NOAA Technical Memorandum NMFS-AFSC-272

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ABSTRACT

Here we assess the feasibility of applying acoustic-trawl (AT) methods to quantify the abundance of age-0 walleye pollock (*Gadus chalcogrammus*) on the eastern Bering Sea (EBS) shelf during the 2011 and 2012 Bering Arctic Subarctic Integrated Salmon International Survey (BASIS). The abundance of age-0 walleye pollock in the water column was estimated by combining acoustic measurements, the acoustic scattering properties of the dominant organisms, and the relative proportions of animals from trawl samples. Age-0 pollock were expected to dominate much of the backscatter in the survey area to the east of the Pribilof Islands in 2011, and a wider area covering much of the offshore part of the survey area in 2012. The overall numerical abundance estimate for 2011 was 7.0×10^{10} age-0 walleye pollock, and 1.8×10^{11} in 2012. This suggests that the abundance of walleye pollock in the survey area was ~2.6 times higher in 2012 than in 2011. The vertical distribution of age-0 walleye pollock was similar in both years, with ~ 50% of fish observed in the upper 50 m, and ~95% of fish in the upper 100 m of the water column. A sensitivity analysis indicates that an abundance index of age-0 walleye is relatively robust to the assumptions made in the analysis (e.g., target strengths used, association of trawl catches and acoustic backscatter, net selectivity) and suggests that an AT estimate of age-0 walleye pollock on the EBS shelf is possible in the context of this survey. A series of short-term and long-term recommendations for implementation of an AT-based age-0 pollock abundance index are provided.

CONTENTS

INTRODUCTION

Members of the Midwater Assessment and Conservation Engineering (MACE) program at the Alaska Fisheries Science Center (AFSC) have conducted acoustic-trawl (AT) surveys in Alaskan waters to estimate the abundance and distribution of adult walleye pollock (*Gadus chalcogrammus*[1], hereafter referred to as pollock), including a summer survey of the eastern Bering Sea (EBS) shelf which was first conducted in 1979. Recently, the MACE program has been tasked with assessing the feasibility of applying similar AT methods to estimate the abundance of age-0 pollock on the EBS shelf during the Bering Arctic Subarctic Integrated Survey (BASIS) conducted in August to early September. The species of interest in the BASIS survey have changed from a focus on Pacific salmon (*Oncorhynchus* spp.) to also include groundfishes and forage fishes, particularly age-0 pollock. This shift is also reflected in the survey's name, as the survey was until recently known as the Bering-Aleutian Salmon International Survey. Part of the rationale for the shift in the objectives of this survey is the anticipation that a robust abundance index of age-0 pollock can be derived and ultimately used to improve the stock assessment of this important species. However, age-0 pollock are often found in mixed species aggregations, and the standard methodology used to convert acoustic backscatter to fish abundance in other AT surveys conducted at AFSC cannot be applied in this situation. Specifically, backscatter from age-0 pollock cannot be assigned to single-species aggregations with much confidence by targeted trawling and interpretation of echograms, as is the practice in most AT surveys (e.g., Simmonds and MacLennan 2005, Karp and Walters 1994,

[1] Formerly known as *Theragra chalcogramma* (Page et al. 2013).

Honkalehto et al. 2013). Here, we build on previous work by Brodeur and Wilson (1996), Swartzman et al. (1999), and Parker-Stetter et al. (2013) to develop and implement methods that could be used to conduct an AT survey to estimate the abundance of age-0 walleye pollock in the eastern Bering Sea.

METHODS

An acoustic-trawl survey was conducted aboard the NOAA ship *Oscar Dyson*, a 64-m stern trawler equipped for fisheries and oceanographic research, and the chartered fishing vessel *Bristol Explorer* as part of the 2011 and 2012 BASIS surveys conducted by the AFSC Ecosystem Monitoring and Assessment group in the eastern Bering Sea. The majority of the 2011 survey was conducted on the NOAA ship *Oscar Dyson*, with the chartered FV *Bristol Explorer* completing about a third of the survey in the northwestern part of the survey grid. The 2012 survey was conducted entirely with the *Oscar Dyson*.

Acoustic Equipment, Calibration, and Data Collection

Acoustic backscatter measurements were collected with Simrad EK60 (*Oscar Dyson*) or ES60 (*Bristol Explorer*) echosounders. In the case of the *Oscar Dyson*, five split-beam transducers (18, 38, 70, 120, and 200 kHz) were mounted on the bottom of the vessel's retractable centerboard, which was extended 9.15 m below the surface in 2011 and 7.6 m in 2012. The *Bristol Explorer* was equipped with hull-mounted ES38-10 and ES120-7C transducers at a depth of 3.7 m. The ES60 echosounder used to measure backscatter on the *Bristol Explorer* is subject to a periodic and systematic error that introduces a maximum amplitude error of ± 0.5 dB (± 12% in linear units) which was removed by fitting the error to the otherwise constant transmit pulse and correcting the raw acoustic data (Ryan and Kloser 2004, Keith et al. 2005). The hull-mounted transducers on the *Bristol Explorer* are susceptible to interference from bubbles swept under the transducers in rough seas and at higher vessel speeds. The 'bottom' data filter described in Honkalehto et al. (2011) was applied to the data from the *Bristol Explorer* to exclude pings where bubble sweepdown was a discernible source of bias.

Standard sphere acoustic system calibrations (Foote et al. 1987) were conducted on the *Oscar Dyson* to measure acoustic system performance. The *Oscar Dyson* was calibrated on two occasions during the preceding pollock summer surveys (e.g., Honkalehto et al. 2013, Jones et al. in review) and during the following winter. The echosounder on the *Bristol Explorer* was calibrated before and after the 2011 cruise. The calibrations did not reveal evidence of changes in echosounder sensitivity during the study period. The two summer calibrations in each year for each vessel were averaged to produce the values of gain and s_A correction (averaged in linear units) applied in post-processing.

Acoustic data were collected at a nominal ping rate of 1 s^{-1} and a pulse length of 1.024 milliseconds (ms) in 2011 and 0.512 ms in 2012. The results presented in this report are based on 38 kHz data with a post-processing S_v integration threshold of –70 dB re 1 m^{-1} applied to ensure comparability with other AFSC surveys (e.g., Honkalehto et al. 2013).

Survey Design

The acoustic survey was conducted as an addition to the pre-existing BASIS survey, which consists of a grid of stations at a separation of 1 degree of longitude and 0.5 degrees of latitude. Surface trawl samples (see below) were taken at these predetermined sites during daylight. The acoustic survey was conducted opportunistically as the vessel transited between stations, and midwater trawl hauls were periodically targeted with the same trawl to sample subsurface fish aggregations observed with the echosounder.

Trawl Sampling

All trawl sampling was conducted during daylight using a Cantrawl rope trawl towed at speeds of ~2 m s^{-1} (Moss et al. 2009). The trawl is 198 m long, has a 122 m headrope, and is constructed with ropes at the leading edge of the net followed by meshes tapering from 162 to 1.2 cm stretched length in the codend liner. At the surface stations, the trawl was equipped with floats to keep the headrope near the surface and towed for 30 min at predetermined locations. A trawl vertical opening of 21.0 ± 4.6 m (mean ± SD) during surface trawling (measured after the doors had spread the net and the net depth was stable) was observed with a trawl sonar used on a subset (n = 104) of trawl hauls. Midwater and near-bottom concentrations of fishes observed acoustically were targeted with the Cantrawl fished in midwater with the floats removed (Parker-Stetter et al. 2013). The vertical opening of the net while trawling in midwater averaged (± SD) 12.8 ± 2.5 m. Trawl catches were weighed, and identified to species. Fork lengths of a subsample of up to 50 fishes and bell diameters of up to 50 undamaged jellyfishes were measured to the nearest 1.0 mm.

Approach to Data Analysis

The abundance of age-0 walleye pollock in the surveyed area was estimated by combining echo integration data with species and size compositions of animals from trawl catches and published measurements of the acoustic properties of these species. Trawl catches during the BASIS survey suggest that the acoustic scattering layers are from multiple species. Thus, converting the acoustic backscatter to species-specific abundances during this survey presents a challenge compared to other AT surveys conducted at the AFSC (e.g., Honkalehto et al. 2013), which make the assumption that, in most cases, acoustically observed aggregations can be assigned to a single species on the basis of targeted trawling and expert opinion.

The initial intent was to apply the methods developed for AT measurements of abundance on the 2006-2010 BASIS surveys (Parker-Stetter et al. 2013). However, the methods used in this analysis relied on several assumptions and interpretations without evaluating the influence that these decisions could have on the abundance estimates. In particular, the assumption that jellyfish (which dominate the trawl catches by weight in these and previous BASIS surveys) are not acoustically detectable above a -67 dB re 1 m^{-1} integration threshold is questionable. This concern was based on theoretical expectations (see Fig. 1), and inspection of acoustic backscatter in areas where jellyfish dominated the catch (Fig. 2). Given that 1) jellyfish dominated the biomass of animals caught in pelagic survey trawls in both the 2011 and 2012 surveys (described below) as well as in previous studies (e.g., Brodeur et al. 2008, Parker-Stetter et al. 2013), and 2) that the sensitivity of the abundance estimates to this and other assumptions made in the analysis are unknown, the decision was made to explore alternative analysis methods. Thus, the analysis described here was not constrained to use the same methodology, and employed different methods including alternative integration thresholds, target strength relationships, and analysis methods. As a result of the difference in analysis methods, the results reported here may not be comparable with those of Parker-Stetter et al. (2013).

