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Acoustic Vessel-of-Opportunity (AVO) Index for Midwater Bering Sea Walleye Pollock,

2014-2015

by

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ABSTRACT

An acoustic vessel of opportunity (AVO) index for midwater walleye pollock (*Gadus chalcogrammus*) has been estimated since 2006 using backscatter information collected during the annual bottom trawl (BT) survey. AVO index estimates for summer 2014 and 2015 are reported here. The 2014 AVO index increased 29% from the 2013 index value, and 36% from 2012. The 2015 AVO index increased slightly (6%) from 2014. Both estimates (2014, 2015) exceeded all earlier time series estimates (2006-2013) based on non-overlapping 95% confidence intervals. Most pollock backscatter appeared to be distributed broadly across the shelf between 50 and 200 m isobaths in 2014 and 2015. The percentage of pollock backscatter east of the Pribilof Islands (east of 170° W longitude) in the AVO index was 24% in 2014 and 25% in 2015. This was similar to the percentage in 2013 (26%), but much greater than reported for summers 2010-2012 (range 4-9%). This implies that there has been more midwater pollock biomass east of the Pribilof Islands in recent years. Comparison of the AVO index and AT survey time series continues to show a strong correlation ($r^2 = 0.90$, $p = 0.0011$).

Midwater hauls were conducted to sample midwater pollock aggregations during the 2014 (n = 31) and 2015 (n = 32) BT surveys to investigate the feasibility of using these hauls to convert the AVO backscatter index to abundance at length or age. Some portions of the AVO index area were not sampled by these hauls in both years. Preliminary analyses of these haul data (ability to target and catch pollock, catch composition, and length-frequency comparisons) showed 1) hauls targeted appropriate fish layers and were dominated by pollock, 2) bottom trawls and midwater trawls caught pollock of different length compositions and 3) length modes in midwater hauls from BT and AT surveys were similar, but occurred in different proportions even when restricted to the same subarea. Due to a number of factors including logistical and

staffing constraints, full evaluation of how well BT survey haul data could be used to convert AVO backscatter to number of fish at length or age was deferred to a later time. Some guidance on what would be required for this analysis is outlined in the Appendix.

CONTENTS

INTRODUCTION

Walleye pollock (*Gadus chalcogrammus*, hereafter pollock), is a commercially important gadid fish species, and the target of a major trawl fishery on the eastern Bering Sea shelf. The fishery-independent time series used to manage this valuable stock include data from two summer research surveys conducted by the Alaska Fisheries Science Center. A bottom trawl (BT) survey is conducted annually to assess demersal pollock, as well as other commercially important groundfish and crab species (Lauth and Nichol 2013). An acoustic-trawl (AT) survey is currently conducted biennially (intervals ranged from 1-3 years in the past) to assess midwater pollock (Honkalehto and McCarthy 2015). In an effort to obtain annual information for midwater pollock, Honkalehto et al. (2011) used acoustic backscatter at 38 kHz collected by BT survey vessels for a portion of the eastern Bering Sea shelf, from near surface to 3 m off bottom, to develop an abundance index that was strongly correlated with the total estimated AT survey pollock biomass ($r^2 = 0.904$, $p = 0.004$, 2006-2012; Honkalehto et al. 2014). This abundance index from vessels of opportunity (AVO) is now estimated annually. It is an important component of the Bering Sea pollock stock assessment because it provides information on midwater pollock in years when the AT survey is not conducted (Ianelli et al. 2015). This report updates and discusses AVO index results for summers 2014 and 2015.

The length-frequency compositions of pollock sampled by BT and AT surveys are known to be different (Ianelli et al. 2015). The BT survey tends to catch larger, older pollock as well as some age-1 juveniles, whereas the AT survey tends to catch smaller, younger pollock, as well as some older individuals where near-bottom schools extend upward into midwater. In addition to conducting bottom trawl hauls with the 83-112 eastern otter trawl (Lauth and Nichol 2013), the BT survey vessels used the same trawl to conduct a number of opportunistic midwater hauls on acoustically-detected midwater pollock aggregations beginning in 2014. The main objective of the midwater trawling effort on the BT survey was to determine whether a representative estimate of midwater pollock size composition could be obtained to convert the AVO backscatter index to pollock numbers at size and age for potential use in the stock assessment model. Confidence in the ability to successfully sample the size composition of midwater pollock using the 83-112 bottom trawl rather than a large midwater trawl such as that used by the AT survey was based on preliminary results from field trials of paired hauls done aboard the NOAA ship *Oscar Dyson* during the 2012 AT survey (Honkalehto et al. 2013). Net selectivity bias was not evident in that study, though a subsequent analysis of these data did indicate a small amount of bias against pollock > 40 cm (Kotwicki et al. in revision). After the 2014 and 2015 field seasons were completed, it was decided that it was not currently feasible to carry out all the work needed to fully convert BT survey backscatter to abundance at length. Instead we evaluated the midwater trawls' catch composition and their effectiveness at catching midwater pollock, and compared length compositions between the BT and AT surveys in 2014. We also provided an appendix with some guidelines for how best to continue the work at a later time if desired.

METHODS

Bottom Trawl Surveys

Groundfish Assessment Program scientists conducted the 2014 and 2015 BT surveys aboard the chartered vessels FV *Vesteraalen* and FV *Alaska Knight* (see Lauth and Nichol 2013). Surveys occurred during June-August in the U.S. Exclusive Economic Zone (EEZ). Trawl stations were generally occupied from east to west across the Bering Sea shelf from eastern Bristol Bay to the U.S. – Russia maritime boundary between roughly the 30 and 300 m isobaths, and between 54°

and 62° N latitude. Bottom trawl hauls were conducted at the fixed stations spaced 37 km (20 nmi) apart. BT survey vessels recorded 38 kHz acoustic backscatter data with Simrad (Simrad, Kongsberg Maritime AS, Horten, Norway) ES38B split-beam transducers and ES60 echosounding systems at approximately 1 ping s^{-1}. These ping data were averaged into 0.5 nautical mile (nmi) intervals along the vessel track. Backscatter data were also collected at 120 kHz but were not used in the AVO index.

AVO Index Computation

Methods for estimating the AVO index are based on Honkalehto et al. (2011). They are briefly described here, emphasizing what pertains to index years 2014 and 2015. Honkalehto et al. (2011) determined that summed 38 kHz backscatter from roughly half of the AT survey area was strongly correlated with total AT survey pollock biomass in a retrospective analysis. The 38 kHz backscatter collected in this 'index area' during 2014-2015 was either classified semi-automatically using custom software (Python Software Foundation, https://www.python.org), or classified manually by trained analysts using Echoview software (Echoview Software Pty Ltd, Hobart, Australia). Semi-automatic classification assumed all backscatter between 30 m from the sea surface and 3 m from the sea floor was pollock. Manual classification was required in regions where species composition was known from the retrospective study to be less certain. Experts classified all backscatter from 16 m below the surface to within 0.5 m of the bottom into approximately half a dozen taxonomic categories based on the concept that the eastern Bering Sea midwater community is dominated by pollock and relatively few other species (Honkalehto et al. 2002, De Robertis et al. 2010). Generally, a line was drawn in Echoview below a near-surface layer attributed to a variable mixture of plankton and individual fishes. Nearly all midwater fish aggregations between that line and a line 0.5 m off bottom were attributed to pollock, with a few exceptions (e.g., backscatter attributed to other fish, age-0 pollock, or dense euphausiid layers were also excluded). All data were stored in an Oracle database at 10 m vertical by 926 m (0.5 nmi) horizontal resolution. Pollock backscatter was vertically integrated, averaged into 37 x 37 km (20 nmi x 20 nmi) blocks surrounding BT survey bottom trawl stations, and summed across the index area to compute the AVO index.

