survey 1) estimated 21,140 t (CV_{geo} = 0.093 and CV_{boot} = 0.164) of pollock and POP combined. The April 2007 survey (Survey 2) estimated 15,383 t (CV_{geo} = 0.196 and CV_{boot} 0.149) of pollock and POP combined. The combined mid-water biomass estimates for pollock and POP in February 2008 (Survey 3) was 34,614 t (CV_{geo} = 0.094 and CV_{boot} = 0.241) and in March 2008 (Survey 4) was 38,194 t (CV_{geo} = 0.262 and CV_{boot} = 0.312) (Table 2). POP made up 9.3% and 10.0% of the mid-water biomass for Survey 1 and Survey 2 and 21.6% and 18.7% of Survey 3 and Survey 4 (Table 2). There was a 21% decline in pelagic fish abundance between March and April 2007. In 2008 the overall biomass remained stable with only a 10% difference from February to March 2008.

Biomass Stability

Although there was a substantial change in abundance between the 2007 and 2008 surveys, in both years there was an apparent eastward shift in pelagic biomass from earlier to later surveys (Fig. 7). For the commonly surveyed region, 50% of the pelagic biomass occurred west of 177.00° W longitude and 177.19° W longitude in Surveys 1 and 3, while 50% of the pelagic biomass occurred west of 176.25° W longitude in Surveys 2 and 4. Kolmogorov-Smirnov tests (Table 3) found significant differences (Holm's corrected p-values < 0.05) in the east-west distributions of fish between Surveys 2 and 3 and between Surveys 3 and 4. There was a notable difference between Surveys 1 and 4 with a Holm's corrected p-value of 0.10. The apparent difference observed between Surveys 1 and 2 with an eastward shift in distribution was not statistically significant (Holm's corrected p-value = 0.33). The distribution of pelagic biomass in Surveys 1 and 3 and Surveys 2 and 4 were statistically similar with p-values of 0.5 and 0.92.

Expanded Uncertainty Analysis

Uncertainty in size composition for this analysis was made up of two components: inter-annual variability in estimated mean length and variability in length-to-weight relationships for both pollock and POP. The mean size of pollock encountered in 2007 survey verification tows (Surveys 1 and 2 at 57.33 cm and 1.69 kg) was smaller than those observed in 2005-2014 fishery data (61.17 cm and 1.96 kg) (Student's T-test, p-value < 0.001 for both length and weight). The mean size of POP observed during 2007 surveys (36.48 cm and 0.69 kg) was not substantially different than the mean observed in 2005-2014 fisheries data (Student's T-test, p-value = 0.15 and 0.38). The mean size of POP (Survey 3 at 36.90 cm and 0.68 kg and Survey 4 at 38.24 cm and 0.73 kg) and pollock (Survey 3 at 60.46 cm and 1.85 kg and Survey 4 at 60.19 cm and

1.80 kg) from 2008 surveys were not significantly different from those observed in the 2005-2014 fishery (Student's T-test, p-value < 0.001 for lengths and weights for both species and surveys). The average annual mean length for 2005 - 2014 applied in the uncertainty analysis for pollock was 61.04 cm with an inter-annual standard deviation of 4.23 cm and for POP 36.55 cm with an inter-annual standard deviation of 1.09 cm. Results from the mixed effects models on pollock and POP log length to log weight relationships are presented in Table 4. These relationships and uncertainty around these values were used in the expanded uncertainty model.

When using fishery size composition distributions in the expanded uncertainty model to estimate survey biomass the mean survey biomass was biased 12.7% and 12.6% higher in the Surveys 1 and 2 and 3.3% and 2.4% higher in Surveys 3 and 4 (Fig. 8). Here proportions of pollock were assumed to be equal to those estimated through verification trawls and were based on 10,000 iterations. The coefficients of variation for survey estimates based on size composition uncertainty alone were 0.0614 and 0.0608 for the 2007 surveys and 0.0499 and 0.0502 for the 2008 surveys.

The expanded uncertainty model also incorporated calibration uncertainty using a standard deviation around the S_v measurement for all surveys of 0.03667, the mean standard deviation around the four sphere calibrations conducted on the *Muir Milach*. Although this does take into account measurement error of the equipment in near static conditions, it does not incorporate error in acoustic measurements due to variability in temperature and salinity during surveys. Measurement error around sphere calibrations added to survey estimates resulted in a coefficient of variation of 0.084 for all four surveys (Fig. 8).

A literature search of target strength by length relationships for *Sebastes* spp. found substantial similarities among studies (Table 1). At the proportion of pollock to POP by number measured during each survey, the Foote (1987) model used for POP resulted in the second lowest estimated biomass for Surveys 1 through 3, exceeding only those estimated using the Foote et al. (1986) model, and fourth lowest for Survey 4, exceeding those estimated using Kang and Hwang (2003), Gauthier and Rose (1998), and Foote et al. (1986) models. Sampling among POP target strength models resulted in the median biomass estimate being 2.4% and 2.5% higher for the 2007 surveys and 4.8% and 3.1% higher for the 2008 surveys than survey estimates employing the Foote (1987) model for POP. The expanded distributions for target strength were near normal for the 2007 surveys due to high proportion of pollock by number (80% and 81%) but were right skewed in the 2008 surveys due to lower proportions of pollock by number (57%). The coefficient of variation due to target strength uncertainty as modeled in this analysis was 0.134 for the 2007 surveys and 0.128 for the 2008 surveys (Fig. 8).

The 1-dimensional fixed block bootstrap analysis when applied to the initial 2007 and 2008 transect estimates resulted in a mean biomass estimate lower than the initial survey estimates by 0.1% and 0.2% in 2007 and 0.1% and 1.9% in 2008. With no other uncertainty introduced, the fixed block bootstrap estimates had a coefficient of variation (CV_{boot}) of 0.1643 and 0.1490 for 2007 surveys and 0.241 and 0.3116 for 2008 surveys (Table 2, Fig. 8).

For size composition, system calibration, target strength uncertainty, and transect spacing uncertainty combined the results were not additive. The fully expanded uncertainty models had coefficients of variation (CV_{total}) of 0.2369 and 0.228 for 2007 surveys and 0.290 and 0.354 for 2008 surveys. However, bias due to differences in size composition data and target-strength models were propagated through to the fully expanded uncertainty distributions. The expanded means were 15.8% and 15.5% higher for 2007 surveys and 8.2% and 8.0% higher in 2008 surveys (Fig. 8).

Sensitivity analyses for species composition using the expanded uncertainty model found that estimates at 100% pollock by number resulted in the lowest mean total biomass and 0% pollock resulted in the highest mean total biomass and variance (Table 5, Figs. 9 and 10). At 100% pollock (by number) median biomass estimates are higher than initial survey estimates by 3.0% and 5.7% for 2007 and lower than initial survey estimates by 7.1% and 4.8% for 2008 surveys. However, in the uncertainty model, median biomass estimates at 100% pollock were consistently lower than median estimates at the sampled species proportions by 8.8% and 6.3% for 2007 surveys and 11.0% and 7.1 % for 2008 surveys. The median biomass estimates at 0% pollock by number compared to initial survey estimates were 85.2% and 87.2% higher for 2007 surveys and 67.9% and 62.1% higher for 2008 surveys. The median biomass estimates at 0% pollock by number compared to the uncertainty model median biomass estimates at the sampled species proportions were 65.0%, 66.0%, 61.0%, and 58.2% higher. The CV_{total} for all four surveys were highest at 0% pollock, quickly drop to their lowest between 25% and 40% pollock, and then increase slowly at higher proportions of pollock up to 100% pollock (Figs. 9 and 10).

DISCUSSION

Technical Feasibility

The main questions concerning the technical feasibility of conducting acoustic surveys using commercial fishing vessels and commercial acoustic systems are on the ability to achieve adequate data quality (Karp 2007). Standard target sphere calibrations (Foote et al. 1986) ensure that an acoustic system is functioning properly and providing a verifiable and standardized measure of backscatter. In this case, it was shown that the commercial acoustic system employed (38 kHz SIMRAD ES60) was stable to within ±0.1 dB with a variance among the four calibrations of 0.19 dB for the duration of the 3-year study. For comparison, the maximum difference from a 38 kHz SIMRAD EK60 scientific echosounder on board the Norwegian research vessel RV *G.O. Sars* built in 2003 was ±0.1 dB for eight calibrations conducted between 2003 and 2008 with a variance among calibrations of 0.22 dB (Knudsen 2009). The target-strength measurements from the *Muir Milach* calibrations were consistent with a jitter of 0.2 dB for the 2006 and 2007 calibrations and 0.9 dB for the more variable 2008 calibration. These results are well within the range of values observed from scientific acoustic systems (0.3 - 1.0 dB; Jech et al. 2005). From these results we conclude that the SIMRAD 38 kHz ES60 acoustic system on board the commercial fishing vessel employed in this study was stable and scientifically reliable.

In addition, a vessel self-noise test was used to establish the maximum acceptable engine speed for sampling and identify other sources of vessel noise that would interfere with data quality. Although alternative methods for determining signal-to-noise ratios have been proposed for scientific echosounders (De Robertis and Higginbottom 2007), these rely on below bottom returns which may not always be accessible from the data recorded by commercial echosounders (e.g., the SIMRAD ES60 often excludes below bottom returns at seemingly random intervals). One important point to note is that we conducted the noise test in shallow water (60 m), while the majority of mid-water scatterers were observed at much deeper depths where noise reflection from the bottom would be expected to be less. It is therefore likely that we exceeded the 10:1 signal-to-noise ratio for these areas. The tests employed to evaluate vessel noise and acoustic system accuracy and stability demonstrate that at least under calm weather conditions the commercial fishing vessel used in this study was an acceptable platform for conducting acoustic surveys.