Acoustic Data Processing

Acoustic measurements were analyzed from 15 m below the surface (the shallowest depth allowing a consistent depth range for both years and survey vessels) to within 0.5 m of the sounder-detected bottom or a maximum of 250 m depth using Myriax Echoview post-processing software (v. 5.3). Acoustic backscatter was attributed to age-0 gadids (i.e., pollock or Pacific cod (*Gadus macrocephalus*), or other species (e.g., capelin (*Mallotus villosus*), adult pollock, and jellyfishes) by an experienced analyst based on the appearance of the fish schools on the echogram. Each interpretation was scored with a qualitative confidence ranking of 1-3, with a confidence of 1 being high (e.g., at the level of most adult pollock surveys), 2 being medium to low (this was often used in mixed species aggregations), and 3 being very poor. A trawl haul was linked to each interpretation based on the observed depth distribution and aggregation pattern of the organisms and the geographic proximity to the trawl and depths sampled, under the assumption that the trawl catch represents the species and size composition of the organisms observed acoustically. Near-bottom aggregations were not sampled but are suspected from previous experience to be adult groundfishes. The backscatter from these near-bottom aggregations, which accounted for 16.0% of total backscatter in 2011 and 23.8% of total backscatter in 2012, was excluded from further analysis. Acoustic observations were echo-integrated at a 0.5 nautical mile (nmi) horizontal by 5 m vertical resolution, and only the observations between sunrise and sunset were analyzed to minimize diel effects on target strength and diel changes in species compositions due to vertical migration of demersal species. In addition, acoustic observations while trawling were not used in the analysis to avoid potential changes in backscatter associated with behavioral responses to trawling vessels (e.g., De Robertis and Wilson 2006).

Partitioning Acoustic Backscatter to Species

The general approach taken in interpreting the acoustic backscatter measurements was that of the 'forward problem' (cf. Holliday and Pieper 1995), in which the scattering expected from animals of a given species and size was computed and used to estimate the proportion of observed acoustic scattering attributable to age-0 pollock. This estimate was then used to infer the abundance of age-0 pollock from measurements of acoustic backscatter along the ship track. A series of target strength (TS) relationships were taken from the literature (Table 1) to estimate the acoustic scattering strength of each species. Backscatter from salmonids was excluded from analysis as previous work has shown that the salmon are likely to be distributed primarily near-surface zone <15 m (Emmett et al. 2004, Parker-Stetter et al. 2013), which was not sampled by the echosounder. The potential acoustic contribution from one salmon shark *Lamna ditropis* and hyperiid amphipods (<0.02% of individuals, but likely very poorly sampled by the net) was also excluded from analysis.

For a given trawl station, the mean backscattering cross section for species s in trawl t is

$$\langle \sigma_{bs} \rangle_{s,t} = \sum_{l} P_{s,l,t} \cdot \sigma_{bs_{s,l}} ,$$

where $P_{s,l.t}$ is the proportion of species *s* in trawl *t* in the 1.0 cm length class *l* and

$$\sigma_{bs_{s,l}} = 10^{(0.1 \cdot TS_{s,l})} ,$$

is the backscattering cross section (m^2) of species *s* in length class *l* where TS is the target strength (dB re m^2) computed using the relationships given in Table 1.

The proportion of backscatter (PB) from species *s* in trawl *t* is computed from the number (N) of individuals of species *s* captured in trawl *t* and was computed as

$$PB_{s,t} = \frac{N_{s,t} \cdot \langle \sigma_{bs} \rangle_{s,t}}{\sum_s N_{s,t} \cdot \langle \sigma_{bs} \rangle_{s,t}} .$$

The measured nautical area backscattering coefficient s_A at location *i* (where trawl *t* is assigned to represent the species composition) was allocated to species *s* and computed as follows

$$s_{A_{s,i}} = s_{A_i} \cdot PB_{s,t} .$$

The areal density ρ [individuals nmi^{-2}] of species *s* at location *i* with a species assemblage described by trawl *t* was computed from the measured nautical area backscattering coefficient following MacLennan et al. (2002)

$$\rho_{s,i,t} = \frac{s_{A_{s,i}}}{(4\pi\langle\sigma_{bs}\rangle_{s,t})}.$$

The survey area was divided into a 1 degree of latitude and longitude grid (Fig. 3), and the area of each grid cell in square nautical miles was computed. The portion of each grid cell that was either on land or below the Alaska Peninsula and outside the survey area was excluded from the estimate of total area. Geographic cells with less than 10 nmi of trackline were excluded from the analysis to avoid biases introduced by including very sparsely sampled cells. The survey-wide abundance for species *s* in numbers of individuals was computed by averaging the density of individuals from locations *i* within grid cell *c* and multiplying by the area of the grid cell, and then adding over the grid cells, that is

$$\langle\rho_{s,c}\rangle = \frac{\sum_{i_c} \rho_{s,i_c}}{n_c},$$

where $\langle\rho_{s,c}\rangle$ is the mean areal density of species *s* taken from locations *i* within cell *c*, and n_c is the number of locations within grid cell *c*, and

$$N_s = \sum_c \langle\rho_{s,c}\rangle A_c,$$

where N_s is the total number of individuals of species *s* in the entire survey area and A_c is the area of grid cell *c*.

Sensitivity Analysis

As many of the parameters used in data processing were uncertain, the impacts of alternate values of the analysis parameters were explored by recalculating the abundance of age-0 pollock under several scenarios. Six scenarios were explored in a simple one-factor-at-a-time sensitivity analysis in which only a single parameter was changed and all other parameters were kept at the baseline levels described above. 1) A length-dependent, logistic trawl selectivity function was applied. This function (Fig. 4) is based on parameters similar to those determined for age-1 and larger pollock using a different midwater trawl (see Williams et al. 2011) for details. 2) The trawl assignments made by the analysts were replaced with the geographically nearest trawl applied to the entire water column. 3) The trawl assignments made by the analysts were replaced in with the geographically nearest trawl in a two depth layer scheme: the nearest surface trawl was applied if the analyst had assigned a surface trawl and the nearest midwater trawl was assigned if the analyst assigned a midwater trawl to the observation. 4) An index similar to that generated by the standard AFSC protocol of allocating only well-defined, single-species aggregations as 100% target species was generated by considering only those observations identified by analysis as juvenile gadiids, and partitioning between age-0 pollock and Pacific cod (which were not distinguished by the analyst) by excluding the acoustic contribution of all species other than age-0 pollock and Pacific cod. This isolated all backscatter judged to be from single-species aggregations of age-0 gadiids and partitioned this backscatter to either cod or pollock by the proportion caught in nearby trawl catch. The sensitivity of the estimate to the TS relations used to partition backscatter to age-0 pollock from the mixed aggregations was evaluated by 5) increasing the TS of all species other than age-0 pollock by 3 dB, or 6) decreasing the TS of all other species by 3 dB.

RESULTS AND DISCUSSION

Nineteen midwater trawls and 74 surface trawls were conducted during the 2011 survey, and 27 midwater trawls and 93 surface trawls were conducted during the 2012 survey (Fig. 5). In both years, the aggregate trawl catch was dominated numerically by small fishes such as age-0 walleye pollock, age-0 Pacific cod, capelin, and Pacific sand lance (*Ammodytes hexapterus*) (Tables 2-3). In 2011, age-0 pollock accounted for 43.5 % of individuals and 0.4 % of total weight captured in the midwater trawl catch, and 27.8 % of individuals and 1.7% of weight in the surface trawl catch (Table 2). In 2012, age-0 pollock accounted for 82.0 % of individuals and 1.6 % of total weight captured in the midwater trawls, and 14.9 % of individuals and 0.3 % of weight captured in the midwater trawl (Table 3). However, in terms of biomass, the trawl catches were dominated by the jellyfish *Chrysaora melanaster*, which accounted for 70.2 % of catch weight in the 2011 midwater trawls , 77.8. % of catch weight in the 2011 surface trawls, 91.1 % of catch weight in the 2012 midwater trawls, and 93.7 % of catch weight in the 2012 surface trawls.

Catch composition varied over the survey region. Age-0 walleye pollock often numerically dominated trawl catches in the offshore portions of the survey area, with capelin often dominating trawl catches in the inshore portion of the survey area (Fig. 6). Age-0 Pacific cod (*Gadus macrocephalus*) and *C. melanaster* were abundant in the southern part of the survey area

(Fig. 6). When expressed as contribution to catch by weight, *C. melanaster* dominated the catch composition over much of the survey area (Fig. 7). However, calculation of the proportion of backscatter (PB) attributable to each species by combining the catch composition and the target strength relationships (Fig. 8: see above for methods) suggested that the proportion of backscatter attributable to a given species resembled the proportion of catch by number (Fig. 6) more than the proportion of catch by weight (Fig. 7). This can be explained by the relatively low mass-specific TS of jellyfish: even though jellyfish are large in size, they are weak scatters, and are unlikely to contribute strongly to overall acoustic backscatter when fishes with swimbladders are present, even if they dominate the biomass (De Robertis and Taylor 2014). Thus, age-0 pollock are expected to dominate much of the backscatter to the east of the Pribilof Islands in 2011, and over a wider area covering much of the offshore part of the survey area in 2012 (Fig. 8).

Acoustic backscatter was highest in the offshore portion of the survey area in bottom depths > 70 m in both years (Fig. 9), and often coincided with the areas where age-0 pollock dominated the trawl catches (i.e., compare Figs. 8 and 9). This suggests that the areas of high backscatter in this region of the EBS shelf were caused by aggregations of age-0 pollock. Acoustic-trawl estimates of age-0 pollock abundance in the 1 by 1 degree analysis grid indicated that age-0 pollock were found primarily in the offshore area of the study grid (i.e., > 70 m depth), and were more abundant in 2012 than in 2011 (Fig. 10).

The overall abundance estimates for age-0 pollock were 7.0×10^{10} fish in 2011 and 1.8×10^{11} fish in 2012 (Fig. 11), indicating there were about 2.6 times more individuals in 2012 than in 2011. However, a smaller area was surveyed in 2011(6.5×10^{4} nmi^{2}) than in 2012

(10.0×10^4 nmi^2), and we thus compared the abundance in areas sampled in both years. When we restricted the survey area to the area sampled in both years (6.1×10^4 nmi^2), the 2012 estimate (1.4×10^{11} fish) was 2.4 times higher than the 2011 estimate of 5.8×10^{10} fish indicating that the higher abundances in 2012 were not due to differences in survey coverage. In contrast, total catches of age-0 pollock in the surface trawls in 2011 were about 6% higher than in 2012 (Tables 2-3), even though more stations were occupied in 2012, suggesting that abundance indices derived from AT estimates of the water column and surface trawls covering the upper part to the water column may not be correlated.