Opportunistic Midwater Trawling

Opportunistic midwater tows were made during the BT survey in 2014 and 2015 using the 83-112 bottom trawl. Methodology and guidelines for midwater trawling were developed from AT survey protocols (Honkalehto et al. 2014) and from field trials done aboard the NOAA ship *Oscar Dyson* during the 2012 AT survey (see Fig. 16 in Honkalehto et al. 2013). These methods required further field trials by BT survey scientists and vessel skippers (who were more familiar with trawling operations) to be successful. The net was fished with a 250-lb weight chain attached to each side of the footrope at the gusset where web changes from a bar cut to a mesh cut (Honkalehto et al. 2002). The *Vesteraalen* used a Simrad FS20 third wire net sounder during midwater tows. The *Alaska Knight* did not have a third wire net sounder and instead relied on a Marport net mensuration system (Marport Deep Sea Technologies, Inc., http://marport.wix.com) to monitor depth of the trawl while fishing in midwater. Opportunistic trawls were conducted when a substantial layer of off-bottom (at least 10 m above the bottom) midwater backscatter likely to be pollock was detected on the ES60 echosounder monitor. Tow duration was up to 60 min with the goal of obtaining 200 pollock for fork length (FL) measurements. Catches were processed following standard BT survey catch processing methods (Lauth and Nichol 2013).

Trained analysts used Echoview software to examine the appearance of backscatter along each midwater trawl path. Data from a temperature-depth sensor located on the trawl headrope were imported into Echoview and displayed along with the corresponding 38 kHz backscatter data to determine the trawl position. The position of the trawl footrope was assumed to be 5 m deeper than the headrope. Mean s_A (nautical area scattering coefficient, m^2 nmi^{-2}; MacLennan et al. 2002) from the targeted backscatter was computed and compared to haul duration and the number of pollock caught in the net.

To determine whether catches from BT survey midwater tows were representative of midwater backscatter, pollock length compositions were compared among three trawl data sets: BT survey midwater tows, BT survey bottom tows, and AT survey tows (midwater and bottom tows used to convert the pollock backscatter to abundance estimates). This was done as follows: first, to ensure the same area was represented in all calculations, only hauls done in the geographic area normally covered by the AT survey (which includes the AVO index area) were used. Second, for each trawl data set, pollock lengths from hauls that caught ≥ 50 pollock were converted to proportions of numbers at length, and an average proportion at length was computed (all hauls weighted equally). Plots of these “raw” proportion-at-length data were also compared to population size composition estimates for the AT survey. These population size composition estimates are generated using raw length compositions from AT survey hauls, a target strength-length relationship, and observed pollock backscatter (Honkalehto and McCarthy 2015).

Survey Methods Specific to 2014

Both AT and BT surveys were conducted in summer 2014. The AT survey was conducted aboard the NOAA ship *Oscar Dyson* using standard acoustic-trawl survey methods as detailed in Honkalehto and McCarthy (2015) and Honkalehto et al. (2008). Standard sphere calibrations were conducted for both 38 and 120 kHz acoustic systems on the BT survey vessels immediately before and after the BT survey. First, split-beam target strength (TS) and echo integration measurements of a tungsten carbide (38.1 mm diameter) sphere were made for each frequency once the sphere was centered on the respective beam axis (stationary sphere method; Foote et al. 1987). Next, on-axis sensitivity and beam characteristics such as along and athwart beam angles and angle offsets were estimated using the post-processing software bundled with the echosounder (calibration.exe; Simrad 2008), based on data collected from the sphere, which was moved throughout the four quadrants of each beam (moving sphere method; Foote et al. 1987). Midwater trawl sampling in 2014 was focused west of 170° W due to BT survey time constraints and because most midwater pollock backscatter had been observed in this survey region in previous years.

Survey Methods Specific to 2015

Only the BT survey was conducted during summer 2015. Standard sphere calibrations were conducted before and after the survey, as described for 2014. Five vessel-days were added to the BT survey schedule to allow more time for midwater trawling. The vessel chief scientists were requested to sample wherever they observed midwater layers. During data processing, it was discovered that the FV *Alaska Knight* ES60 recording stream lost GPS position data on 21 June 2015. This was remedied on 11 July 2015, but position data were absent from the ES60 .raw binary files during this time period. To correct for this, GPS data recorded separately by

Globe navigation software (at much lower resolution (~8 fixes/nmi) than normally present in the .raw files (~378 fixes/ nmi); Electronic Charts Company, Inc., Seattle, USA) were used to fill missing position data in the .raw files. The GPS fixes from Globe were found within the time range of each .raw file, inserted into the .raw file structure and then new .raw files were written with attached sparse GPS data. The reduced resolution of the secondary GPS data source and a time lag offset of 5.6 min between the ES60 computer time and the navigation computer time resulted in some loss of data and accuracy in the recovered position information for acoustic data. However, given the scale at which the AVO index is computed (1,369 km^2 [400 nmi^2] block averages), it is unlikely that this loss of position accuracy affected the AVO index results.

Relative Estimation Error and Spatial Distribution

The 1-D geostatistical relative estimation errors (Petitgas 1993), and approximate 95% confidence intervals describing sampling variability were calculated for 2014 and 2015 AVO index values following methods described by Honkalehto et al. (2011). Maps of acoustic backscatter and center of gravity estimates (Bez et al. 1997; Woillez et al. 2007, 2009) were used to compare pollock distribution patterns from the AVO index and the AT survey.

RESULTS

Calibration

The integration gains used in processing the 2014 38-kHz backscatter data were based on the June 2014 on-axis measurements for *Alaska Knight*, and on the May 2014 on-axis measurements for *Vesteraalen*. August 2014 calibrations for both vessels occurred under poor conditions so results were not used in post-processing but were sufficient to establish that no major changes in transducer sensitivity (< 1% difference in integration gain) had occurred during the summer field season. The integration gain used for 2015 38-kHz backscatter data for *Alaska Knight* was based on the mean of May and July 2015 calibrations. The gain used for *Vesteraalen* was based on the August 2015 calibration which occurred under better conditions than in May 2015. Changes to the 38 kHz integration gain values were relatively small between years (1% for Alaska Knight, 6.5% for Vesteraalen).

Biomass

The 2014 AVO index increased 29% over the 2013 index value and 36% over the 2012 index value (Table 1, Fig. 1). The 2015 AVO index increased slightly (6%) over 2014. Both estimates (2014, 2015) exceeded all earlier time series estimates (2006-2013) based on non-overlapping 95% confidence intervals. The 2014 and 2015 confidence intervals overlapped with each other, but not with prior values in the time series. For comparison, the summer 2014 AT survey estimate of midwater pollock biomass increased nearly 90% over that from the previous AT survey conducted in 2012. With the addition of the 2014 AVO index and AT survey biomass estimates, comparison of the AVO index and AT survey time series continues to show a strong correlation ($r^2 = 0.90$, $p = 0.0011$, Fig. 2).

Spatial Distribution

Midwater pollock backscatter from the AVO index and AT survey exhibit similar spatial patterns across the eastern Bering Sea (EBS) shelf in 2014 (Fig. 3). Most pollock backscatter appeared to be distributed in a broad band throughout the center of the AT and AVO survey areas between the 50 and 200 m isobaths. AVO pollock backscatter data show this relatively widespread distribution pattern in 2013 and 2015 as well (Fig. 3, and see Honkalehto et al. 2014), which in turn is reflected in the lower estimation errors for 2013-2015 compared with the earlier years of the time series (Table 1). The percentage of pollock backscatter east of the Pribilof Islands (east of 170° W longitude) in the AVO index was 24% in 2014 and 25% in 2015 (Figs. 3, 4). This is similar to the percentage in 2013 (26%) but much greater than the percentage in summers 2010-2012 (range 4-9%), implying there has been more midwater pollock biomass east of the Pribilof Islands in recent years. The pollock center of gravity estimates from both the AVO index and the AT survey also indicate a steady south and eastward shift since 2012 (Fig. 5). Finally, the percentage of the 2014 AT survey biomass inside the AVO index area fell from 85% in 2012 to 66% in 2014, consistent with a pollock distribution shift to the south and east since 2013.