As expected, sea state and vessel speed were found to affect data quality. The probability of missing samples increased as winds increased and was greatest when winds came from directions with the greatest fetch. In this study, the probability of missing samples was highest at slower vessels speeds. This result, although somewhat counter-intuitive, makes sense in that the vessel slowed during poor weather conditions particularly when moving against the current. Such conditions would increase turbulence under the hull and air bubbles in front of the transducer face. Because of this, we developed a rule of thumb for the 2007 and 2008 surveys where elementary distance sampling units (EDSUs) with greater than 10% missing samples were excluded from analysis and survey work was halted when weather conditions would be expected to cause such issues. In this case, due to the hull characteristics of the *Muir Milach* and location of the transducer at the deepest point of the vessel's hull, such conditions were rare even in the rough to very rough sea states commonly encountered in the central Aleutian Islands in the winter and spring.

The *Oscar Dyson* had very few missing samples while conducting acoustic surveys (0.1% of samples compared to 4.4% for the *Muir Milach*). This was largely due to the vessel's design with placement of the transducer on a retractable keel, but also, in part, because survey operations were halted in lower sea states than when surveying on the commercial fishing vessel. The *Oscar Dyson*, although built for acoustic survey work, handled worse than the commercial fishing vessel under the often poor weather conditions encountered in the study area. Rough sea states and moderate wind conditions created significant difficulty in conducting verification trawls on board the larger research vessel and survey operations were halted due to crew safety concerns because of pitch and roll well before acoustic sampling was substantially affected. Due to the fishers' long experience with fishing in heavy weather in the area and the better seaworthiness of the fishing vessel, verification trawls were efficiently cast and retrieved even in very rough conditions and near pinnacles and steep canyons. Additionally costs of running the *Oscar Dyson* in the 2008 study exceeded US $15,000 per day. In contrast, the *Muir Milach* was contracted at US $6,857 per day in 2008.

The 2006-2008 AICASS adequately demonstrated the suitability of using commercial fishing vessels for conducting acoustic surveys in the winter on pelagic fish resources in the Aleutian Islands region. The acoustic system and hull configuration of the *Muir Milach* is no different than most fixed-propeller, stern trawl fishing vessels used in the region. The quality and quantity of data collected by the *Oscar Dyson* were superior, but for the purposes of this study and potential use of these survey data to set catch limits by area for a local fishery, the fishing vessel was adequate. The calibration procedure and vessel self-noise testing employed in this study should be standard practice for conducting quantitative acoustic survey work from commercial fishing vessels.

Biomass Stability

The 2006 through 2008 AICASS surveys have been the only research conducted on winter mid-water fish distribution and temporal stability in the Aleutian Islands west of 170° west longitude. The 2006 effort resulted in multiple acoustic surveys of the area of high pollock abundance near Atka Island. The abundance of pollock in this area remained stable in the beginning of the survey period then decreased rapidly as both fishing occurred and the proportion of spawning and spent pollock in the region increased (Barbeaux and Fraser 2009). The abundance and distribution of pollock near Atka Island in 2006 was consistent with the 2007 and 2008 surveys. Although the 2008 surveys encountered higher densities of fish, all four 2007 and 2008 surveys consistently observed high densities of pollock and POP in the same areas. The pollock and POP maturity and length data collected during the three studies suggest that these were pre-spawning aggregations (Logerwell et al. 2009). Areas where pollock and POP abundance were high were also areas with high pollock and POP catches in the 1990s winter fisheries (Barbeaux et al. 2015, Spencer and Ianelli 2014). The three years of consistent cooperative survey results and a 20-year history of high catches suggest that bathymetry and perhaps oceanographic conditions make these areas preferred habitat for forming pre-spawning aggregations of pollock and POP. Further, the 2008 surveys show that abundance and size composition of pollock and POP in the region between 174° and 178° W longitude remains consistent from February through March, while the pollock maturity stage progressed towards a higher proportion of pre-spawning and spawning fish (Logerwell et al. 2009). We cannot determine for certain given the available data that paired surveys observed the same population in a given year; however, the preponderance of evidence suggests this to be the case.

Although the overall pelagic fish biomass was relatively stable within the study area for a given year, there was considerable change in biomass between years. The 2007 biomass estimates were substantially lower than the 2008 estimates for the same region. Both pollock and POP are relatively long-lived species and annual stock assessments for both (Barbeaux et al. 2015, Spencer and Ianelli 2014) do not show a large increase in abundance from 2007 to 2008. The apparent change in abundance must be due to either a change in their temporal-spatial distribution or availability to the survey. Oceanographic data collected during the surveys (Barbeaux and Fraser 2009, Logerwell et al.2009) show a stark change in water column structure between years with warmer surface waters and a distinct thermocline in 2007 between 80 m and

100 m, but colder, well-mixed temperature profiles in 2008 with no distinct thermocline. Either timing of aggregation or availability to the echosounders may have been different between the years. In his study of spawning hoki (*Macruronus novaezelandiae*), O'Driscoll (2004) shows the highest imprecision of abundance estimates were due to migration of hoki into and out of the survey area. Pollock and POP spawning aggregations show similar behavioral characteristics in other regions (Duffy-Anderson et al. 2015) and cues for spawning aggregation are likely similarly tied to oceanographic conditions in the central Aleutian Islands.

Considerable uncertainty remains on effects of migration of pollock and POP and of changes in environmental conditions on the persistence of these species within the study area. Although intra-annual fish biomass was relatively stable, there was considerable interannual variability in overall biomass and species proportions that cannot be explained by population growth or mortality. Whether these fluctuations are due to oceanographic conditions or differences in detection probability is unknown. For the proposed management system to work, a better understanding of the seasonal flow of fish through the study area will be necessary. One means of assessing this seasonal flow would be with an upward-facing transducer (Axenrot et al. 2004) mounted on the seafloor in at least one of the biomass hotspots. An upward-facing transducer would not only provide data on seasonal fluctuations, but also diel variability in detectability. Alex De Robertis (A. De Robertis. Pers. commun. AFSC, NOAA, Seattle, WA, USA) designed an upward-facing acoustic system which was deployed in the Gulf of Alaska in winter 2015. Duplicating this effort in the central Aleutian Islands in cooperation with local fishers would be relatively inexpensive (equipment costs of US $65,000) and provide data that would substantially reduce uncertainty in survey estimates.

Modeling Uncertainty

The approach used in the expanded uncertainty model provided a framework to investigate sources of error and their relative contributions to overall survey uncertainty. It should be noted that this was not an attempt at fully quantifying total uncertainty in survey estimates, but rather a means of quantifying the contribution of the main effects for which data were available and estimating whether alternative data sources such as commercial fishery species and size composition could be used in lieu of survey verification trawls for biomass estimation. Of the components investigated, spatial uncertainty was the largest contributor to overall survey uncertainty in all four surveys, followed by imprecision in target strength to length models, calibration imprecision, and finally, interannual variability in size composition.

Using fishery size composition data introduced a positive bias to mean biomass estimates. Pollock lengths and weights observed in the fishery were larger and heavier than observed during the surveys. The most obvious reason for this disparity is that commercial trawls were likely more selective for larger fish as survey gear had net liners installed which reduced codend mesh size. Positive bias in biomass estimates would be problematic for developing an ecologically precautionary management system. Under current regulations, trawling would not be allowed inside W-SSL critical habitat prior to evaluating whether fishing would adversely impact local W-SSL foraging success. One means of compensating for the bias due to using fishery size composition data would be to develop a selectivity model for commercial nets and adjust fishery size composition estimates accordingly. Although this would correct the bias, it would also increase uncertainty in estimates as any selectivity model would introduce its own error.

The aggregated target strength to length approach explored in the expanded uncertainty model resulted in mean biomass estimates 2% to 5% higher than those produced using the Foote (1987) generic physoclist model alone. The POP target strength to length relationship has never been quantified and the generic physoclist model is likely incorrect for POP. Although a specific POP target strength to length model would likely improve the precision of estimates, the results of this study show that using the generic model results in more conservative biomass estimates than using the combined target strength to length models approach applied in this study. Therefore using the generic model would better attain the objective of an ecologically conservative management approach.

We were unable to determine the level of differential availability or selectivity of verification trawls between pollock and POP. Therefore a full range of pollock proportions from 0 to 1.0 was used to investigate the sensitivity of biomass estimates and uncertainty to this parameter. As a rule, underestimating the proportion of pollock caused biomass estimates to be biased high, while overestimating caused biomass estimates to be biased low. For management purposes when setting a local multispecies quota if verification trawls cannot be conducted, it would be ecologically precautionary to assume 100% pollock proportion by number with the understanding that estimates would likely be biased low. For the 2007 and 2008 surveys, assuming 100% pollock proportion by number would have resulted in biomass estimates 6% to 9% lower than the verified survey estimates. Assuming 100% pollock proportion by number would also negate the additional bias and uncertainty introduced by not knowing the POP target strength to length relationship.