Although comparable large-scale abundance estimates for age-0 pollock in the EBS generated by other means are unavailable, the long-term estimates of age-1 pollock from the stock assessment model average 2.2×10^{10} fish, and have been close to this value in recent years (Ianelli et al. 2012). The AT abundance estimates of age-0 pollock in the BASIS sampling regions are 3.2 and 8.2 times the average age-1 pollock estimates in 2011 and 2012, respectively. Although this calculation is highly uncertain, this is encouraging as it can be interpreted to mean that the AT estimates of age-0 pollock derived here are biologically plausible (as there are more age-0 than age-1 pollock), and potentially of the right order of magnitude.

The confidence codes assigned to each acoustic observation by the analyst during data processing indicated that in 2011 approximately 30% of age-0 pollock identifications were associated with a high confidence, while 41 % of the age-0 pollock identifications were associated with high confidence in 2012 (Fig. 11). The remainders of the age-0 pollock were assigned a medium, or more rarely (< 5% of age-0 biomass) a low confidence. The medium and low confidence assignments were primarily due to a lack of nearby midwater trawl sampling or the presence of a mixed species aggregation. Conducting more trawls targeted at the locations and depths where age-0 pollock are most abundant will decrease this uncertainty.

Although by no means comprehensive, the one-factor-at-a-time sensitivity analysis indicates that the biomass estimates of age-0 pollock are not highly sensitive to the choice of analysis parameters (Table 4). The ratio of age-0 pollock abundance in 2011 and 2012 was relatively robust to changes in the input parameters, ranging from 2.2 to 2.8 (Table 4), which indicates that an index of abundance from these years would not be highly sensitive to the parameters chosen for data processing. The largest difference from the baseline (Table 4, scenario 4, ~45-50% lower abundance) was observed when the traditional AT survey method (i.e., analysts identify single-species aggregations) was applied. This method will produce estimates that are biased low because it does not enumerate age-0 pollock from mixed-species aggregations. This relatively large bias indicates that a method allowing for interpretation of backscatter from multi-species aggregations is desirable in this application. Adding an assumed trawl selectivity (Table 4, scenario 1) curve increased age-0 abundance by ~ 15% because the smaller age-0 pollock were undersampled by the trawl net. Although the size and species selectivity of the Cantrawl net is unknown, the relatively modest effect of applying this selection curve indicates that the impacts of net selectivity may have been moderate in this case due to the moderate size range of fishes in the trawl catches associated with high age-0 pollock backscatter (i.e., most fishes captured were of similar size and the size selectivity of the sampling gear thus had a limited effect). Assigning the nearest haul (Table 4, scenario 2), or the nearest midwater or surface haul (Table 4, scenario 3) resulted in estimates within 18% of those of baseline. This indicates that the species assignments were robust, likely because the onboard acousticians targeted the high density aggregations,which contributed most of the biomass, with midwater trawls. This suggests that if higher variance is acceptable (e.g., in a rough recruitment index), analysis time could be curtailed by applying a distance based-algorithm to relate trawl catches to backscatter observations rather than relying on the time consuming post-survey interpretations and trawl-assignments of an analyst. Altering the TS of all taxa other than age-0 pollock by ± 3 dB (i.e., a factor of 2 in linear terms) resulted in less than a 10.5 % change in age-0 abundance (Table 4, scenarios 5-6) indicating that the abundance estimates were not highly sensitive to the TS values used for species other than age-0 pollock, as most of the age-0 pollock biomass comes from areas where age-0 pollock are the dominant acoustic targets..

The vertical distribution of age-0 pollock was similar in both years, with ~ 50% of fish observed in the upper 50 m, and ~95% of fish in the upper 100 m of the water column (Fig. 12). Age-0 pollock in the upper 15 m of the water column are not available to this survey methodology, and the proportion of fish in the unobserved upper 15 m is unclear. However, the maximum abundances were at depths of ~ 30-40 m, and decreased towards the surface, which indicates that there may not be large amounts of age-0 pollock in the acoustically unsampled upper 15 m of the water column. If the density of age-0 pollock from the 15-20 m layer is assumed to be representative of that in the upper 15 m of the water column, one would expect the method described here to have underestimated age-0 pollock abundances by ~12.9 % in 2011 and 14.7 % in 2012. However, the abundance of pollock strongly increased with depth from 15-30 m (Fig. 12), and the assumption that pollock are equally abundant at 0-15 and 15-20 m depth is likely to be an overestimate of the proportion of fish that were present in the near-surface zone. Thus, as has been previously suggested by Parker-Stetter et al. (2013), the vertical distribution of the age-0 pollock suggests that only a relatively small fraction of the age-0 pollock are available to the surface trawl, which only sampled the upper 20 m of the water column. The relatively shallow distribution of the age-0 pollock raises the concern that vessel avoidance behavior may bias the abundance estimates, as vessel avoidance behavior by shallowly distributed fishes can substantially bias abundance estimates (reviewed in De Robertis and Handegard 2012).

The majority of age-0 pollock were distributed well above the seafloor (Fig. 13), for example, only 7.9% and 4.6% of individuals were within 10 m of the seafloor in 2011 and 2012, respectively. This suggests it is unlikely that a large fraction of age-0 pollock are in close proximity to the seafloor where they are acoustically unobservable (Ona and Mitson 1996), or that the near-bottom demersal backscatter excluded from the analysis contained a high proportion of age-0 pollock.

In both years, walleye pollock were most abundant in areas where the seafloor depth ranged between ~70 and 125 m (Fig. 14). However, much of the sampling was conducted in shallower areas: approximately 25-30% of the sampling effort occurred at seafloor depths shallower than 60 m, but only 5-7 % of the age-0 pollock were observed at depths of < 60 m. If age-0 walleye pollock are an important target species for this survey, survey effort could be re-prioritized to the depths where age-0 pollock are abundant, and to extend the survey farther to the west as age-0 pollock remained abundant at the western boundary of the survey area (Fig. 10).

Conclusions and Recommendations for Further Development

This work builds on that of Parker-Stetter et al. (2013), and suggests, that despite the challenges associated with species identification in mixed assemblages, an acoustic-trawl survey for age-0 walleye pollock is possible in the eastern Bering Sea. It should be kept in mind that age-0 pollock appeared to be relatively abundant in 2011 and 2012, and that the biases associated with species identification explored in the sensitivity analysis may be higher under different conditions, particularly if age-0 pollock are scarce and/or other sound scatterers are abundant. For example, in previous surveys of adult pollock in the EBS, high non-pollock backscatter has been observed in the southeast Bering Sea, and an extensive near-surface scattering layer of unknown composition, which would coincide in depth with age-0 pollock, has been observed during AT surveys of the EBS shelf (De Robertis et al. 2008, Wolliez et al. 2012). However, these scattering layers were not reported to be widespread during the BASIS surveys in 2006-2012 (Parker-Stetter et al. 2013, this study), which suggests that these conditions may be relatively rare in recent years in the BASIS survey area.

It should be recognized that a survey of age-0 pollock in this environment is substantially more challenging than the acoustic-trawl (AT) surveys currently conducted for adult pollock (e.g., Honkalehto et al. 2011) and implementing this type of survey on a routine basis will require a substantial investment in terms of staff training. Implementing an AT age-0 pollock abundance index as part of the BASIS survey will require ship time and will detract from the other goals of the survey (salmon and oceanographic research), and the scientific benefits of this effort should be clearly established prior to committing to an extensive large-scale survey effort.

The accepted best practice in AT survey methodology is to be pragmatic and adopt initial methods to develop useful abundance indices and then continuously refine the methodology used while accounting for the impacts on survey time series. There is a long tradition of this at AFSC (e.g., Williamson and Traynor 1984, Traynor et al. 1996, De Robertis and Williams 2008, De Robertis and Wilson 2011, Honkalehto et al. 2011, Williams 2013). In this vein, there are several areas where the current BASIS survey could be improved in both the near and long-term if an AT survey becomes a major portion of this late summer survey.

Short-term Improvements

1) The cruise track should be designed to ensure good coverage in areas where age-0 pollock are expected, and survey vessel should not transit at night to avoid gaps in the daytime acoustic measurements used for analysis (i.e. see the incompletely sampled cells in Fig. 10).

2) A smaller, more quickly deployed, and presumably less selective trawl such as the modified Marinovich trawl used in the Arctic EIS project should be used to minimize deployment time, and the effects of net selectivity.

3) Additional targeted trawling should be conducted to help identify acoustic scatterers. The surface trawls are of only limited utility as they do not sample the depths and areas where age-0 pollock are most abundant. Given previous experience in 2011-2012, ~45-70 trawl

hauls targeted in the areas and depths where age-0 pollock are most abundant would be a reasonable compromise between need for acoustic species identification the amount of time needed.

4) One should avoid using multiple midwater nets (e.g., Marinovich and Cantrawl) for acoustic species identification to avoid introducing uncertainties introduced by differences in trawl selectivity.

5) Blocking of the acoustic signal by air bubbles swept under the transducer is a concern for hull-mounted transducers in bad weather. When using charter vessels, the susceptibility to bubble sweepdown should be considered and time should be available to ensure high-quality data collection by reducing vessel speeds or waiting until weather subsides.

6) Electronic logging of catch data will reduce transcription errors, and will reduce the time needed for catch processing.

Long-term Improvements

1) If age-0 pollock are a primary target species for this survey, efforts should be made to cover a larger fraction of the population. For example, the current sampling effort on the inner shelf where age-0 pollock are not abundant could be redirected to the unsampled middle and outer shelf to the north-west where age-0 pollock are likely to be abundant. It is possible that the existing summer EBS AT survey for age 1+ pollock could be expanded to provide an age-0 pollock abundance estimate if this is a priority.

2) Further studies of the size and species selectivity of the trawl gear such as those conducted by Williams et al. (2011) would reduce the uncertainty of the abundance estimate.

3) Given that the partitioning of the acoustic contributions of mixed species assemblages depends on knowledge of target strength, further studies of the acoustic scattering properties of the primary species encountered are required.

4) The errors introduced by the age-0 pollock in the near-surface and near-bottom zones unobserved by the echosounders should be quantified.

5) The reactions of age-0 pollock to the survey vessel should be evaluated, as there is potential for substantial bias in abundance estimates introduced by vessel avoidance behavior in near-surface fishes.

6) Application of recent developments in sampling methods such as optical methods to establish species compositions (e.g., Williams et al. 2010, Rosen et al. 2013), and depth-stratified trawl sampling (Engas et al. 1997) will prove helpful in efficiently converting acoustics to species abundances.