Midwater Trawling

The *Alaska Knight* conducted 18 midwater trawl hauls and the *Vesteraalen* conducted 24 in 2014 (Fig. 3). Pollock dominated the catches by number caught (81%), but made up slightly less than half of the total catch weight (47%), with jellyfish (*Chrysaora melanaster*) making up most of the remainder (53%; Table 2). Of the 42 total hauls, 32 targeted pollock backscatter and 31 captured more than 50 pollock. The remaining 10 hauls appeared to have targeted jellyfish or other backscatter in the near surface mixed layer. For comparison, the 2014 AT survey conducted 89 hauls (72 using a midwater trawl and 17 using a bottom trawl), which were used to convert the AT survey backscatter into pollock biomass estimates. Pollock dominated the AT survey catches both numerically (92%) and by weight (81%), followed by *Chrysaora melanaster* (15% by weight). Midwater trawls made during the 2014 BT survey appear to have successfully targeted the regions west of the Pribilof Islands with high-density pollock backscatter (Fig. 3). The relatively high-density backscatter observed east of the Pribilof Islands was not sampled as the BT survey vessels were advised to not conduct midwater trawls in that area (see Methods).

The *Alaska Knight* conducted 11 midwater trawl hauls and the *Vesteraalen* conducted 29 in 2015 (Fig. 3). Pollock represented most of the catch by number (90%) and by weight (52%), with *Chrysaora* comprising 47% by weight (Table 2.) Of the 40 total hauls, 37 targeted pollock backscatter and 32 caught 50 or more pollock. The remaining three hauls either missed their target or targeted non-pollock backscatter. Although more of the shelf east of the Pribilof Islands was sampled in 2015 than in 2014, some high-density backscatter regions on the outer shelf west and north of the Pribilof Islands were not sampled for logistical reasons (Fig. 3).

Evaluation of the BT survey midwater haul paths indicated that they were appropriately located to sample midwater pollock backscatter. Examination of the net position relative to backscatter during the midwater hauls in both years indicated that the aggregation or schooling patterns of pollock may affect their catchability with the relatively small 83-112 bottom trawl. For a given s_A, for example, the bottom trawl tended to catch more pollock when the backscatter was relatively evenly distributed and not extremely patchy or clumped (Figs. 6a,6b). Often, considerably higher densities (i.e., larger mean s_A) of clumped backscatter were necessary to catch similar numbers of pollock (Figs. 6a,6c).

Comparing pooled proportions of pollock-at-length from BT survey bottom hauls, BT survey midwater hauls and AT survey midwater hauls, as well as AT survey-based population size composition in the geographic area covered by the AT survey and where BT midwater hauls were conducted (to the area west of 170° W) led to three observations (Fig. 7) . First was that in 2014, BT survey bottom hauls (n = 264) caught pollock of relatively different lengths than pollock caught in BT survey midwater hauls (n = 31) and AT survey hauls (n = 89). The smallest and largest pollock were captured frequently on or near the bottom, while intermediate sizes/ages were captured far more frequently in midwater (compare red bars with blue bars and black dotted line in Fig. 7a). Second, the BT survey midwater hauls generally had the same dominant length modes as the AT survey trawls (15-16 cm, 25-27 cm, and 38-40 cm FL), but the modes were in different proportions to one another. Third, the AT survey population size composition estimate differed from all three haul data sets (Fig. 7a). We did not estimate a population size composition based on BT survey midwater hauls, a target-strength to length relationship, and BT-survey midwater backscatter (i.e., scale pollock backscatter using haul length data; see Discussion).

The proportion at length from BT survey midwater hauls (n = 32, blue bars in Fig. 7b) in 2015 showed a predominant mode at 36 cm FL (likely the 2012 year class), as well as a 25-27 cm FL mode (likely the 2013 year class), with few fish larger than 50 cm, suggesting the continued midwater presence of the two predominant juvenile length classes seen in the 2014 survey (Fig. 7a). As in 2014, the proportion at length from BT bottom trawl hauls (n = 266) comprised smaller and larger fishes (red bars in Fig. 7b) than caught in midwater hauls. There was no AT survey in summer 2015.

DISCUSSION

Abundance and Distribution

The AVO index indicated higher midwater pollock biomass in 2014-2015 compared with earlier years in the time series (2006-2013). The continued strong correlation between the AVO index pollock backscatter and the AT survey biomass suggests that the index area itself, a subarea of the more wide-scale AT and BT surveys, still correctly represents annual variation in midwater pollock biomass (Figs. 1-3). The continued ability to restrict the AVO post-cruise analysis to data collected from the index area is valuable because it dramatically reduces the effort required (in terms of staff time) to generate the annual AVO index. Expanding the analysis beyond the current index area would either require more manual processing, or would require a new retrospective analysis to determine if the pollock distribution has changed relative to that of other species contributing to the midwater backscatter, and if so, whether there are more areas that could be semi-automatically processed.

The changes in pollock spatial patterns in 2013, 2014, and 2015 compared with earlier years of the time series, including a) the increased relative proportion of the midwater pollock east of 170◦ W (Figs. 3-4), b) the eastward progression of center of gravity estimates (Fig. 5), and c) a smaller proportion of AT survey biomass in the AVO index area, could all be explained by the distribution of the large 2012 pollock year class. The AT survey observed large aggregations of this year class east of 170◦ W in 2014. This distribution may also partly explain why the 2014 AT survey pollock biomass increased more than twice as much as the AVO index estimates between 2012 and 2014: there are fewer AVO index area cells east than west of 170◦ W, and it is possible that the biomass increase on the eastern shelf detected by the AT survey was underrepresented by the AVO index. In any case, the recent changes in pollock distribution reinforce the value of continuing to monitor the correlation between the AVO index and AT survey biomass.

Midwater Trawling and Pollock Length Frequency

As the AT and BT surveys observe different components of the EBS pollock population, neither index alone is sufficient to assess the entire stock (Ianelli et al. 2015, Kotwicki et al. in review; Fig. 7). Midwater trawling during the BT survey in support of the AVO index was initiated as a feasibility study in 2014-2015. The objective was to determine whether it was possible to obtain representative size compositions for midwater pollock aggregations in years when no AT survey was conducted using a limited number of opportunistic midwater hauls and a non-standard approach (i.e., a bottom trawl fished in midwater) because of BT vessel logistical constraints. If this were possible, the subsequent objective was to determine the feasibility of using the midwater haul data to convert the AVO index to estimates of pollock number and biomass at length and age for use in the pollock stock assessment. An important overarching consideration for this work was that it could be accomplished for a relatively modest cost to both the data collection phase in the field and post-processing data analysis phase in the lab.

The first objective of the midwater trawling effort, obtaining representative size compositions for midwater pollock aggregations using a limited number of bottom trawls fished in midwater was partly successful. Most midwater hauls targeted and adequately sampled midwater pollock aggregations. Although jellyfish comprised a relatively high proportion of the catch by weight, their presence was not a concern as their relative contribution to backscatter is known to be extremely low (De Robertis and Taylor 2013). Differences observed in pooled length compositions between the BT and AT midwater trawls in 2014 were likely due to slight differences in relative selectivity of the trawl gear (83-112 vs. AT) for older pollock (>40 cm; Kotwicki et al. in revision) and to the number and locations of hauls relative to the distribution of pollock backscatter. The differences in size composition between pooled AT survey haul data and AT survey population estimates (dotted and solid lines in Figs. 7a and 7b) reflected how haul data were weighted by the observed pollock backscatter to compute the population estimates (e.g., Honkalehto and McCarthy 2015).