The acoustic detection probability of the target species is an important contributor to overall survey uncertainty (Rose et al. 2000, O’Driscoll 2004). Differences in fish association with the bottom due to diel migration and effects of tide (Barbeaux and Fraser 2009, Barbeaux et al. 2013) likely caused significant variation in the acoustic detection probability for both pollock and POP in the central Aleutian Islands. However, detection probability was not assessed in these studies, but was assumed to be 1.0. Given the steep topography and large acoustic dead zone (Ona and Mitson 1996) observed in the central Aleutian Islands acoustic data (Barbeaux and Fraser 2009), a detection probability of 1.0 is likely higher than in reality, particularly during daylight hours and during times of high tidal flow. However, a precautionary management system assuming an acoustic detection probability of 1.0 would provide an ecologically conservative biomass estimate.

Conclusions

While it is feasible to conduct multispecies acoustic surveys in the central Aleutians, there are still a number of technical issues that must be addressed before such surveys can be used in a small-scale cooperative management system. In the introduction, we identified five issues that must be addressed for successful implementation of the proposed cooperative management system. These studies have provided preliminary pathways to address the first three issues, however, for the proposed management system to work the final two issues will need to be addressed. We found that assuming 100% pollock proportion by number and full detectability produces the most conservative estimates and would be consistent with a precautionary approach, however seasonal migration, environmental effects on availability, and persistence of the aggregations are not well understood and will require further research.

Determining the proportion of fish to allocate to the fishery while allowing enough forage for the local W-SSL population to recover is one of several challenges in implementing an ecosystem-based approach to fishery management, but it is beyond the scope of this study. An initial estimate could be made by applying the single-species derived harvest rate for the Aleutian-wide pollock stock to the portion that is available to the Adak-based fishery, but the spatial extent of a fishery is only one element of setting an ecosystem-based fishery catch quota. While considerable effort has been expended to understand the seasonal nutritional requirements for individual W-SSLs (Winship et al. 2002, Sigler et al. 2004, Rosen 2009), less is known about the size of local, seasonal prey populations required to support the recovery of W-SSL populations. For instance, the abundance of pollock, Pacific cod (*Gadus macrocephalus*), Atka mackerel (*Pleurogrammus monopterygius*) and other prey necessary for central Aleutian Islands W-SSLs during the winter (Sinclair and Zeppelin 2002, Sinclair et al. 2013) is not simply limited to the fish they consume, but also includes the much larger number of fish necessary in the environment to guarantee successful foraging (Womble et al. 2005, Womble and Sigler 2006, Sigler et al. 2009). Womble et al. (2005) and Sigler et al. (2009) concluded that the relationship between Steller sea lion abundance at seasonal haulouts and local prey biomass (e.g. temporary spawning aggregations) is exponential: more prey energy per sea lion is necessary as the number of sea lions increases. For example, an estimated 5 TJ of prey energy is required within ~20 km of a haulout to temporarily attract and support 500 Steller sea lions, but to support twice as many, a four-fold increase in nearby prey energy is necessary. Implementing an ecosystem-based fisheries management plan for an Adak-based winter Aleutian pollock fishery would involve setting a catch level that accounts for sea lion requirements, but it would likely also include distribution of effort to minimize the likelihood of localized depletion (Fritz et al. 1995). Even when the technical and ecosystem challenges for this type of management system have been addressed, in the end its feasibility will depend on the perception of the Aleut Corporation, fishers, and fish processors on whether this system, which imposes a larger portion of the management costs on the industry, remains cost effective and results in a profitable and sustainable fishery.

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CITATIONS

Axenrot, T., T. Didrikas, C. Danielsson, and S. Hansson. 2004. Diel patterns in pelagic fish behaviour and distribution observed from a stationary, bottom-mounted, and upward-facing transducer. ICES J. Mar. Sci. 61: 1,100-1,104.

Barbeaux, S., and D. Fraser. 2009. Aleutian Islands cooperative acoustic survey study for 2006. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-198, 91 p.

Barbeaux, S., J. Horne, and M. Dorn. 2013. Characterizing walleye pollock (*Theragra chalcogramma*) winter distribution from opportunistic acoustic data. ICES J. Mar. Sci. 70: 1,162-1,173.

Barbeaux, S., J. Horne, and J. Ianelli. 2014. A novel approach for estimating location and scale specific fishing exploitation rates of eastern Bering Sea walleye pollock (*Theragra chalcogramma*). Fish. Res. 153: 69-82.

Barbeaux, S., J. Ianelli, and W. Palson. 2015. Assessment of the pollock stock in the Aleutian Islands for 2014. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Management Council, 605 West 4th, Suite 306, Anchorage, AK 99501-2252.

Cahalan, J., J. Mondragon, and K. Gasper. 2010. Catch sampling and estimation in the federal groundfish fisheries off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-205, 42 p.

Canty, A., and B. Ripley. 2014. Boot: Bootstrap R (S-Plus) Functions. R package version 1.3-13.

Demer, D. 2004. An estimate of error for the CCAMLR 2000 survey estimate of krill biomass. Deep-Sea Res. Pt. II 51: 1,237-1,251.

De Robertis, A., and I. Higginbottom. 2007. A post-processing technique to estimate the signal-to-noise ratio and remove echosounder background noise. ICES J. Mar. Sci. 64: 1,282-1,291.

Duffy-Anderson, J., S. Barbeaux, E. Farley, R. Heintz, J. Horne, S. Parker-Stetter, C. Petrik, E. Siddon, and T. Smart. 2015. The critical first year of life of walleye pollock (*Gadus chalcogrammus*) in the eastern Bering Sea: Implications for recruitment and future research. Deep-Sea Res. Pt. II 134: 283-301.

Ermolchev, V. 2011. Results of ten-year research on acoustic target strength TS in situ and their dependence on length L_T for main commercial fish species in the seas of the Northeast Atlantic. Underwater Acoustic Measurements: Technologies and Results. 4th International Conference and Exhibition (UAM2011). 20-24 June 2011. Available: http://promitheas.iacm.forth.gr/UAM_Proceedings/uam2011/UAM2011%20Paper%2022.5.pdf

Foote, K. 1987. Fish target strength for use in echo integrator surveys. J. Acoust. Soc. Am. 82: 981–987.

Foote, K., A. Aglen, and O. Nakken. 1986. Measurement of fish target strength with a split-beam echo sounder. J. Acoust. Soc. Am. 80: 612–621.

Foote, K., and J. Traynor. 1988. Comparison of walleye pollock target strength estimates determined from *in situ* measurements and calculations based on swimbladder form. J. Acoust. Soc. Am. 83: 9–17.

Fritz L. W., R. Ferrero, and R. Berg. 1995. The threatened status of Steller sea lions, *Eumetopias jubatus*, under the Endangered Species Act: Effects on Alaska groundfish fisheries management. Mar. Fish. Rev. 57(2):14–27.

Gauthier, S., and G. Rose. 1998. An in situ target strength model for Atlantic redfish, p. 1,817–1,818. *In* P. K. Kull, and L. A. Crum (eds.), Proceedings of the 16th International Congress on Acoustics and 135th Meeting of the Acoustical Society of America, Seattle, Washington, 20–26 June 1998. Acoustical Society of America Publications, Sewickey, PA., U.S.A.

Gauthier, S., and G. Rose. 2001. Target Strength of Encaged Atlantic redfish (*Sebastes* spp.). ICES J. Mar. Sci. 58: 562–568.

Gauthier, S., and G. Rose. 2002. In situ target strength studies on Atlantic redfish (*Sebastes* spp.). ICES J. Mar. Sci. 59: 805–815.

Hall, P., J. Horowitz, and B. Jing. 1995. On blocking rules for the bootstrap with dependent data. Biometrika 82: 561-574.

Hayfield, T., and J. Racine. 2008. Nonparametric Econometrics: The np Package. J. Stat. Softw. 27(5). Available: http://www.jstatsoft.org/v27/i05/. 32 p.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scand. J. Stat. 6(2): 65–70.

Honkalehto, T., D. Jones, A. McCarthy, D. McKelvey, M. Guttormsen, K. Williams, and N. Williamson. 2009. Results of the echo integration trawl survey of walleye pollock (*Theragra chalcogramma*) on the U.S. and Russian Bering Sea shelf in June and July 2008. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-194, 56 p.

Jech, J., K. Foote, D. Chu, and L. Hufnagle. 2005. Comparing two 38-kHz scientific echosounders. ICES J. Mar. Sci. 62: 1,168-1,179.

Kang, D., and D. Hwang. 2003. Ex situ target strength of rockfish (*Sebastes schlegeli*) and red sea bream (*Pagrus major*) in the Northwest Pacific. ICES J. Mar. Sci. 60: 538–543.

Karp, B. 2007. Collection of acoustic data from fishing vessels. ICES Coop. Res. Rep. 287, 83 p.

Kloser, R., T. Ryan, A. Williams, and M. Lewis. 2001. Development and application of a combined industry/scientific acoustic survey of orange roughy in the Eastern Zone: Final report. CSIRO Marine Research, Hobart, Australia FRDC Project-99/111. 210 p.

Kloser, R., T. Ryan, A. Williams, and M. Soule. 2000. Development and implementation of an acoustic survey of orange roughy in the Chatham Rise spawning box from a commercial factory trawler, FV *Amaltal Explorer*. CSIRO Marine Research, Hobart, Australia. 90 p.

Knaus, J. 2013. Snowfall: Easier cluster computing (based on snow). R package version 1.84-6. Available: http://CRAN.R-project.org/package=snowfall.