ACKNOWLEDGMENTS

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TABLES AND FIGURES

Table 1. -- Target strength to size relationships from the literature used to allocate 38 kHz acoustic backscatter to species in this study. The symbols in the equations are as follows: a is the bell radius, L is length, Z is depth in m. The species for which the TS was derived as well as the reference is given.

Species or group	**TS** (dB re 1 m^2)	**TS derived for which species**	**Reference**
Gadiids	$TS = 20\log_{10}L - 66$	*Theragra chalcogramma* *Gadus morhua*	Traynor 1996 Rose and Porter 1996
Capelin	$TS = 20\log_{10}L - 70.3$	*Mallotus villosus*	Guttormsen and Wilson 2009
Jellyfish	$TS = 10\log_{10}(\pi a^2)$	*Chrysaora melanaster*	De Robertis and Taylor 2014
Sandlance	$TS = 56.5\log_{10}L - 125.1$	*Ammodytes personatus*	Yasuma et al. 2009
Smelts	$TS = 20\log_{10}L - 65.9$	*Osmerus eperlanus*	Peltonen et al. 2006
Squid	$TS = 20\log_{10}L - 75.4$	*Todarodes pacificus*	Kang et al. 2005
Herring	$TS = 20\log_{10}L - 67.4 - 2.320\log_{10}(1+z/10)$	*Clupea harengus*	Ona 2003
Atka mackerel	$TS = 18.5\log_{10}L - 81$	*Pleurogrammus monopterygius*	Gauthier and Horne 2004
Other fishes	$TS = 20\log_{10}L - 67.4$	physoclists	Foote et. al. 1987

Table 2. -- Catch by species from 19 Cantrawl hauls conducted in midwater (A) and 74 Cantrawl hauls conducted near surface (B) during the 2011 survey. Less abundant species were pooled into the 'other' category.

A

Common name	Scientific name	Number	(%)	Weight (kg)	Weight (%)
walleye pollock (0-age)	*Gadus chalcogrammus*	11,193	43.5	19.8	0.4
capelin	*Mallotus villosus*	4,848	18.8	24.1	0.5
sea nettle	*Chrysaora melanaster*	4,796	18.6	3,607.1	70.2
walleye pollock (>0-age)	*Gadus chalcogrammus*	3,881	15.1	1,443.5	28.1
Pacific cod (0-age)	*Gadus macrocephalus*	681	2.6	1.8	< 0.1
threespine stickleback	*Gasterosteus aculeatus*	149	0.6	0.1	< 0.1
other		185	0.7	44.4	0.9
Totals		25,733		5,140.7	

B

Common name	Scientific name	Number	(%)	Weight (kg)	Weight (%)
Pacific cod (0-age)	*Gadus macrocephalus*	70,879	43.7	215.9	3.4
walleye pollock (0-age)	*Gadus chalcogrammus*	45,093	27.8	106.7	1.7
capelin	*Mallotus villosus*	32,626	20.1	173.2	2.7
sea nettle	*Chrysaora melanaster*	6,252	3.9	4,990.1	77.8
squid	Teuthida (order)	1,851	1.1	2.1	< 0.1
Pacific cod (>0-age)	*Gadus macrocephalus*	1,128	0.7	7.3	0.1
sockeye salmon	*Oncorhynchus nerka*	843	0.5	157.0	2.4
nine-spine stickleback	*Pungitius pungitius*	659	0.4	0.3	< 0.1
Pacific herring	*Clupea pallasi*	517	0.3	54.5	0.8
chum salmon	*Oncorhynchus keta*	406	0.3	406.9	6.3
Pacific sand lance	*Ammodytes hexapterus*	397	0.2	0.3	< 0.1
pink salmon	*Oncorhynchus gorbuscha*	322	0.2	20.3	0.3
yellowfin sole	*Limanda aspera*	232	0.1	98.8	1.5
Pacific sandfish	*Trichodon trichodon*	200	0.1	4.1	0.1
walleye pollock (>0-age)	*Gadus chalcogrammus*	193	0.1	6.1	0.1
lion's mane	*Cyanea capillata*	176	0.1	13.6	0.2
hydromedusa	*Aequorea* sp.	138	0.1	20.3	0.3
hyperiid amphipod	*Themisto libellula*	103	0.1	0.3	< 0.1
other		322	0.2	135.5	2.1
Totals		162,337		6,413.4	

Table 3.-- Catch by species from 24 Cantrawl hauls conducted in midwater (A) and 93 Cantrawl hauls conducted near surface (B) during the 2012 survey. Less abundant species were pooled into the 'other' catagory.

A

Common name	Scientific name	Number	(%)	Weight (kg)	Weight (%)
walleye pollock (0-age)	*Gadus chalcogrammus*	42,433	82.0	75.2	1.6
sea nettle	*Chrysaora melanaster*	5,703	11.0	4343.8	91.1
capelin	*Mallotus villosus*	1,319	2.5	8.1	0.2
Pacific cod (0-age)	*Gadus macrocephalus*	1,099	2.1	2.2	< 0.1
walleye pollock (>0-age)	*Gadus chalcogrammus*	450	0.9	291.8	6.1
lion's mane	*Cyanea capillata*	179	0.3	21.2	0.4
hydroid	Hydrozoa (class)	129	0.2	0.2	< 0.1
hydromedusa	*Aequorea* sp.	126	0.2	8.6	0.2
hydromedusa	*Neoturris breviconis*	71	0.1	0.6	< 0.1
jellyfish	Scyphozoa (class)	68	0.1	1.0	< 0.1
other		193	0.4	17.9	0.4
Totals		51,770		4,770.4	

B

Common name	Scientific name	Number	(%)	Weight (kg)	Weight (%)
capelin	*Mallotus villosus*	140,338	49.0	256.4	1.1
Pacific sand lance	*Ammodytes hexapterus*	67,034	23.4	11.0	< 0.1
walleye pollock (0-age)	*Gadus chalcogrammus*	42,637	14.9	57.3	0.3
sea nettle	*Chrysaora melanaster*	24,456	8.5	21,313.5	93.7
Pacific cod (0-age)	*Gadus macrocephalus*	5,151	1.8	13.0	0.1
sockeye salmon	*Oncorhynchus nerka*	3,084	1.1	153.1	0.7
hydromedusa	*Aequorea* sp.	1,386	0.5	88.3	0.4
lion's mane	*Cyanea capillata*	513	0.2	92.2	0.4
hydroid	Hydrozoa (class)	385	0.1	0.4	< 0.1
chum salmon	*Oncorhynchus keta*	315	0.1	494.7	2.2
yellowfin sole	*Limanda aspera*	244	0.1	111.0	0.5
whitecross jellyfish	*Staurophora mertensii*	187	0.1	1.6	< 0.1
rockfish (larval)	*Sebastes* sp.	150	0.1	1.9	< 0.1
Pacific herring	*Clupea pallasi*	102	< 0.1	40.3	0.2
squid	Teuthida (order)	91	< 0.1	0.3	< 0.1
flatfish (0-age)	Pleuronectiformes (order)	79	< 0.1	0.1	< 0.1
Greenland halibut	*Reinhardtius hippoglossoides*	54	< 0.1	0.1	< 0.1
other		377	0.1	103.4	0.5
Totals		286,583		22,738.5	

Table 4. -- Effect of changing post-processing parameters on total estimate of age-0 pollock abundance. The results are expressed as the percent change in total abundance from that computed under the baseline scenario used in this paper. The ratio of age-0 pollock abundance observed in 2012 and 2011 is also listed.

Scenario considered	Effect on 2011 age-0 pollock abundance	Effect on 2012 age-0 pollock abundance	2012/2011 age-0 pollock abundance
Baseline	n/a	n/a	2.56
(1) add trawl selectivity	+15.5 %	+ 14.1 %	2.53
(2) assign nearest haul	+16.0 %	-0.5%	2.20
(3) assign nearest haul with midwater and surface zones	+8.1 %	+17.3%	2.78
(4) traditional AT method	-46.5%	-48.7%	2.46
(5) increase TS of all taxa except age-0 pollock by 3 dB	-10.4%	-8.33%	2.62
(6) decrease TS of all taxa except age-0 pollock by 3 dB	+9.5%	+6.6%	2.50