Whether any of these length composition differences are a concern would require completing the second objective of the trawling effort: generating a size composition estimate from BT survey acoustic and midwater haul data to compare with AT population size composition estimates over a similar surveyed area. However, this was not completed. Discussions with the EBS stock assessment author (J. Ianelli, AFSC, pers. comm.) confirmed that low priority should be assigned to the additional survey/research work needed to potentially expand the current AVO project to provide an abundance-at-length index, given the current, relatively low-cost AVO scenario, which provides annual abundance indices (i.e., Fig. 1). Therefore no further BT survey midwater trawling is planned at this time.

Should estimating abundance-at-length for the AVO index become a high stock assessment priority and adequate staff resources be allocated to conduct the necessary work in the future, suggested guidelines are attached (Appendix). These include the following: 1) mitigate spatial gaps in midwater haul sampling such as those that occurred in 2014-2015 using a sampling stratification scheme to facilitate assigning hauls to backscatter, 2) either adjust hauls for net selectivity using the current results (Kotwicki et al. in revision), or evaluate the results using a sensitivity analysis and augment with further sampling if needed, 3) examine the effect of using bottom trawls to scale some of the AT midwater data, and 4) convert pollock backscatter to abundance at length from the area that both surveys adequately sampled with midwater hauls (e.g., west of 170° W in 2014). Carrying out these steps would lead to comparable abundance at length estimates for BT and AT surveys in the same year. If the comparison were favorable, this would provide a method to estimate AVO index-derived pollock abundance at length for use in stock assessment.

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Table 1. -- Acoustic vessel of opportunity (AVO) index values and acoustic-trawl survey biomass within the U.S. Exclusive Economic Zone since 2006. Relative estimation errors are one-dimensional geostatistical estimates of sampling variability.

	AT survey biomass (million metric tons)	AT survey biomass (scaled to mean AT 1999-	95% CI	Relative estimation error, AT survey	AVO index (scaled to mean AVO 1999-2004)	95% CI	Relative estimation error, AVO
2006	1.560	0.470	0.0362	0.0393	0.555	0.0555	0.0510
2007	1.769	0.534	0.0469	0.0449	0.638	0.1082	0.0865
2008	0.997	0.301	0.0450	0.0764	0.316	0.0399	0.0643
2009	0.924	0.279	0.0481	0.0881	0.285	0.0672	0.1203
2010	2.323	0.701	0.0831	0.0605	0.679	0.1142	0.0858
2011	NO SURVEY	NO SURVEY	NO SURVEY	NO SURVEY	0.543	0.0609	0.0572
2012	1.843	0.556	0.0458	0.0421	0.661	0.0809	0.0625
2013	NO SURVEY	NO SURVEY	NO SURVEY	NO SURVEY	0.694	0.0531	0.0390
2014	3.439	1.037	0.0944	0.0464	0.897	0.0752	0.0428
2015	NO SURVEY	NO SURVEY	NO SURVEY	NO SURVEY	0.953	0.0852	0.0456

Table 2. -- Catch by species from midwater trawls with the 83-112 net during the 2014 (n = 42 trawls) and 2015 (n = 40 trawls) bottom trawl surveys of the eastern Bering Sea shelf.

		2014 Catch			
Species name	Scientific name	Number	%	Weight (kg)	%
walleye pollock	*Gadus chalcogrammus*	12,155	81.4	2,761.2	47.0
Northern sea nettle	*Chrysaora melanaster*	2,386	16.0	3,096.0	52.7
jellyfish unident.	Scyphozoa (class)	214	1.4	8.6	0.1
Aurelia sp.	*Aurelia* sp.	166	1.1	5.8	0.1
Salp unident.	Thaliacea (class)	4	<0.1	0.5	<0.1
Pacific herring	*Clupea pallasii*	2	<0.1	1.1	<0.1
chum salmon	*Oncorhynchus keta*	2	<0.1	2.8	<0.1
Aequoria sp.	*Aequoria* sp.	1	<0.1	0.6	<0.1
Total		14,930		5,876.6	

		2015 Catch			
Species name	Scientific name	Number	%	Weight (kg)	%
walleye pollock	*Gadus chalcogrammus*	15,384	89.7	4,791.0	51.9
Northern sea nettle	*Chrysaora melanaster*	1,591	9.3	4,345.4	47.1
lion's mane	*Cyanea capillata*	152	0.9	66.8	0.7
jellyfish unident.	Scyphozoa (class)	10	0.1	8.0	0.1
Pacific cod	*Gadus macrocephalus*	4	<0.1	14.4	0.2
Fried egg jellyfish	*Phacellophora camtschatica*	3	<0.1	1.1	<0.1
northern rock sole	*Lepidopsetta polyxystra*	2	<0.1	1.1	<0.1
Pacific herring	*Clupea pallasii*	2	<0.1	0.8	<0.1
comb jelly unident	Ctenophora (phylum)	2	<0.1	<0.1	<0.1
smooth lumpsucker	*Aptocyclus ventricosus*	1	<0.1	3.3	<0.1
chinook salmon	*Oncorhynchus tshawytscha*	1	<0.1	2.0	<0.1
Aequoria sp.	*Aequoria* sp.	1	<0.1	0.3	<0.1
Total		17,153		9,234.2	