Knudsen, H. 2009. Long-term evaluation of scientific-echosounder performance. ICES J. Mar. Sci. 66: 1,335-1,340.

Kotwicki, S., T. Buckley, and T. Honkalehto. 2005. Variation in the distribution of walleye pollock (*Theragra chalcogramma*) with temperature and implications for seasonal migration. Fish. Bull., U.S. 103: 574-587.

Logerwell, L., S. J. Barbeaux, and L. Fritz. 2009. A cooperative pollock acoustic biomass survey for management of fisheries interactions with Steller sea lions in the Aleutian Islands. North Pacific Fisheries Research Board Final Report, 106 p. [Available from http://doc.nprb.org/web/07_prjs/730%20Revised%20Final%20Report.pdf].

Madden, R. 2008. The forgotten people: the relocation and interment of Aleuts during World War II. Am. Indian Cult. Res. J. 16: 55-76.

Melvin, G., R. Stephenson, M. Power, F. Fife, and K. Clark. 2000. Industry acoustic surveys as the bases for in-season decisions in a co-management regime, p. 559-572. *In* F. Funk, J. Blackburn, D. Hay, A. Paul, R. Stephenson, R. Toreson, and D. Witherell (eds.), Herring 2000: Expectations for a New Millennium. 18th Lowell Wakefield Fisheries Symposium, Anchorage, Alaska, 23–26 February 2000. University of Alaska Sea Grant, Fairbanks, AK-SG-01-04; 2001.

Mitson, R. 1995. Underwater noise of research vessels. ICES Co-operative Research Report 209: 61.

O'Driscoll, R. 2004. Estimating uncertainty associated with acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) in Cook Strait, New Zealand. ICES J. Mar. Sci. 61: 84-97.

O’Driscoll, R., and G. Macaulay. 2005. Using fish-processing time to carry out acoustic surveys from commercial vessels. ICES J. Mar. Sci. 62:295-305.

Ona, E., and R. B. Mitson. 1996. Acoustic sampling and signal processing near the seabed: the deadzone revisited. ICES J. Mar. Sci. 53: 677–690.

Orlowsky, A. 1987. Acoustic estimation of redfish stocks and their distribution in the Reykjanes Ridge area. Rep. Sea Fish. Inst., Gdynia 22: 23-47.

NDBC (National Data Buoy Center). 2014. Station Adak2. Accessed 4 May 2014. Available: http://www.ndbc.noaa.gov/station_page.php?station=adka2.

Pebesma, E. 2004. Multivariable geostatistics in S: the gstat package. Comp. Geosciences 30: 683-691.

Pebesma, E., B. Graeler, and M. Pebesma. 2015. Package 'gstat'. Available: http://kambing.ui.ac.id/cran/web/packages/gstat/gstat.pdf.

Petitgas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES J. Mar. Sci. 50: 285-298.

Pikitch, E., C. Santora, E. Babcock, A. Bakun, R. Bonfil, D. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. Houde, J. Link, P. Livingston, M. Mangel, M. McAllister, J. Pope, and K. Sainsbury. 2004. Ecosystem-based fishery management. Science 305: 346-347.

Politis, D., and H. White. 2004. Automatic block-length selection for the dependent bootstrap. Economet. Rev. 23: 53-70.

R Development Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Renard, D., N. Bez, N. Desassis, H. Beucher, F. Ors. and F. Laporte. 2014. RGeostats: The Geostatistical package v10.0.8. MINES Paris Tech. Available: http://cg.ensmp.fr/rgeostats.

Reynisson, P. 1992. Target strength measurements of oceanic redfish in the Irminger Sea. ICES Fish Capture Comm. ICES CM 1992/B:8, 13 p.

Rose, G., B. DeYoung, D. Kulka, S. Goddard, and G. Fletcher. 2000. Distribution shifts and overfishing the northern cod (*Gadus morhua*): a view from the ocean. Can. J. Fish. Aquat. Sci. 57: 644-663.

Rosen, D. 2009. Steller sea lions (*Eumetopias jubatus*) and nutritional stress: Evidence from captive studies. Mammal Rev. 39: 284-306.

Sigler, M., D. Tollit, J. Vollenweider, J. Thedinga, D. Csepp, J. Womble, M. Wong, M. Rehberg, and A. Trites. 2009. Steller sea lion foraging response to seasonal changes in prey availability. Mar. Ecol. Progr. Ser. 388:243–261.

Sigler, M., J. Womble, and J. Vollenweider. 2004. Availability to Steller sea lions (*Eumetopias jubatus*) of a seasonal prey resource: a Pre-spawning aggregation of eulachon (*Thaleichthys pacificus*). Can. J. Fish. Aquat. Sci. 61:1,475–1,484.

Simmonds, J., and D. MacLennan. 2005. Fisheries Acoustics Theory and Practice, Second edition, Blackwell Publishing, Ames, Iowa.

Sinclair, E., D. Johnson, T. Zeppelin, and T. Gelatt. 2013. Decadal variation in the diet of western stock Steller sea lions (*Eumetopias jubatus*). U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-248, 67 p.

Sinclair, E., and T. Zeppelin. 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). J. Mammal. 82: 973-990.

Spencer, P., and J. Ianelli. 2014. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, 605 West 4th, Suite 306, Anchorage, AK 99501-2252.

Traynor, J. 1996. Target-strength measurements of walleye pollock (*Theragra chalcogramma*) and Pacific whiting (*Merluccius productus*). ICES J. Mar. Sci. 53: 253-258.

Traynor, J., and N. Williamson. 1983. Target strength measurement of walleye pollock (*Theragra chalcogramma)* and a simulation study of the dual beam method. FAO Fish. 300:112-124.

Venables, W., and B. Ripley. 2002. Modern Applied Statistics with S. Springer, New York, New York.

von Szalay, P. , C. Rooper, N. Raring, and M. Martin. 2011. Data Report: 2010 Aleutian Islands bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-215, 153 p.

Walline, P. 2007. Geostatistical simulations of eastern Bering Sea walleye pollock spatial distributions, to estimate sampling precision. ICES J. Mar. Sci. 64: 559-569.

Williamson, N., and J. Traynor. 1996. Application of a one-dimensional geostatistical procedure to fisheries acoustic surveys of Alaskan pollock. ICES J. Mar. Sci. 53: 423-428.

Winship, A., A. Trites, and A. Rosen. 2002. A bioenergetic model for estimating food requirements of Steller sea lions *Eumetopias jubutus* in Alaska, USA. Mar. Ecol. Progr. Ser. 229: 291-312.

Woillez, M., J. Rivoirard, and P. Fernandes. 2009. Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical simulations. ICES J. Mar. Sci. 66: 1,377-1,383.

Womble, J., and M. Sigler. 2006. Seasonal availability of abundant, energy-rich prey influences the abundance and diet of a marine predator, the Steller sea lion *Eumetopias jubatus*. Mar. Ecol. Progr. Ser. 325:281-293.

Womble J., M. Willson, M. Sigler, B. Kelly, and G. VanBlaricom. 2005. Distribution of Steller sea lions *Eumetopias jubatus* in relation to spring-spawning fish in SE Alaska. Mar. Ecol. Progr. Ser. 294:271–282.

Zar, J. 1999. Biostatistical Analysis Fourth Addition. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Zuur, A., E. Ieno, N. Walker, A. Saveliev, and G. Smith. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer. New York, New York.

Table 1. -- Target strength to length relationships used for *Sebastes* species collected at 38 kHz frequency. The functional dependence of target strength (TS) on fish length L is TS = m $\log_{10}$(L)+b.

Species	Location	m(dB)	b(dB)	Reference
Sebastes marinus	Norwegian Sea	20	- 67.1	Foote et al. 1986
Physoclist fishes	Atlantic	20	- 67.5	Foote 1987
Atlantic redfish, *Sebastes* spp.	Atlantic	20	- 69.4	Orlowsky 1987
Atlantic redfish, *Sebastes* spp.	Irminger Sea	20	- 71.3	Reynisson 1992
Atlantic redfish, *Sebastes* spp.	Atlantic, Newfoundland	20	- 67.6	Gauthier and Rose 1998
Atlantic redfish, *Sebastes* spp.	Atlantic, Newfoundland	19	- 66.6	Gauthier and Rose 2001
Atlantic redfish, *Sebastes* spp.	Atlantic, Newfoundland	20	- 68.7	Gauthier and Rose 2002
Sebastes schelgeli	N.W. Pacific	20	- 67.7	Kang and Hwang 2003
Sebastes marinus	Barents Sea	18	-67.5	Ermolchev 2011
Sebastes marinus	Norwegian Sea	20	- 69.5	Ermolchev 2011
Sebastes marinus	Irminger Sea	20	- 69.5	Ermolchev 2011

Table 2. -- Results and estimation error for the 2006-2008 Aleutian Islands Cooperative Acoustic Survey Studies. All biomass estimates are combined POP and pollock biomass. Proportions are proportion of pollock to POP. CV is the simple transect coefficient of variation for each survey calculated as the biomass standard deviation by transect over transect mean biomass. CV_{geo} are the 1-dimensional geostatistical relative estimation errors, CV_{boot} are the fixed block-bootstrap relative estimation errors, and CV_{total} are the estimates from the expanded uncertainty model.