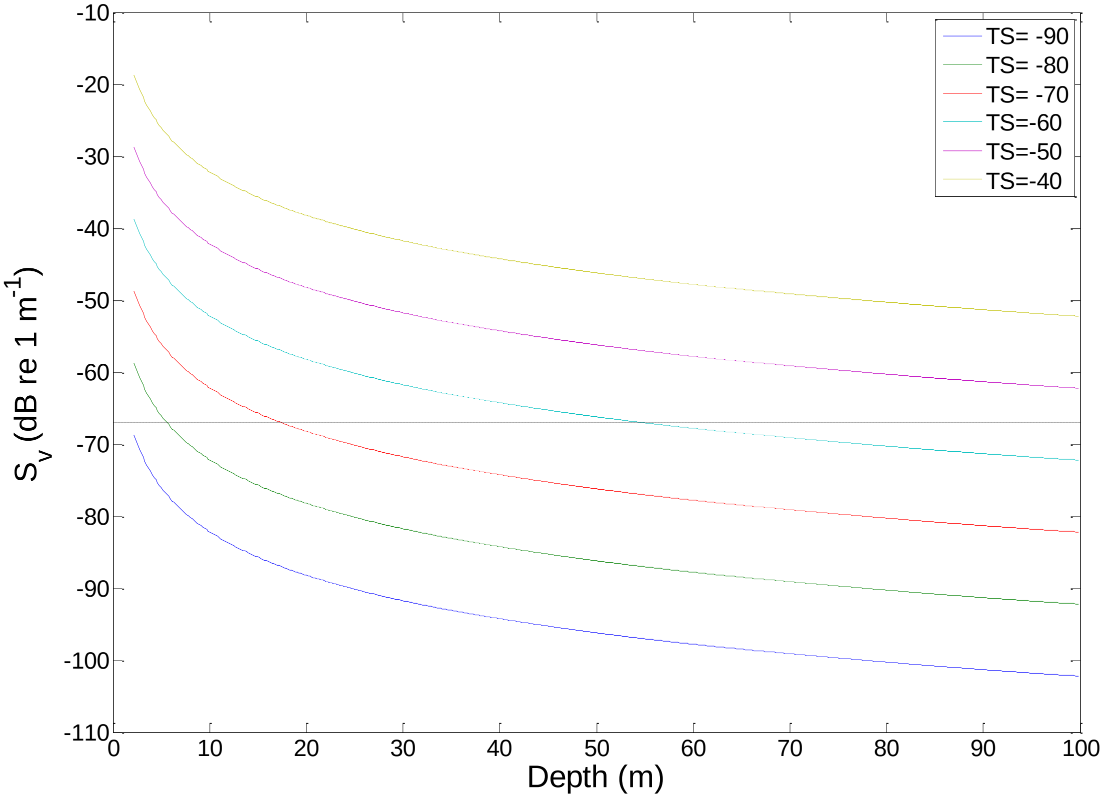


Figure 1.-- Volume backscatter (S_v dB re 1 m^{-1}) for a single target on the beam axis as a function of target strength for a 38 kHz 7° echosounder operated at 1.024 ms pulse length. The curves show that under a wide range of plausible target strengths (TS), the backscatter from a single jellyfish in the acoustic beam is likely to be above the -67 re 1 m^{-1} dB integration threshold used to eliminate jellyfish in Parker-Stetter, 2012. Recent TS measurements of *Chrysaora melanaster* suggest that the TS for a 25 cm bell diameter individual is approximately -60 dB re 1 m^{-2} (De Robertis and Taylor 2014), which suggests that a single jellyfish in the beam is detectable to a range of 50 m with the 7° beamwidth transducer used in this study. Note that calculations are for a pulse duration of 1.024 ms (which was used in 2011 and by Parker-Stetter et al. 2013). The 0.512 ms pulse duration used in 2012 will increase the detection range by ~15 m.

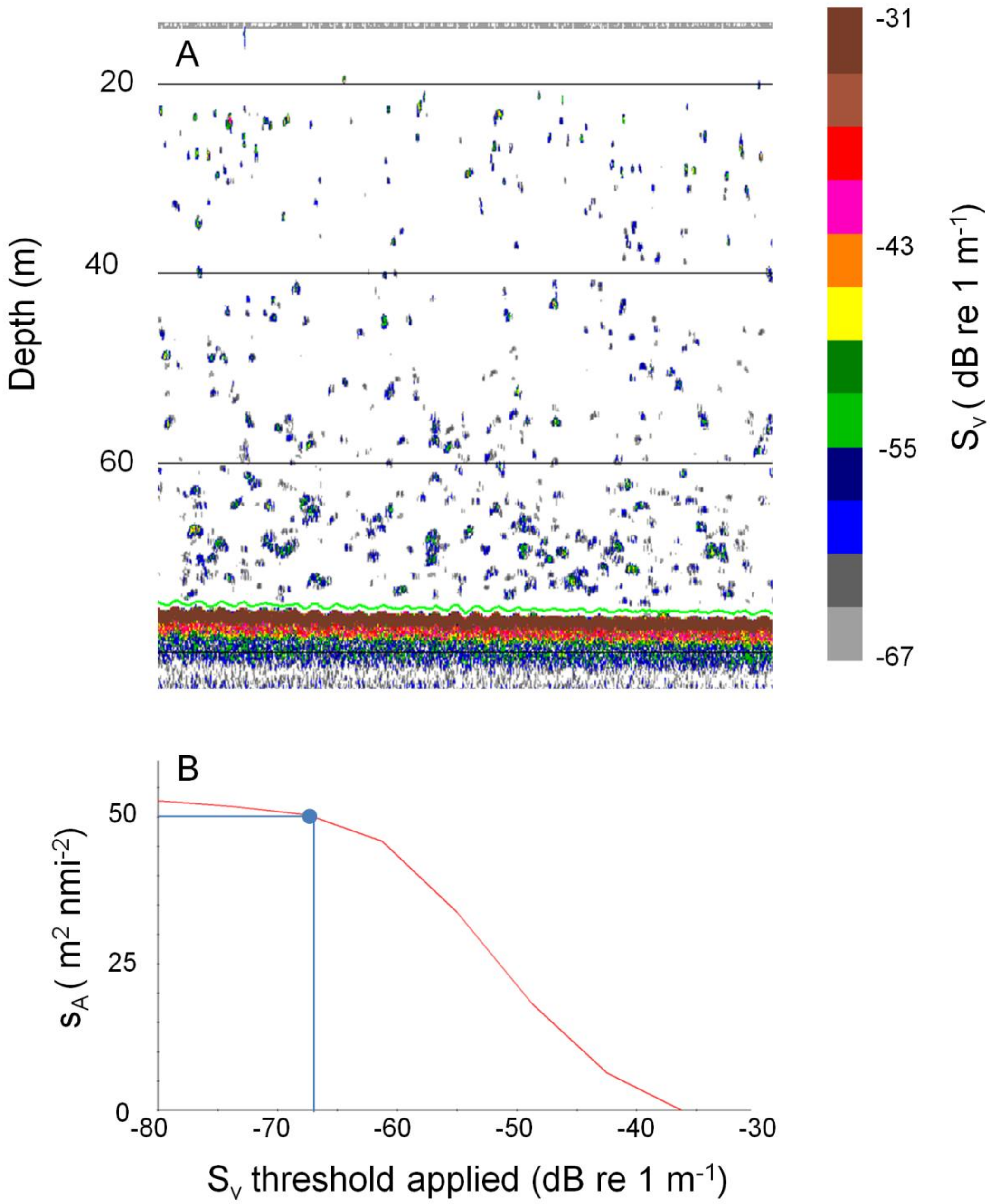


Figure 2. -- A) Echogram of an area dominated by jellyfish shown with a minimum display threshold of -67 dB re 1 m^{-1}. A surface trawl was used to sample the upper 25 m of the water column, and a midwater trawl was used to sample at a depth of 20-40 m at the same location. Combined, these two trawls caught 654 kg of jellyfish (99.8 % *C. melanaster* by number). B) Threshold response graph showing the backscatter as a function of threshold for the 15-40 m depth zone. In this case, a -67 dB integration threshold (blue line) will remove < 5 % of the energy from the jellyfish, and a threshold of approximately -40 dB would be required to remove all of the energy from the jellyfish.

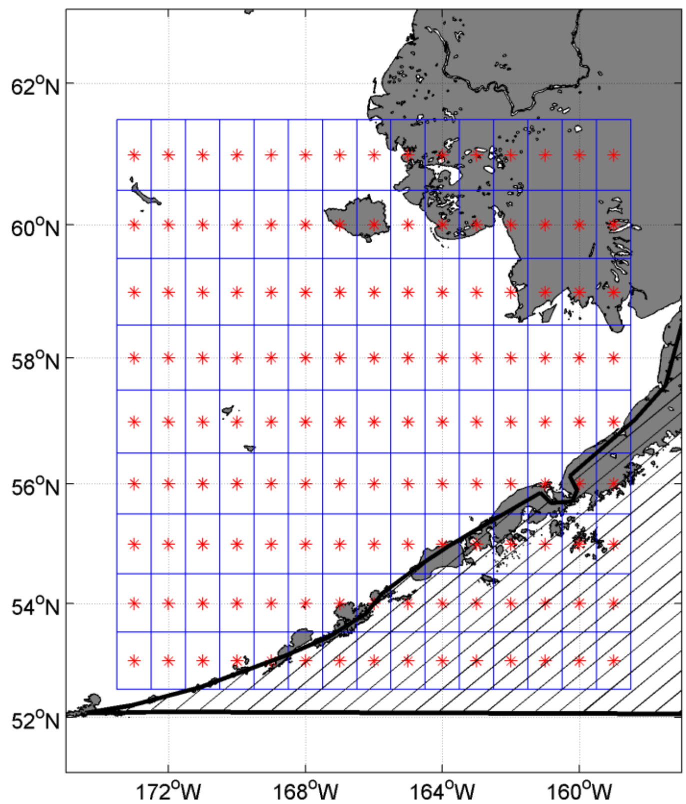


Figure 3. -- Grid used in data analysis. The available acoustic data in each 1° by 1° latitude/longitude grid cell (pictured as a blue grid with asterisks at the grid cell midpoint) was extrapolated over the area of the grid cell if > 10 nmi of acoustic observations were available in the cell. The area on land and areas south of the Alaska Peninsula (hatched area) was excluded from the calculated survey area.