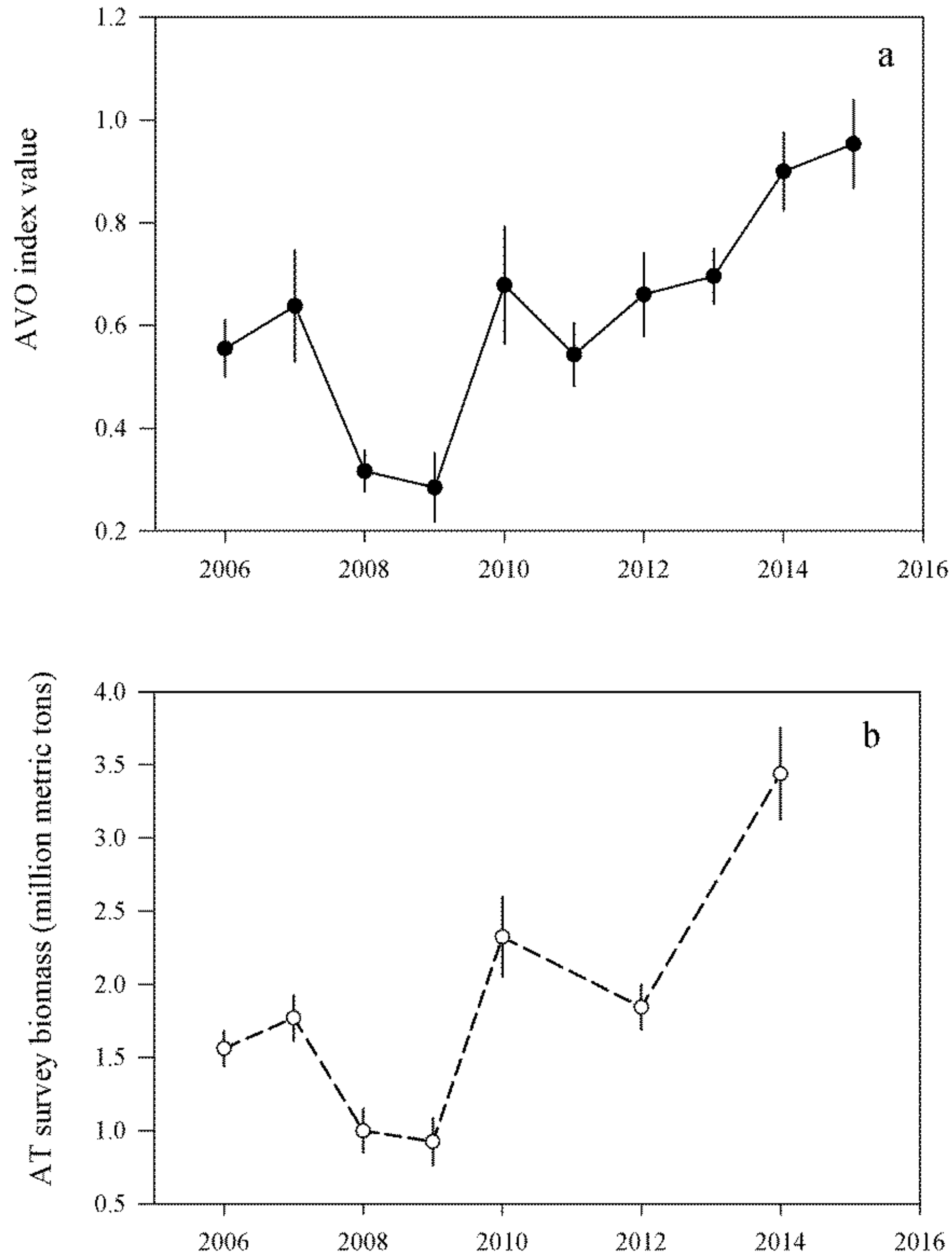


Figure 1. -- Acoustic vessel-of-opportunity (AVO) Index estimates for 2006-2015 from the BT survey (a) and corresponding acoustic-trawl (AT) survey biomass estimates in the U.S. Exclusive Economic Zone (EEZ; b). Error bars are 95% confidence intervals based on 1-D geostatistical estimates of sampling variability. The AVO index was scaled to its mean value for the period 1999-2004.

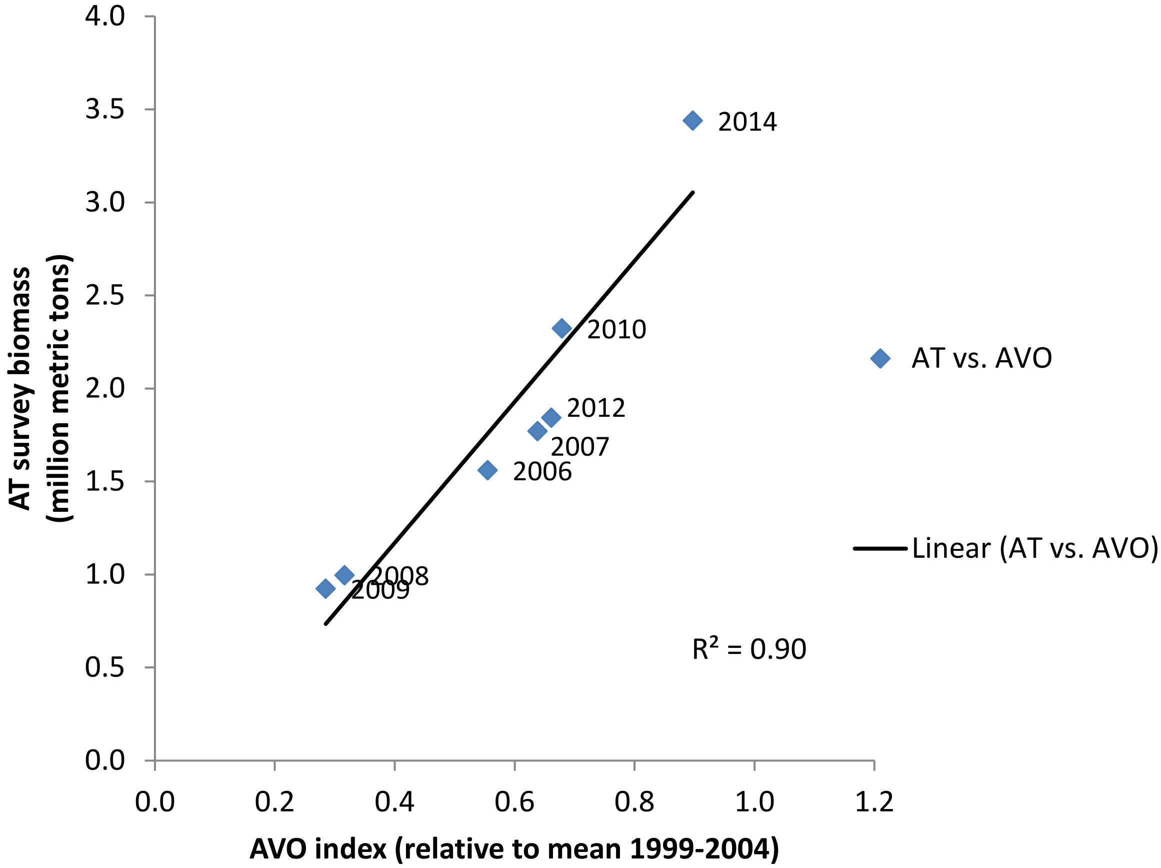


Figure 2. – Regression of the acoustic-trawl (AT) survey biomass (million metric tons) on the acoustic vessel-of-opportunity (AVO) index value, 2006-2015.