Year	2006	2006	2006	2006	2006	2006	2007	2007	2008	2008
Survey	1	2	3	4	5	6	1	2	3	4
Start date	14-Mar	23-Mar	24-Mar	28-Mar	1-Apr	3-Apr	14-Mar	14-Apr	19-Feb	23-Mar
End date	15-Mar	24-Mar	24-Mar	29-Mar	1-Apr	4-Apr	21-Mar	18-Apr	27-Feb	27-Mar
Transect statistics										
Inter-transect distance (nmi)	1.5	1.5	0.5	1	1	1.5	2.5	2.5	2.5	2.5
Number of transects	18	22	7	12	12	23	88	88	58	58
Mean biomass(t)	565	494	130	284	211	167	246	179	597	682
CV	0.76	0.81	0.85	0.91	0.62	0.72	1.48	1.38	1.73	2.17
Total										
Proportion pollock by number	1.00	1.00	1.00	1.00	1.00	1.00	0.81	0.80	0.57	0.57
Proportion pollock by weight	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.90	0.78	0.76
Biomass (t)	10,175	10,865	910	3408	2534	3839	21,140	15,383	34,614	38,194
CV_{geo}	0.15	0.18	0.10	0.08	0.16	0.09	0.09	0.20	0.09	0.26
CV_{boot}	0.17	0.17	0.30	0.33	0.17	0.16	0.16	0.15	0.24	0.31
CV_{total}	NA	NA	NA	NA	NA	NA	0.237	0.228	0.290	0.354

Table 3. -- Kolmogorov-Smirnov D-statistic, and Holm's corrected p-value for multiple tests to investigate similarities of distribution of cumulative biomass of pollock and POP combined from west to east for the overlapping survey area of the 2007 and 2008 surveys.

Comparison	D-statistic	Holm's corrected p-value
2007 S1 – 2007 S2	0.22	0.33
2007 S1 – 2008 S3	0.19	0.50
2007 S1 – 2008 S4	0.28	0.10
2007 S2 – 2008 S3	0.31	0.04
2007 S2 – 2008 S4	0.10	0.92
2008 S3 – 2008 S4	0.33	0.02

Table 4. -- Results from the length-weight log-normal linear regression model with a random year effect for pollock and POP including standard errors (SE) of the estimates and the Year effect and Residual standard deviations (SD).

Species	Intercept		Slope		Year effect	Residual
	Estimate	SE	Estimate	SE	SD	SD
Pollock	-11.23	0.46	2.89	0.11	0.03	0.17
POP	-11.23	0.17	3.01	0.05	0.03	0.14

Table 5. -- Results for the 2007-2008 Aleutian Islands Cooperative Acoustic Survey Studies from the fully expanded uncertainty model. All biomass estimates are combined POP and pollock biomass. Surveyed proportions estimates were calculated using the proportion of pollock to POP by number from the verification trawls, assuming 100% pollock biomass estimates were calculated with all echosign attributed to pollock and 0% pollock biomass estimates were calculated with all echosign attributed to POP.

Year	2007	2007	2008	2008
Survey	1	2	3	4
Surveyed proportions				
Proportion pollock by number	0.81	0.80	0.57	0.57
Median biomass (t)	23,877	17,349	36,108	39,142
Upper CI (0.975)	37,601	26,993	62,352	74,419
Lower CI (0.025)	14,909	11,012	20,175	18,684
CV_{Total}	0.28	0.23	0.29	0.35
100% pollock				
Median biomass (t)	21,775	16,260	32,146	36,367
Upper CI (0.975)	40,948	26,137	64,512	68,529
Lower CI (0.025)	10,709	9,637	15,285	17,642
CV_{Total}	0.36	0.26	0.40	0.37
0% pollock				
Median biomass (t)	39,159	28,791	58,129	61,905
Upper CI (0.975)	91,056	61,652	147,669	149,097
Lower CI (0.025)	16,786	15,452	24,372	26,056
CV_{Total}	0.45	0.38	0.49	0.46

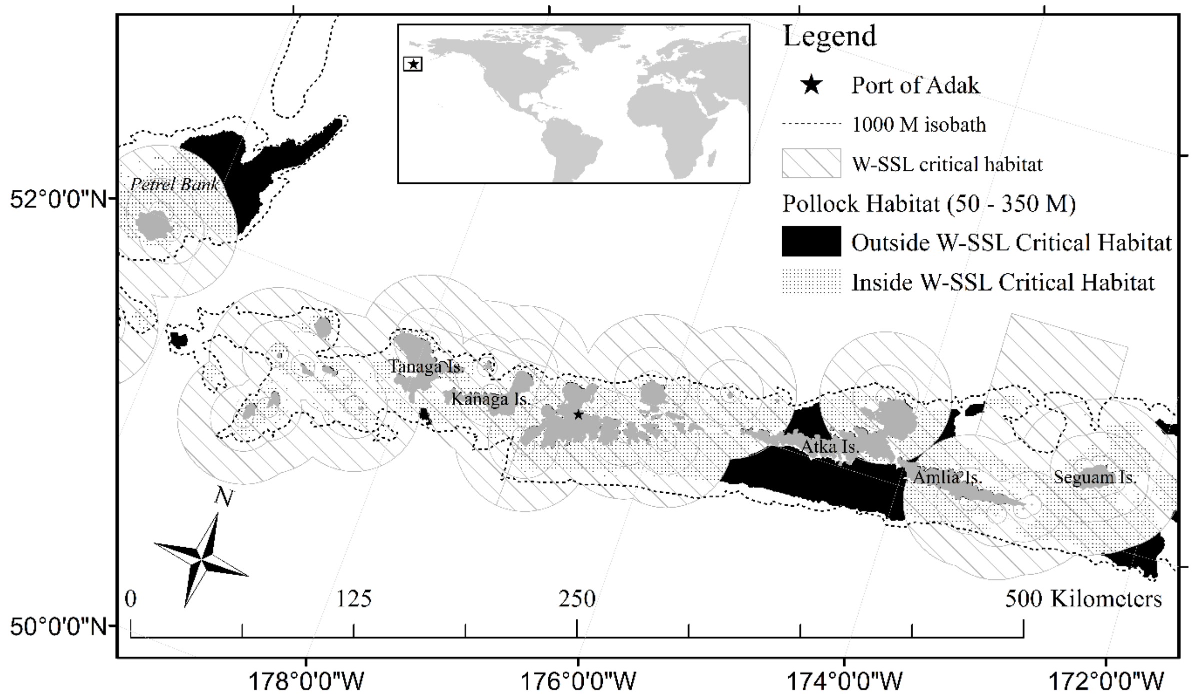

Figure 1. -- Map of study area showing suitable pollock habitat within 250 km of the Port of Adak and overlap with W-SSL critical habitat.

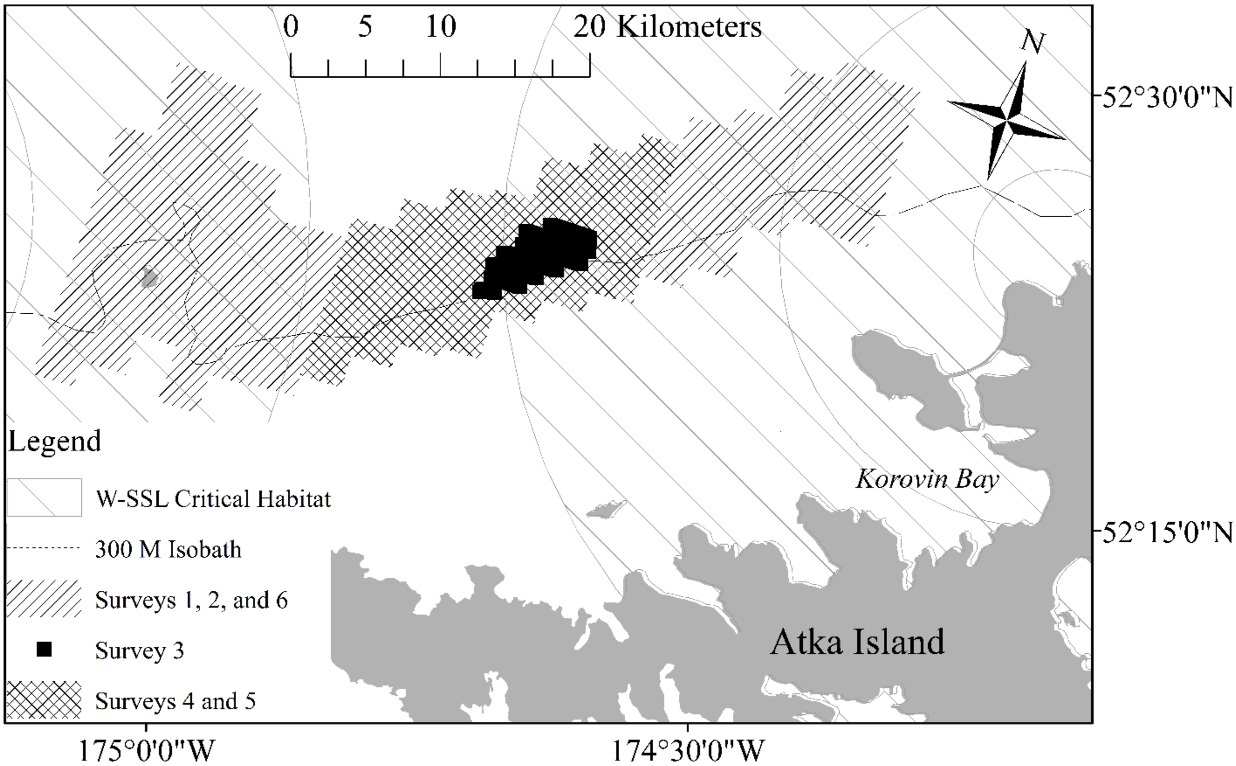

Figure 2. -- Survey areas for the 2006 Aleutian Islands Cooperative Acoustic Survey Study.