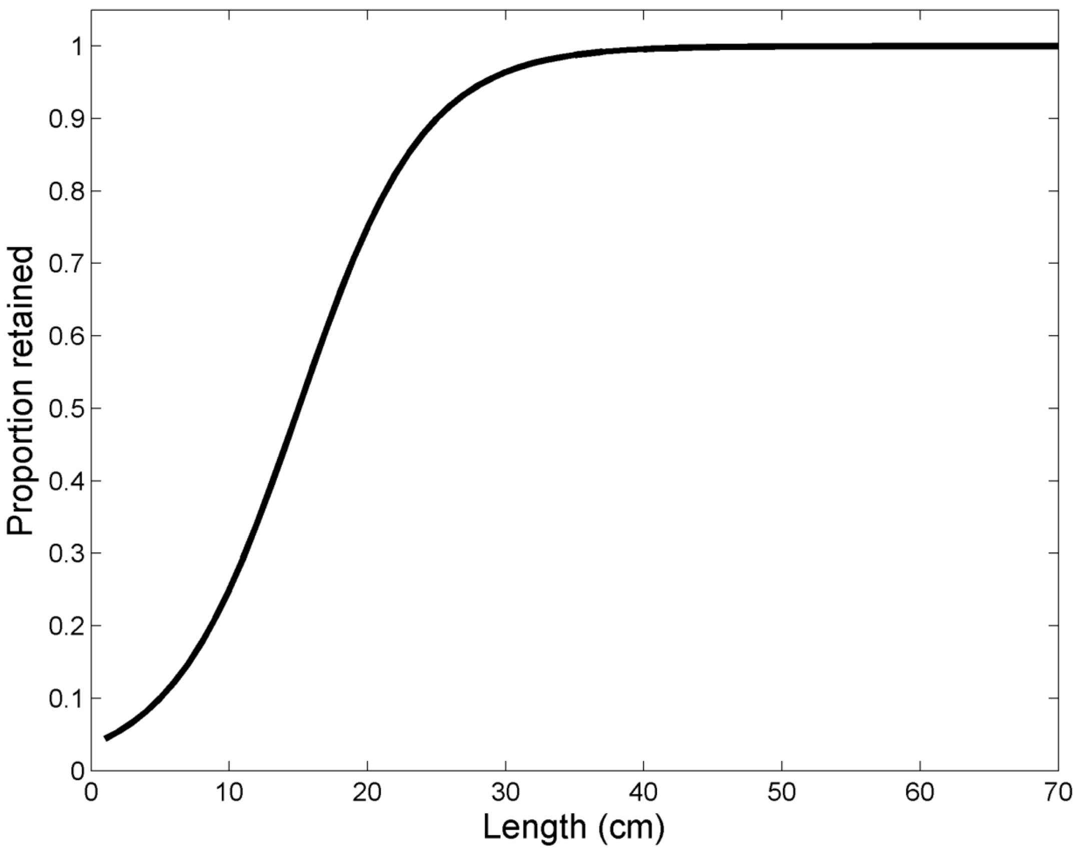
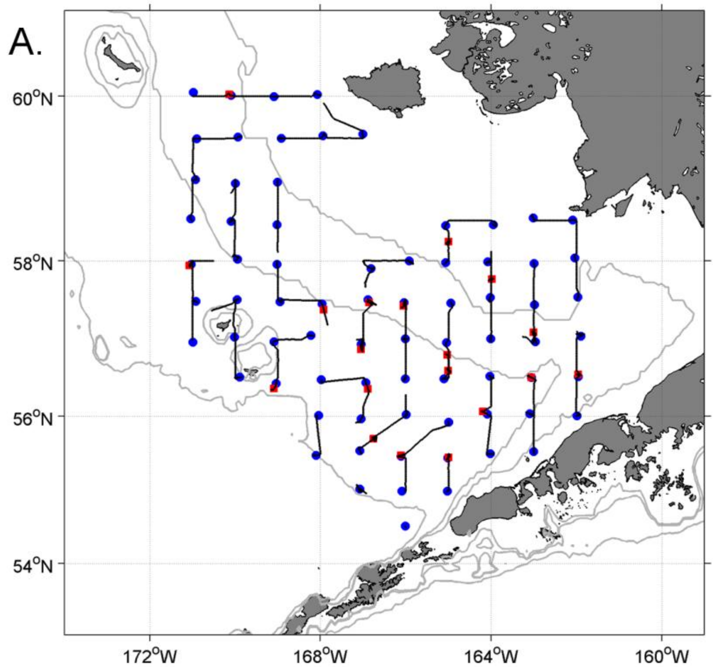


Figure 4. -- Size-dependent logistic selectivity function applied as part of the alternate scenarios considered. The length-at-50%-retention (L50) was set to 15 cm and the selection range (SR; length in cm between 25 and 75% retention) was set to 10 cm (see Williams et al. 2011 eq. 1 for details).



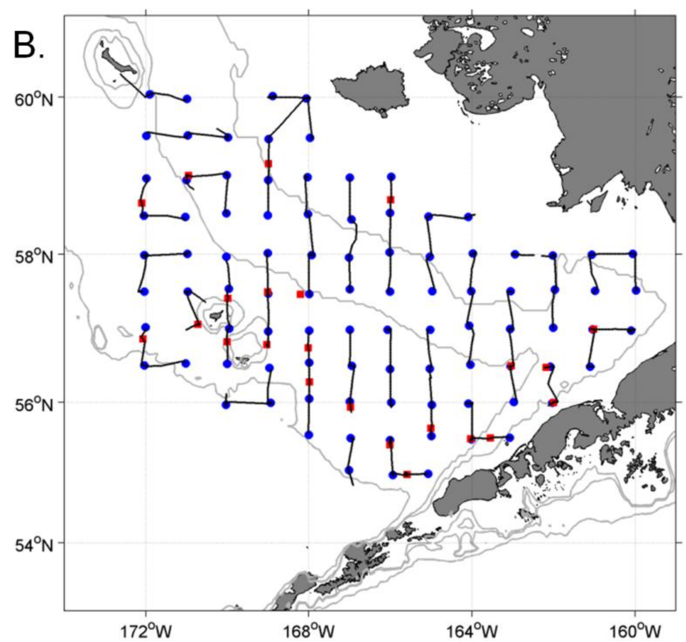


Figure 5. -- Map of survey effort in A) 2011 and B) 2012 showing valid acoustic trackline (black lines), and locations of surface trawls (blue circles), and targeted midwater trawls (red squares). The 50, 70, and 200 m depth contours are given as light gray lines.

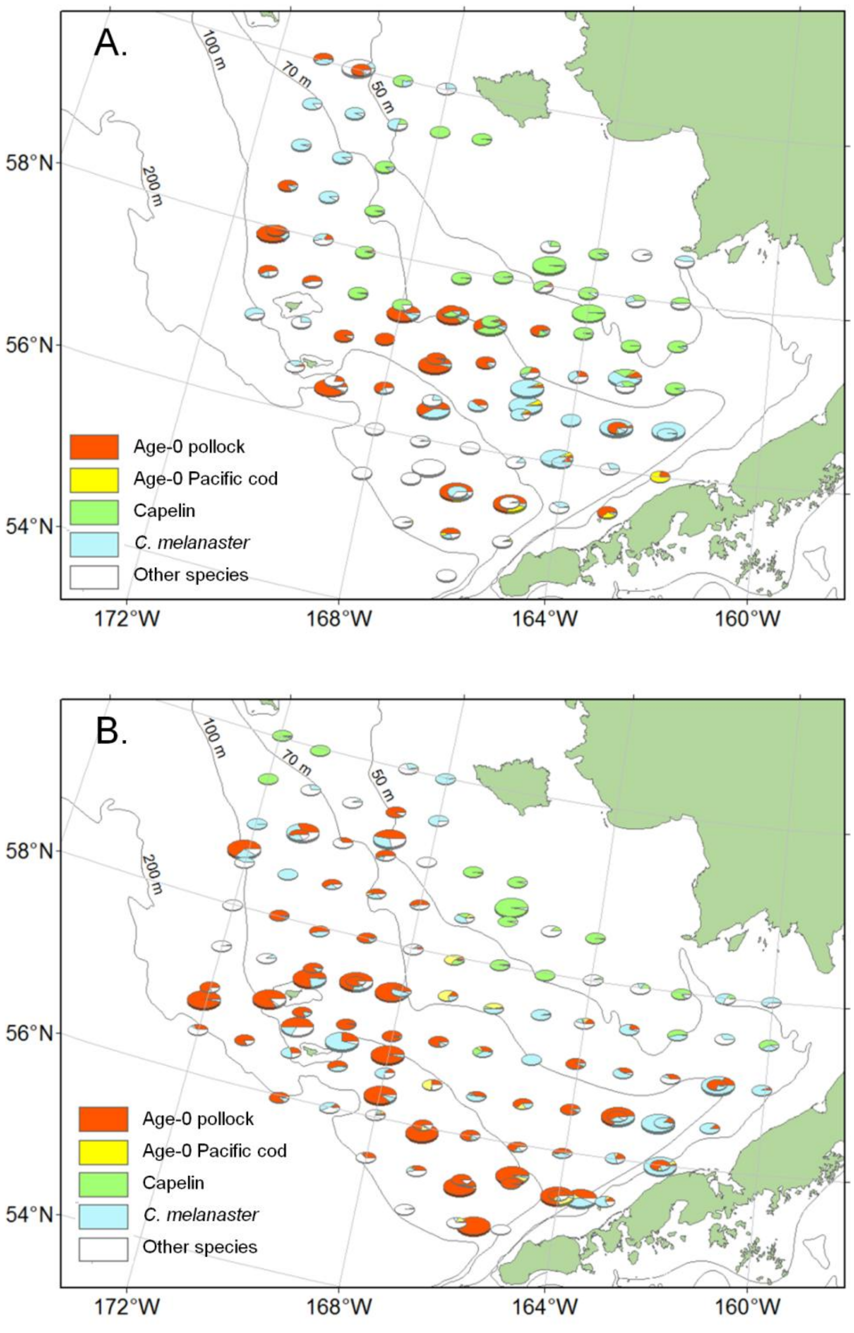


Figure 6. -- Catch composition expressed as proportions of individuals caught in A) 2011 and B) 2012. The larger pie graphs represent midwater trawl hauls and the smaller ones represent near-surface trawls. The 50, 70,100 and 200 m depth contours are shown as thin grey lines.