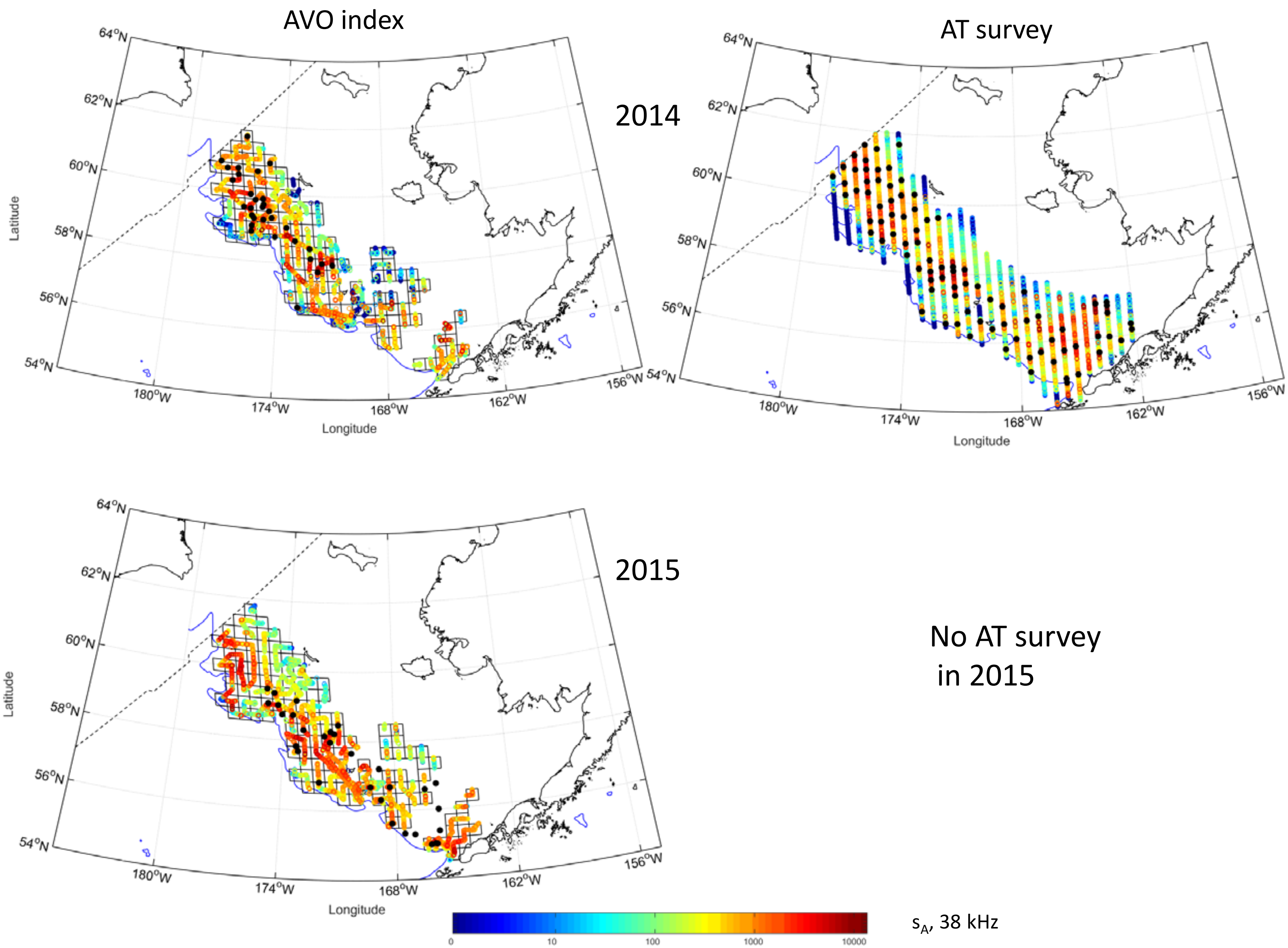


Figure 3. --Pollock s_A (m^2 nmi^{-2}) in acoustic vessel-of-opportunity (AVO) index (left column) and acoustic-trawl (AT) survey (right column) data sets, 2014-2015. The bottom trawl (BT) survey grid cells used for the AVO index are shown in the left column. Midwater trawl locations (plus 17 bottom trawls used to scale backscatter in the AT survey) for each survey are shown as black dots. There was no AT survey in 2015. The 200 m bathymetric contour is indicated in blue, and the boundary between the U.S. and Russian Exclusive Economic Zones is denoted by a black line across the upper left corner of the plot. Note color scale is logarithmic.

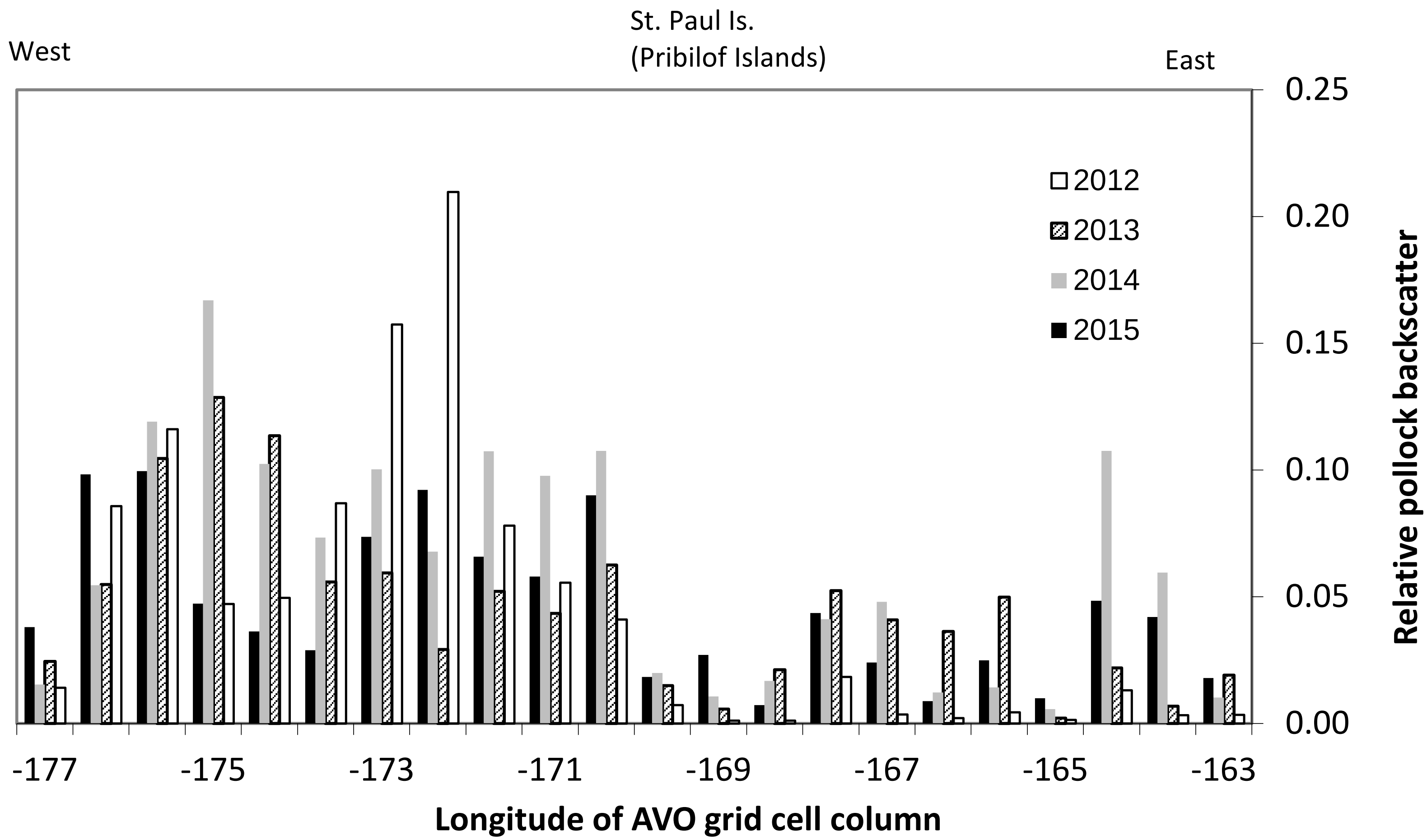


Figure 4. -- Relative pollock backscatter 2012-2015, computed by summing pollock s_A (m^2 nmi^{-2}) along north-south columns of grid cells, and expressing the result as a proportion of all pollock backscatter in each year. The location of the east and west boundaries of the U.S. Exclusive Economic Zone and the approximate longitude of St. Paul Island are indicated at top.