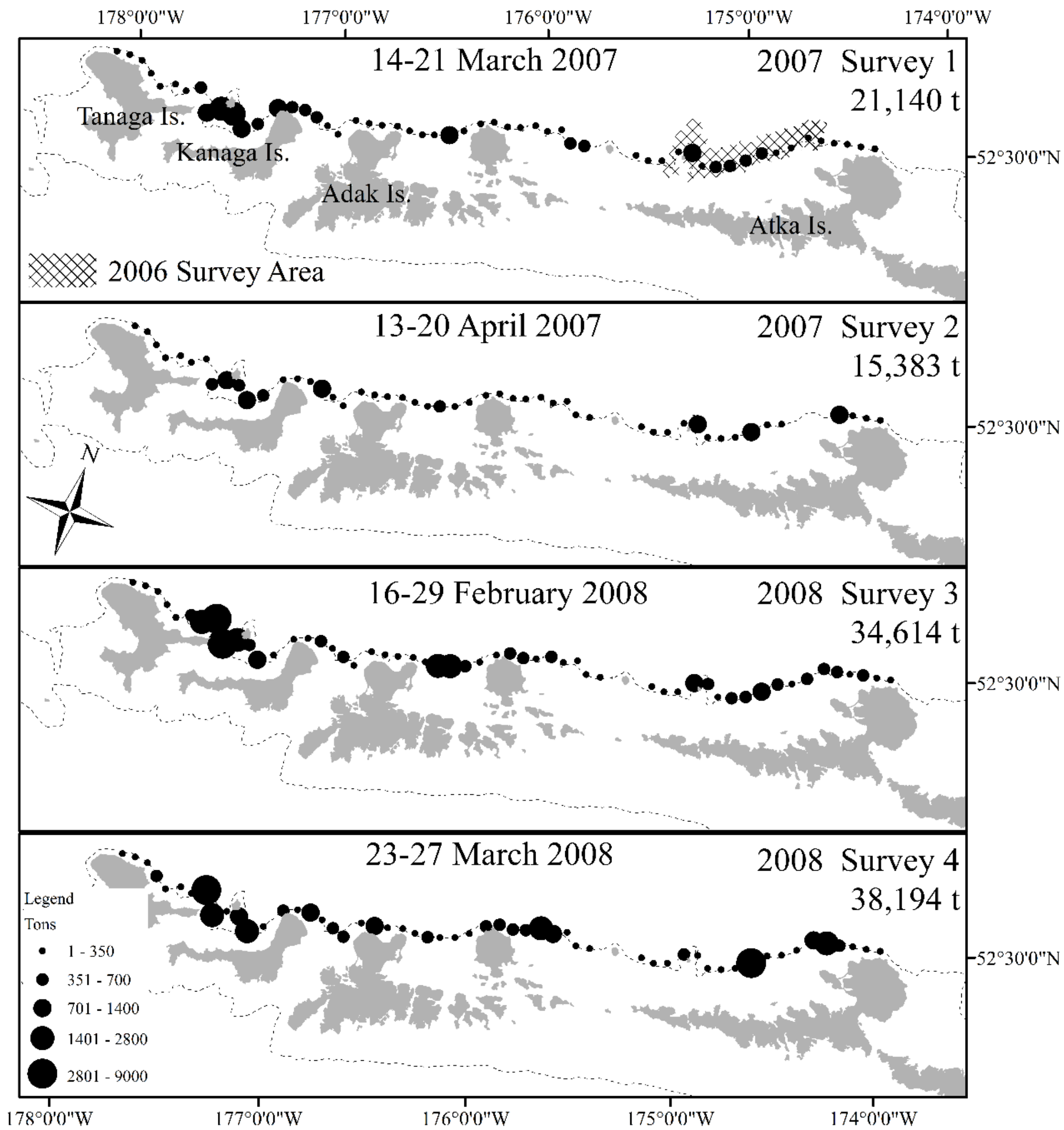

Figure 3. -- Distribution of Pacific ocean perch and pollock combined biomass (t) by transect for the 2007 and 2008 studies. Dashed line is the 300 m isobath. Hatched area is the extent of the 2006 study.

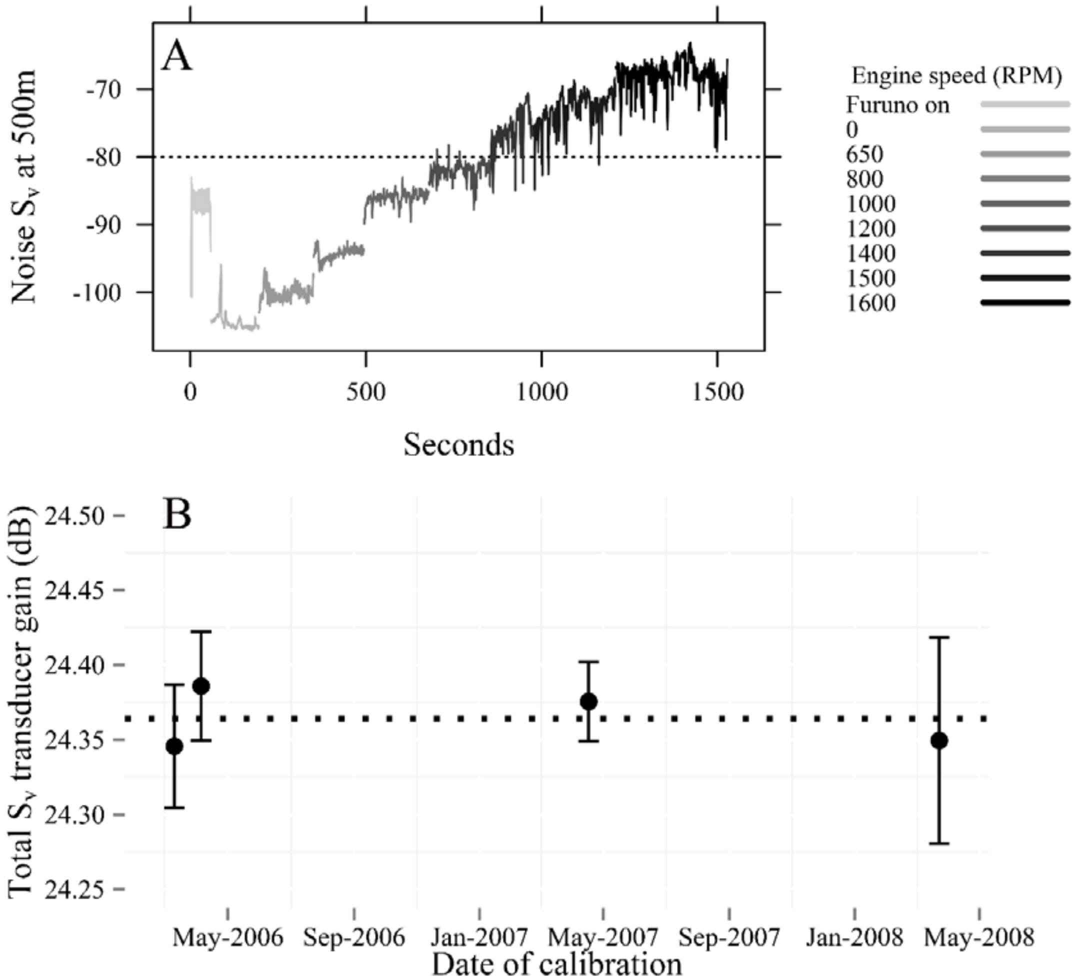

Figure 4. -- (A) Self-noise test on the FV *Muir Milach* showing increasing engine speed over time with resulting increases in noise level (S_v dB re 1m^{-1} at 500 m). “Furuno on” is the noise level at 0 RPM when a Furuno 55 kHz echosounder remained on. The dotted line at -80 dB is the 10:1 signal-to-noise ratio at 500 m deemed acceptable for this survey with an integration threshold set at -70 dB and maximum depth of 500 m. (B) Calibration results for FV *Muir Milach* showing stability of the commercial acoustic system over the 3-year study period with S_v transducer gain (dB) derived from sphere calibrations. Factory settings for S_v transducer gain was 26.5 dB.