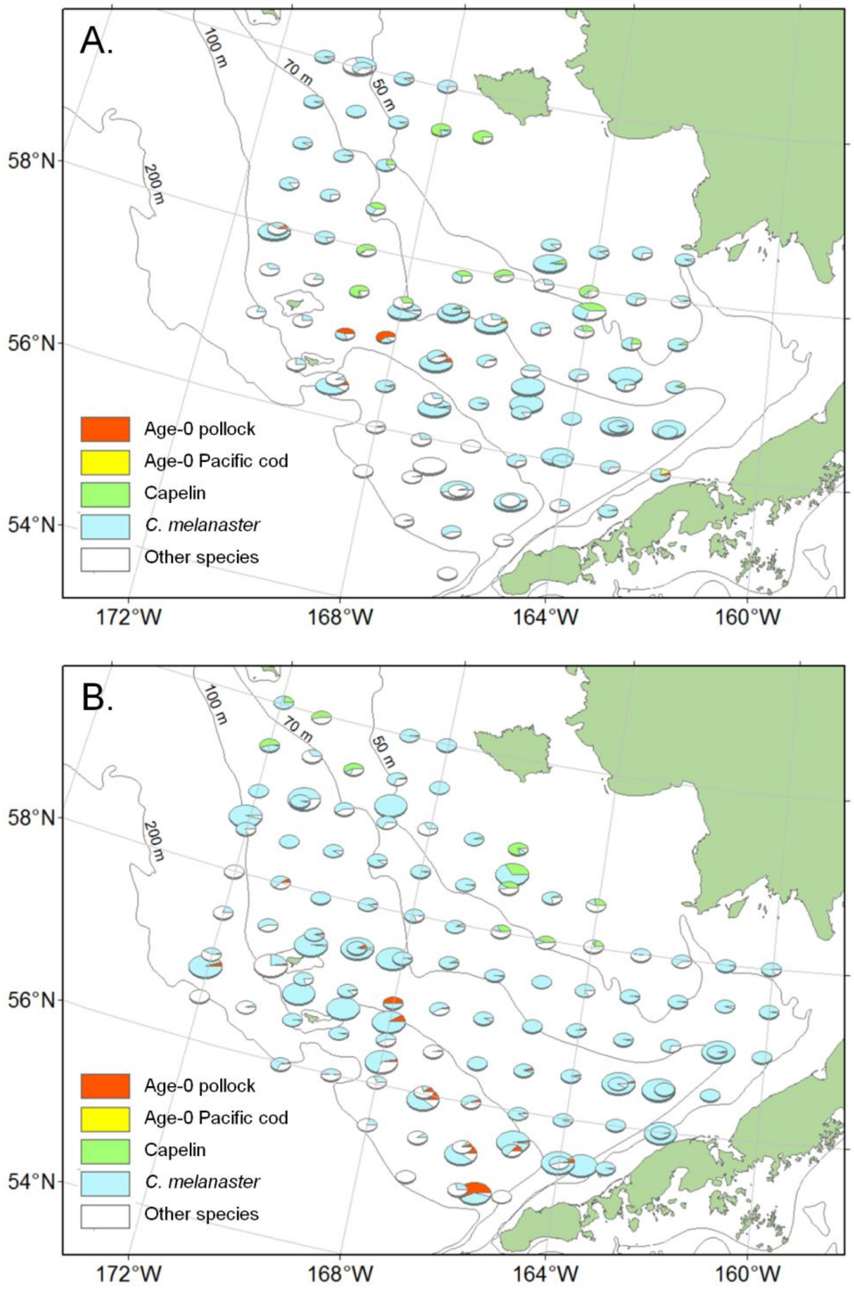


Figure 7. -- Catch composition expressed as proportion of catch by weight caught in A) 2011 and B) 2012. The larger pie graphs represent midwater trawl hauls and the smaller ones represent near-surface trawls. The 50, 70,100 and 200 m depth contours are shown as thin grey lines.

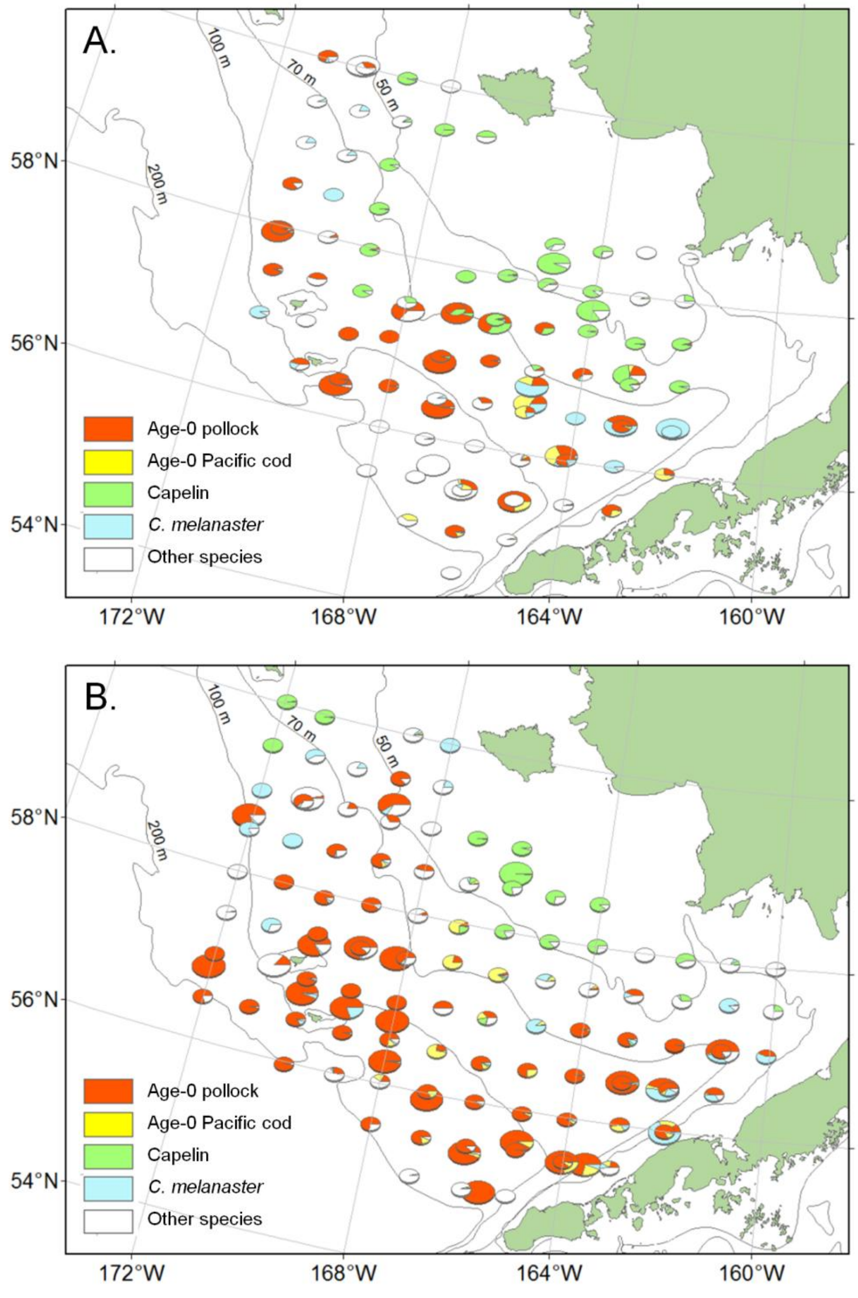


Figure 8. -- Estimated proportion of backscatter (*PB*) attributable to key species derived by combining estimates of species composition from trawl catches and estimates of target strength listed in table 1 for the BASIS survey in A) 2011 and B) 2012. The larger pie graphs represent estimates for midwater trawl hauls and the smaller ones represent near-surface trawls. The 50, 70,100 and 200 m depth contours are shown as thin grey lines.

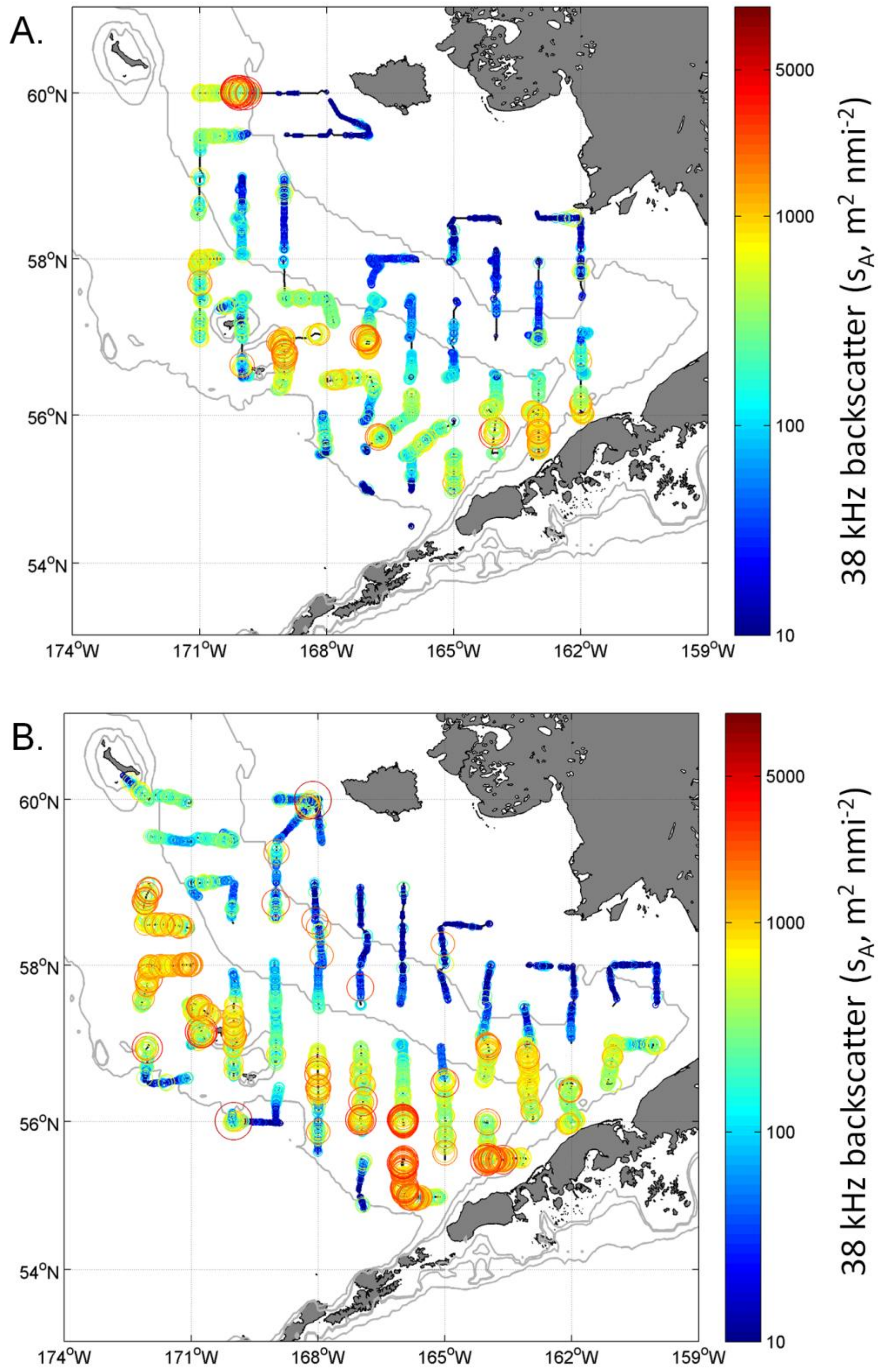


Figure 9.-- Integrated 38 kHz backscatter in the water column along the vessel track in A) 2011, and B) 2012. Symbol size and color is proportional to the observed acoustic scattering. The 50, 70, and 200 m depth contours are given as light gray lines.