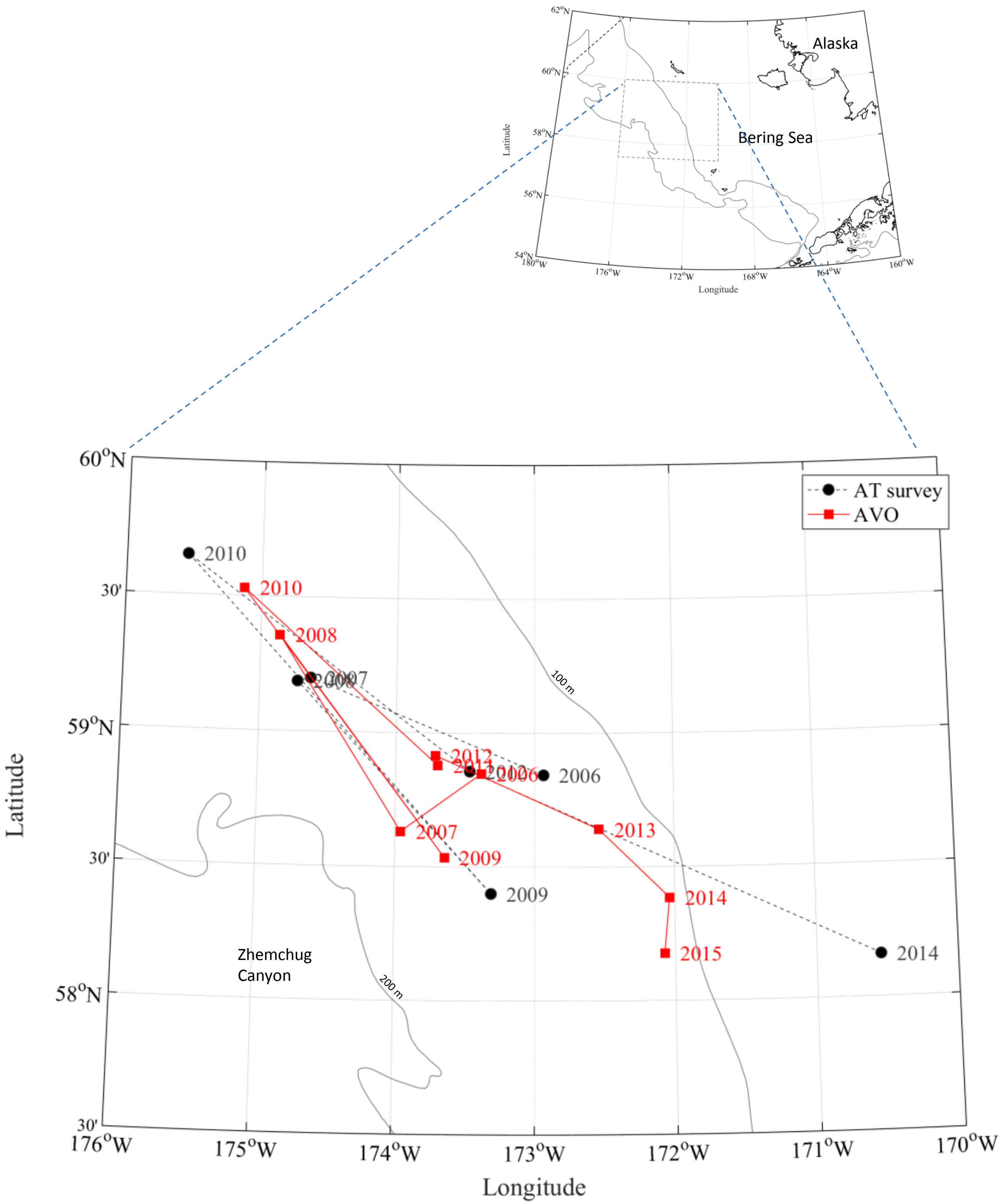


Figure 5. -- Geographic center of gravity estimates derived from pollock s_A (m^2 nmi^{-2}) from acoustic-trawl (AT) survey (black circles) and acoustic vessel-of-opportunity index (red squares). The 100 and 200 m bathymetric contours are indicated in gray.

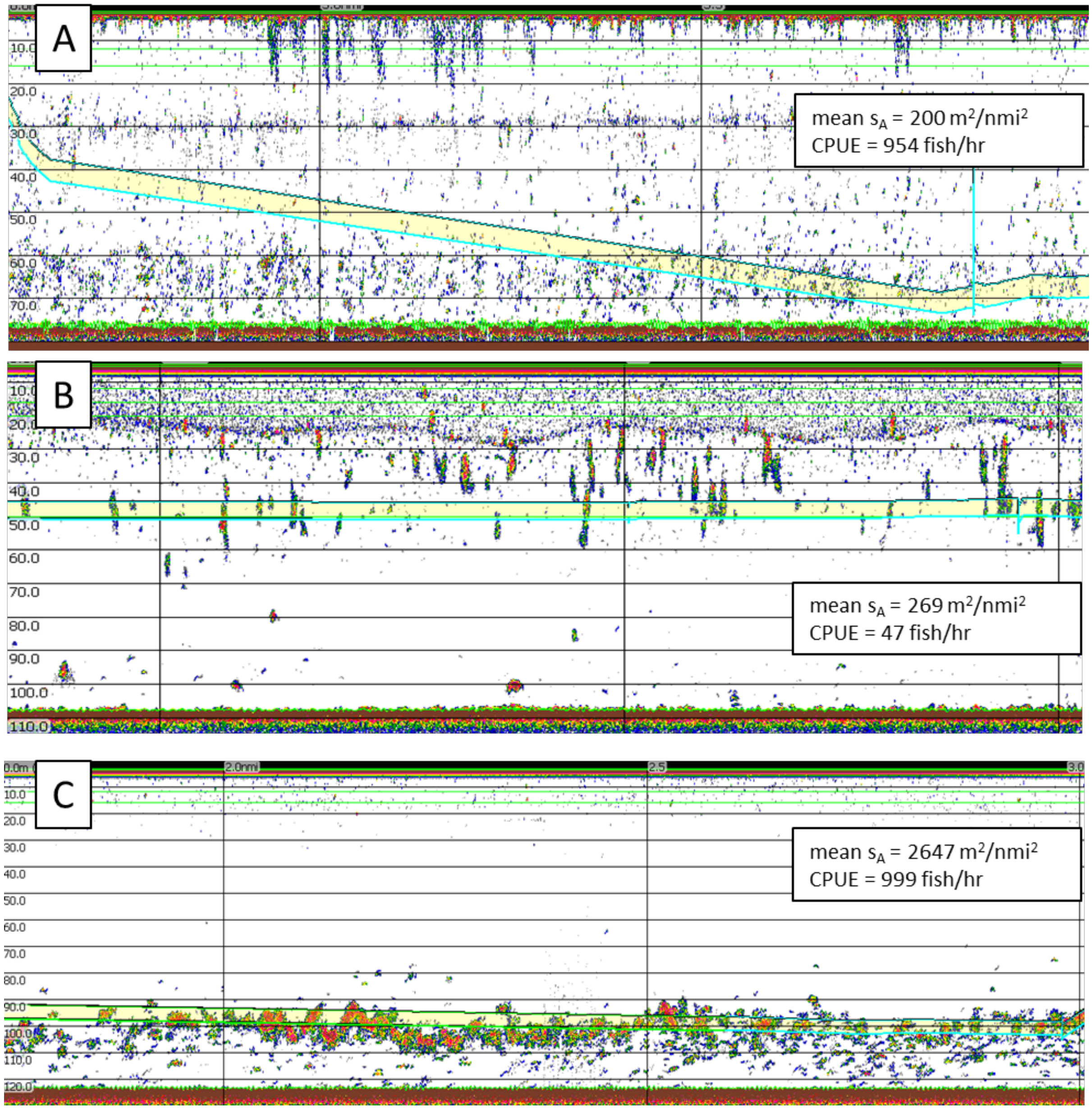


Figure 6. -- Three echograms (a,b,c) showing the bottom trawl (yellow region) through various types of walleye pollock backscatter. Vertical grid lines denote 0.5 nmi and horizontal grid lines 10 m. Mean s_A was computed by integrating a 2.5 nmi x 20 m region over the targeted backscatter. Catch Per Unit Effort (CPUE) is reported as the number of fish caught per hour trawled.