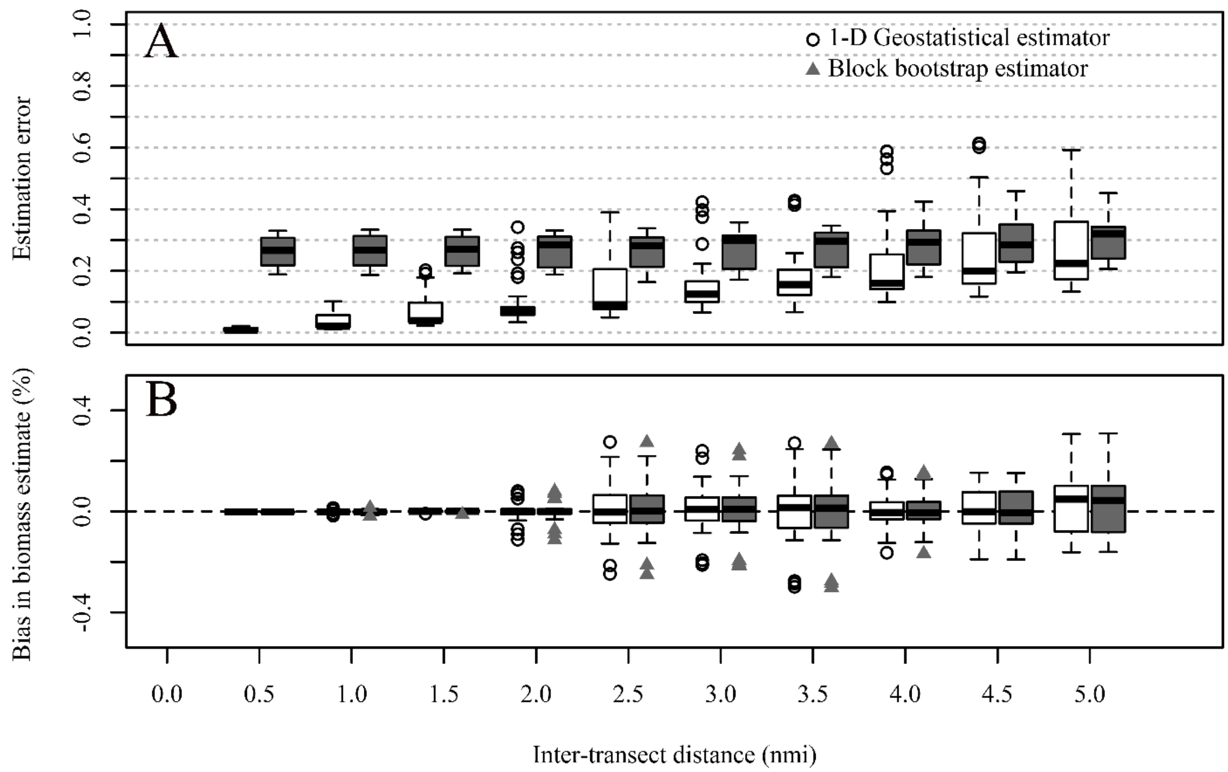

Figure 5. -- Boxplots of (A) estimation error by transect distance for both the 1-dimensional (1-D) geostatistical (white) and block-bootstrap (shaded) methods survey data and (B) percent bias in the survey biomass estimates by transect distance. Both plots were created using 10 random samples per inter-transect distance of IDW simulated distributions generated from the 2006 surveys with 1.5 nautical miles (nmi; 2.78 km) spacing.

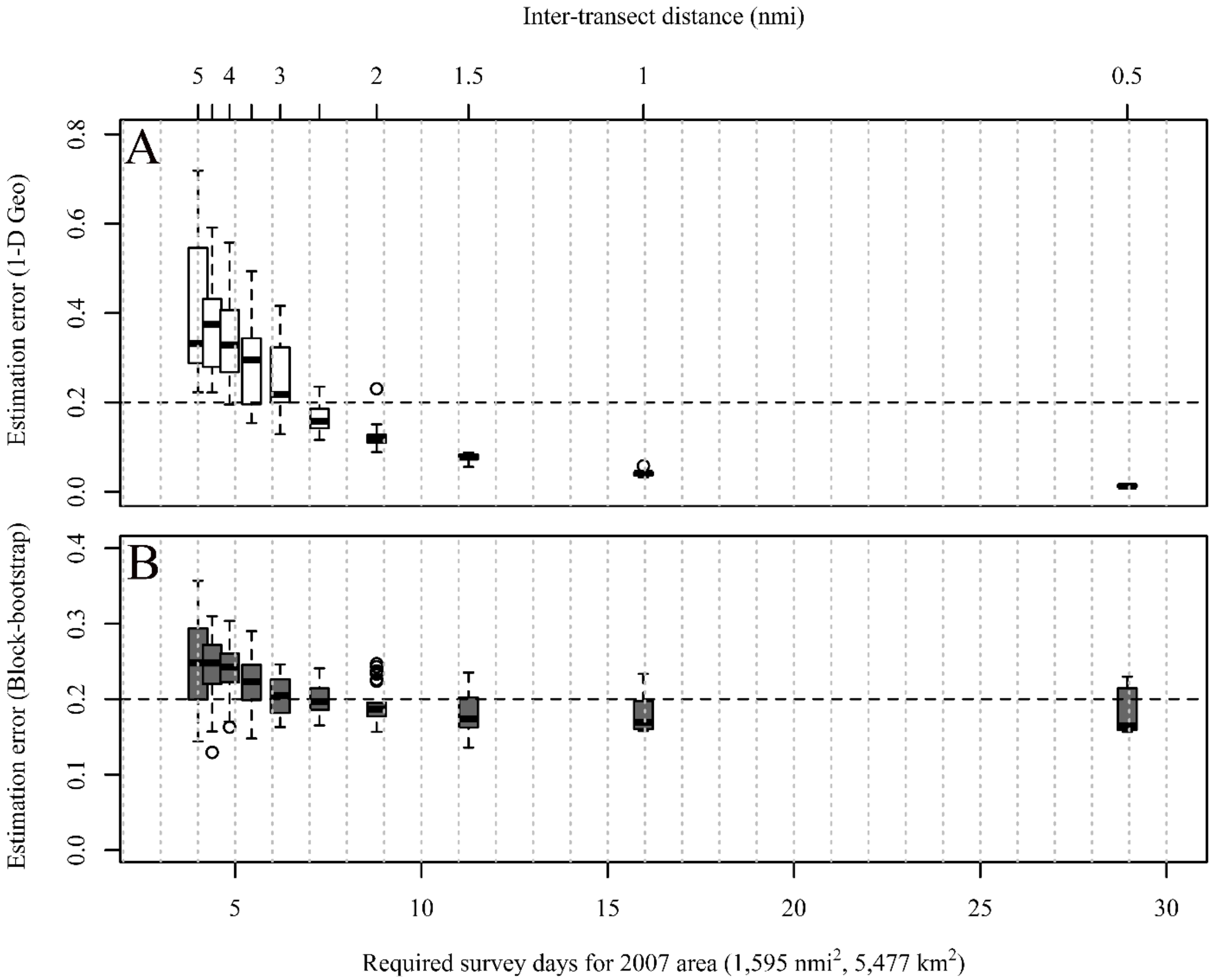

Figure 6. -- Boxplots of (A) estimation error by transect distance and estimated costs in number of 16-hour days for both the 1-dimensional (1-D) geostatistical and (B) block-bootstrap methods. Both plots were created using 10 random samples per inter-transect distance of IDW simulated distributions generated from the 2006 surveys with 1.5 nautical miles (nmi; 2.78 km) spacing.

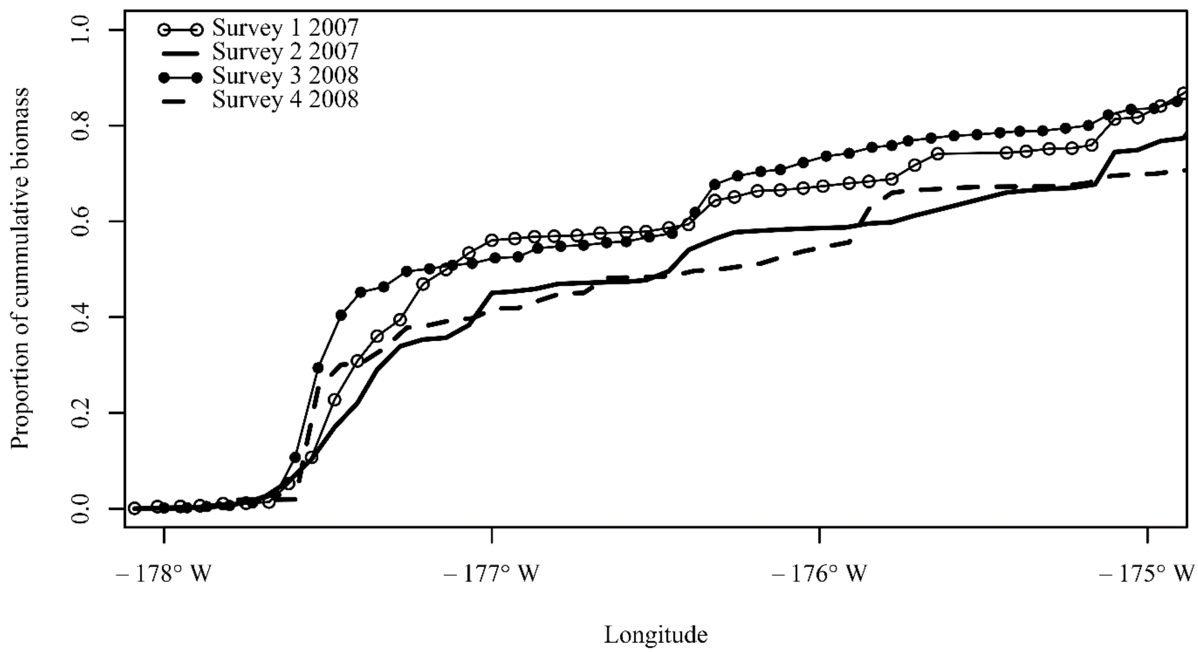

Figure 7. -- Cumulative biomass estimates from west to east in the four 2007 and 2008 surveys, showing an eastward shift in biomass in the later surveys for both years.