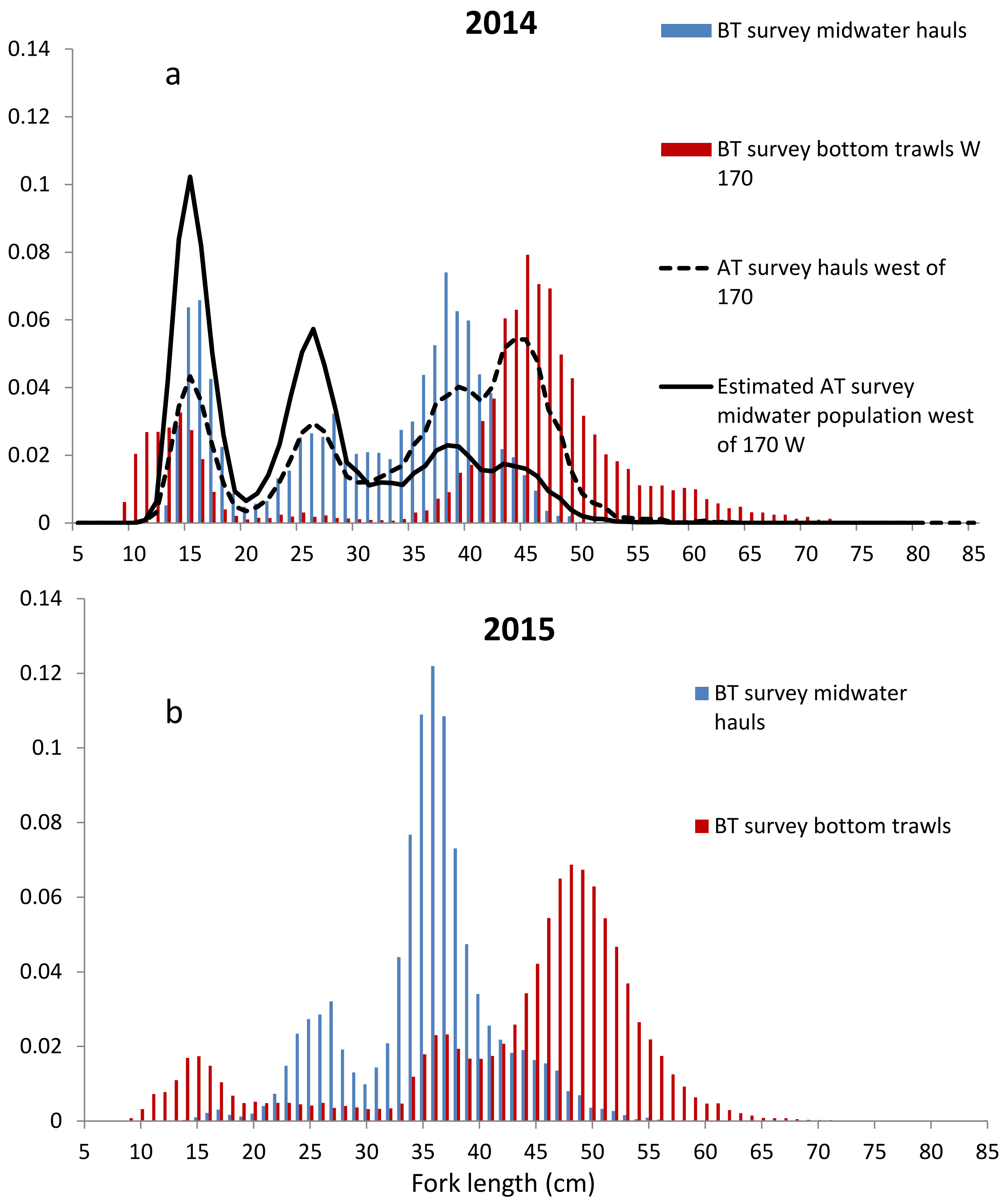


Figure 7. – Proportion of fish (numbers) by length from 1) BT survey midwater trawl catches (blue bars), 2) BT survey bottom trawl catches within the AT survey area (red bars), 3) AT survey midwater and bottom trawl catches used to scale the AT survey backscatter (black dashed line), and 4) the AT survey estimated population at length from combined trawls and backscatter (solid black line). Data are from 2014 (a), and 2015 (b) when there was no AT survey.

Appendix

Outline of methods to determine whether it is possible to obtain acoustic estimates of midwater pollock abundance-at-length during a BT survey using a limited number of opportunistic midwater hauls.

1) For 2014, compare BT survey-derived acoustic estimates of abundance at length with AT survey abundance-at-length over the spatial domain that was adequately sampled with midwater hauls by both surveys (e.g., west of 170°) to evaluate whether the results are comparable. Reanalyze both AT and BT midwater survey data in exactly the same way to ensure comparability.

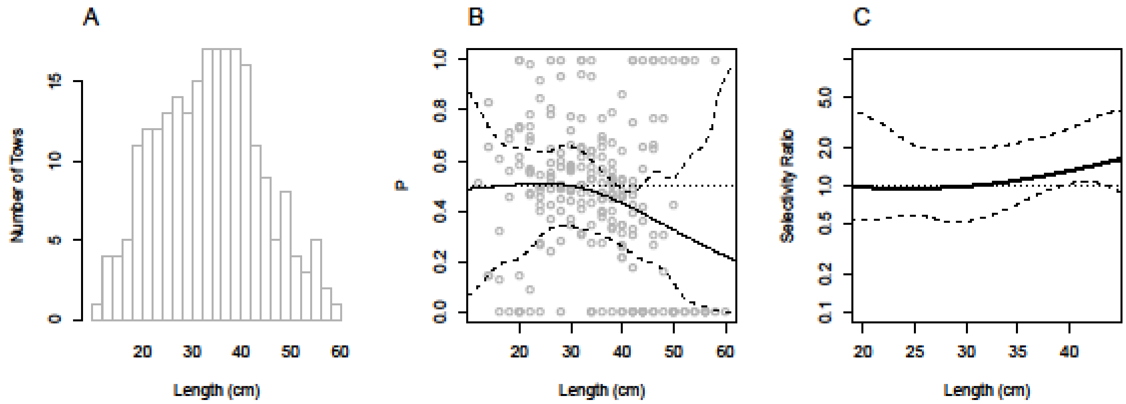
2) Correct 83-112 midwater hauls for selectivity using Kotwicki et al. in revision relationship (Figs. A,B and C). See 6) below.

3) Estimate midwater pollock size composition from both data sets based on midwater hauls, a target-strength to length relationship, and pollock backscatter. Use nearest haul approach to assign hauls to backscatter by dividing the data into 'adult' and 'juvenile' sign types, or by using a 2-depth-stratum, nearest-haul (e.g., De Robertis et al. 2017) or a one-depth-stratum, nearest haul (e.g., Lauffenburger et al. 2016) approach.

4) Implement procedures to get better midwater haul coverage in the future. This might include stratification of the AVO index area to ensure adequate haul coverage of the predicted pollock backscatter distribution, plus additional BT survey staff training sessions on best practices of when to sample midwater backscatter.

5) Computing the AT survey abundance-at-length estimates typically includes predominantly midwater trawls, but also includes a few near- or on-bottom trawls depending on the vertical distribution of backscatter, seafloor composition, and even weather conditions during sampling. The BT survey hauls consisted largely of midwater hauls but may also have included a few hauls sampled close to the seafloor. When comparing abundance at length indices from the two surveys, the proximity of trawl sampling to the bottom should be as similar as possible since the length-frequency of near bottom pollock is known to be different from midwater pollock. For example, one could limit the hauls used in the analysis based upon the distance between the trawl footrope and the bottom to greater than 3 m off bottom, or set some other sampling rule to try to create comparability in near-bottom sampling between data sets.

6) Look at the existing trawl selectivity data for the 83-112 and determine what if anything needs to be done (e.g., more data for 45+ cm fish?). For example, do a bootstrap analysis to see at what fork lengths the sensitivity lies and where improvements are needed. If discussions with the authors (Kotwicki et al. in revision) suggest more work should be done, consider doing more paired trawls to further refine the relationship for older fish (increase the sample size of older fish).


A
B
C
Number of Tows
P
Selectivity Ratio
Length (cm)
Length (cm)
Length (cm)