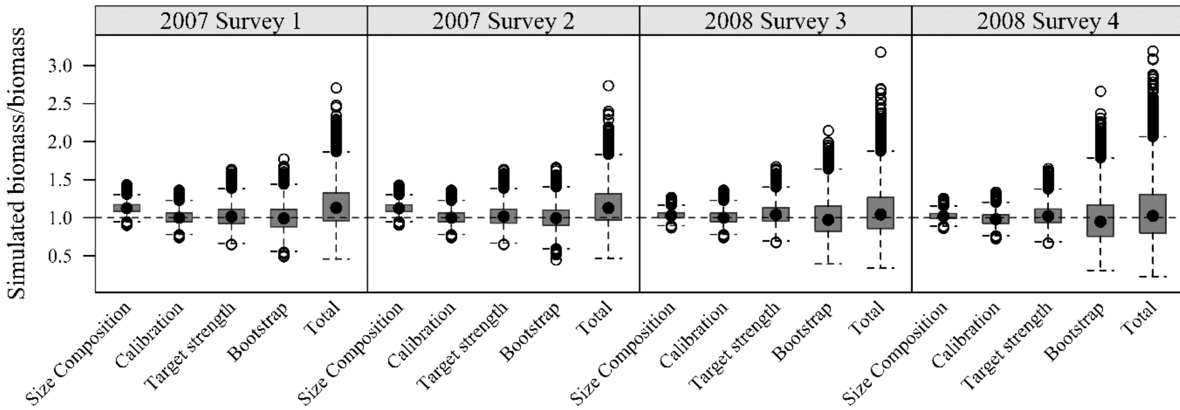

Figure 8. -- Boxplots of simulated 2007 and 2008 survey biomass estimates divided by the initial survey biomass estimates from each of the respective uncertainty probability distributions, fixed block bootstrap (Bootstrap) for estimating spatial sampling uncertainty, or for all combined (Total).

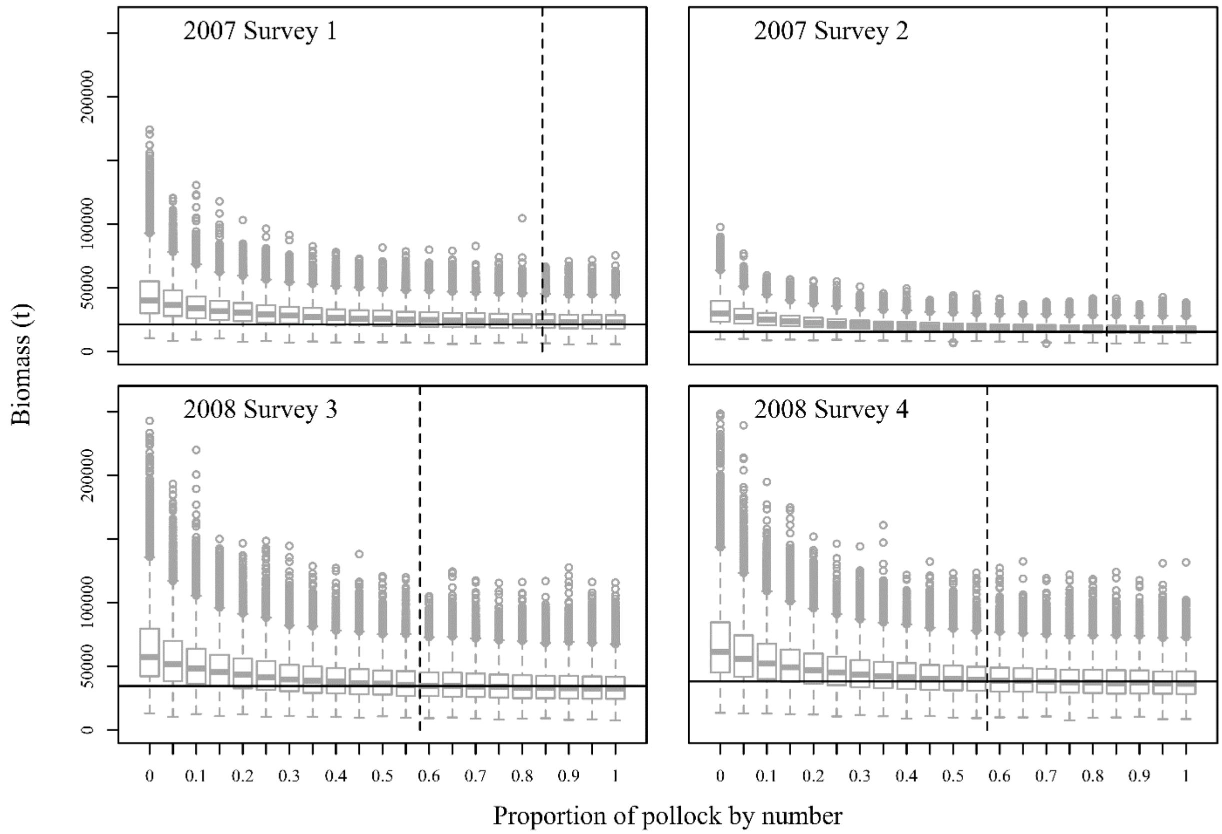

Figure 9. -- Boxplots of simulated 2007 and 2008 biomass estimates over the proportion of pollock from the expanded uncertainty probability distribution incorporating calibration, target-strength model, size composition, and spatial sampling. The horizontal solid lines are the initial biomass estimates at the proportion of pollock by number observed in each survey from verification trawls (vertical dashed line).

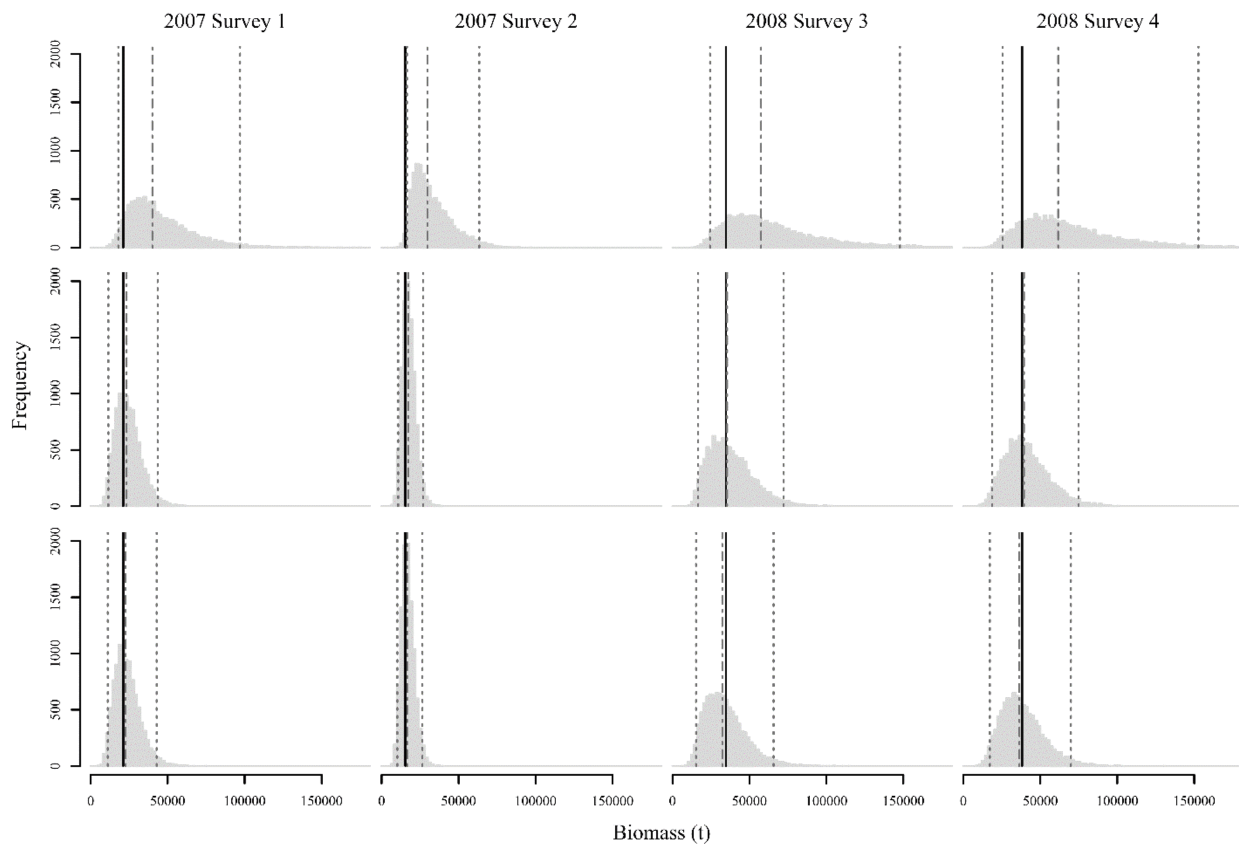

Figure 10. -- Modeled biomass distributions for 2007 and 2008 surveys showing biomass estimates at (top) 100% Pacific ocean perch, (middle) the survey estimated proportions of pollock (horizontal solid lines from Fig. 9), and (bottom) 100% pollock from the expanded uncertainty model. The solid lines are the initial biomass estimates. The median biomass estimate from the full uncertainty model (dashed-dot line) and 95% confidence intervals (dotted lines) are also shown.

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