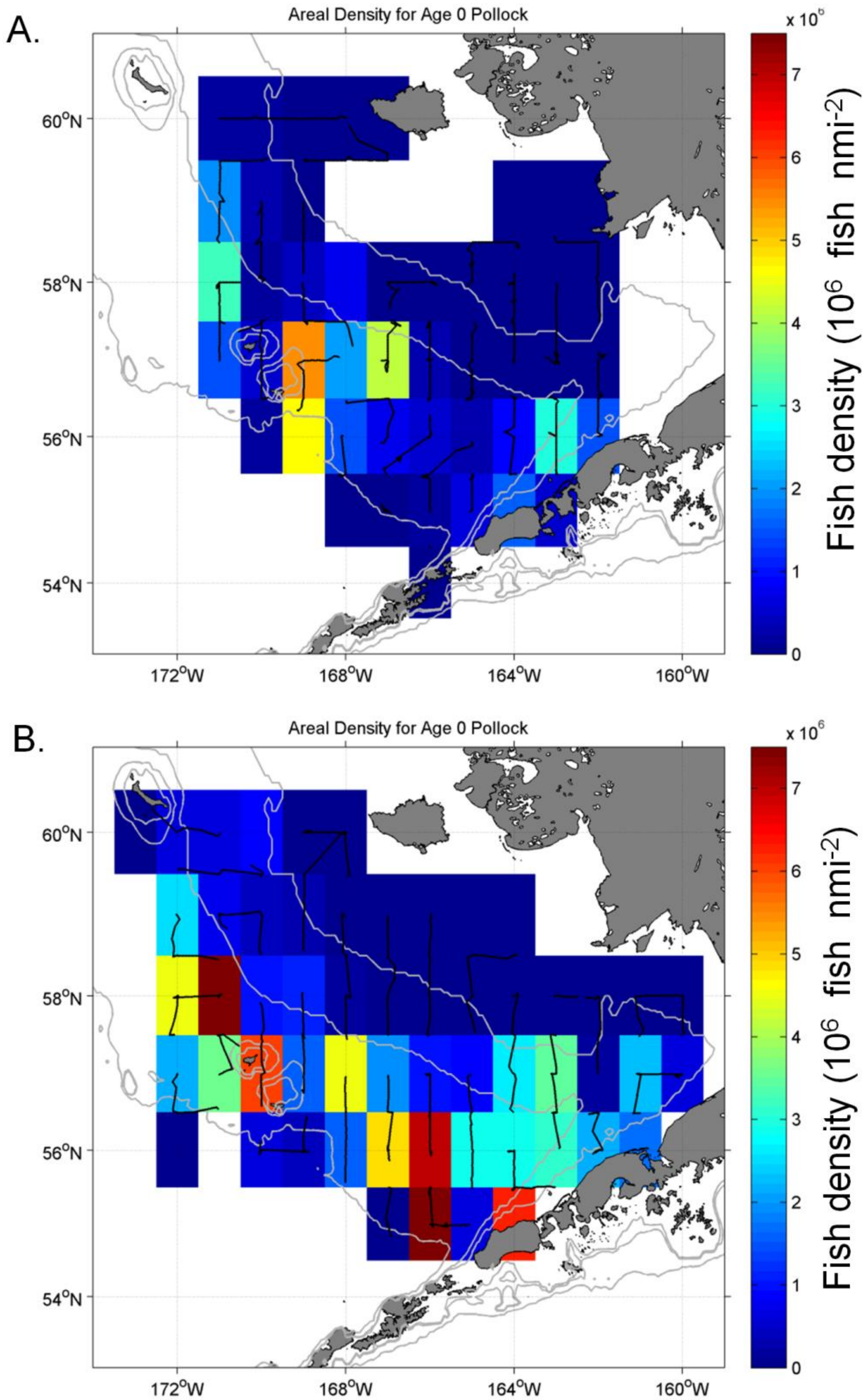


Figure 10. -- Average density of age-0 walleye pollock in each analysis grid cell in A) 2011 and B) 2012. The vessel track during daylight is given as a black line. The 50, 70, and 200 m depth contours are given as light gray lines.

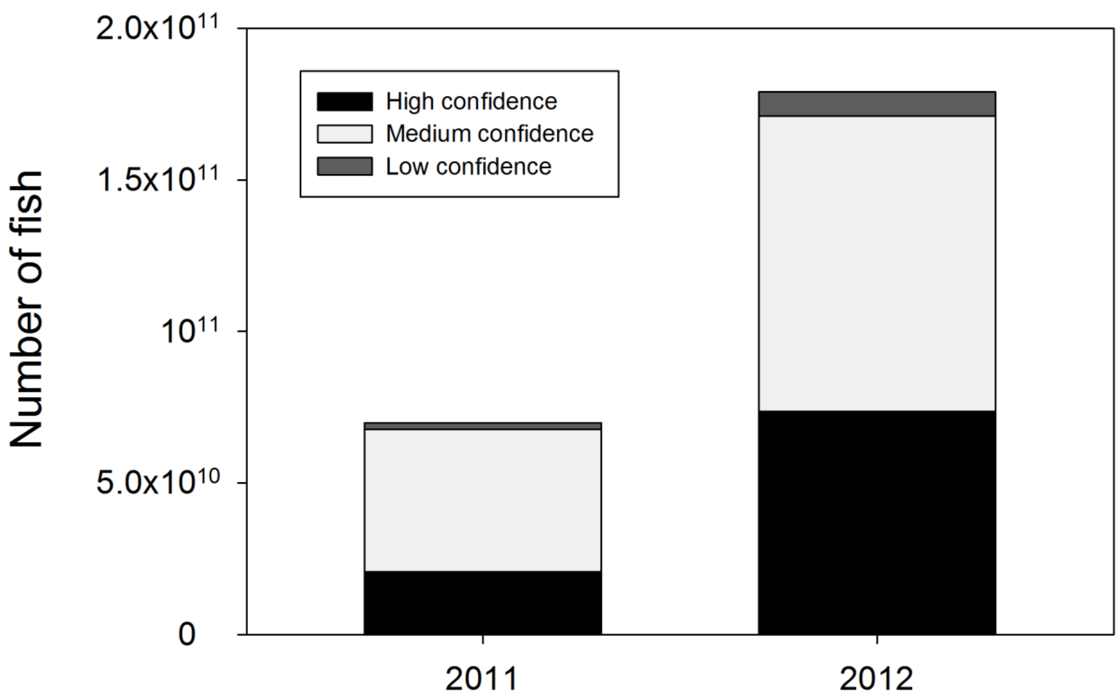


Figure 11. -- Total number of age-0 walleye pollock observed in each confidence class in 2011 and 2012.

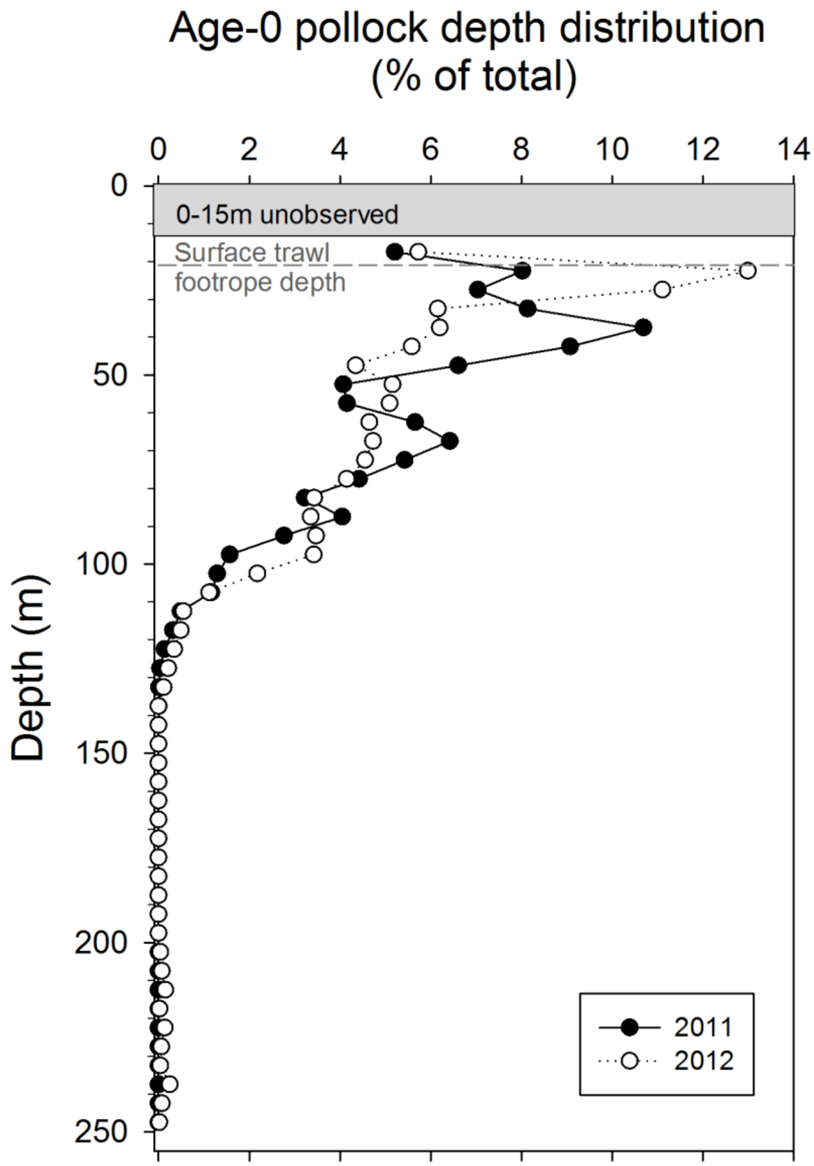


Figure 12. -- Depth distribution of age-0 pollock estimated by acoustic-trawl methods in 2011 and 2012. The upper 15 m of the water column, where abundance estimates are not available are shaded gray, and the mean depth of the surface trawl footrope is indicated by a dashed line.

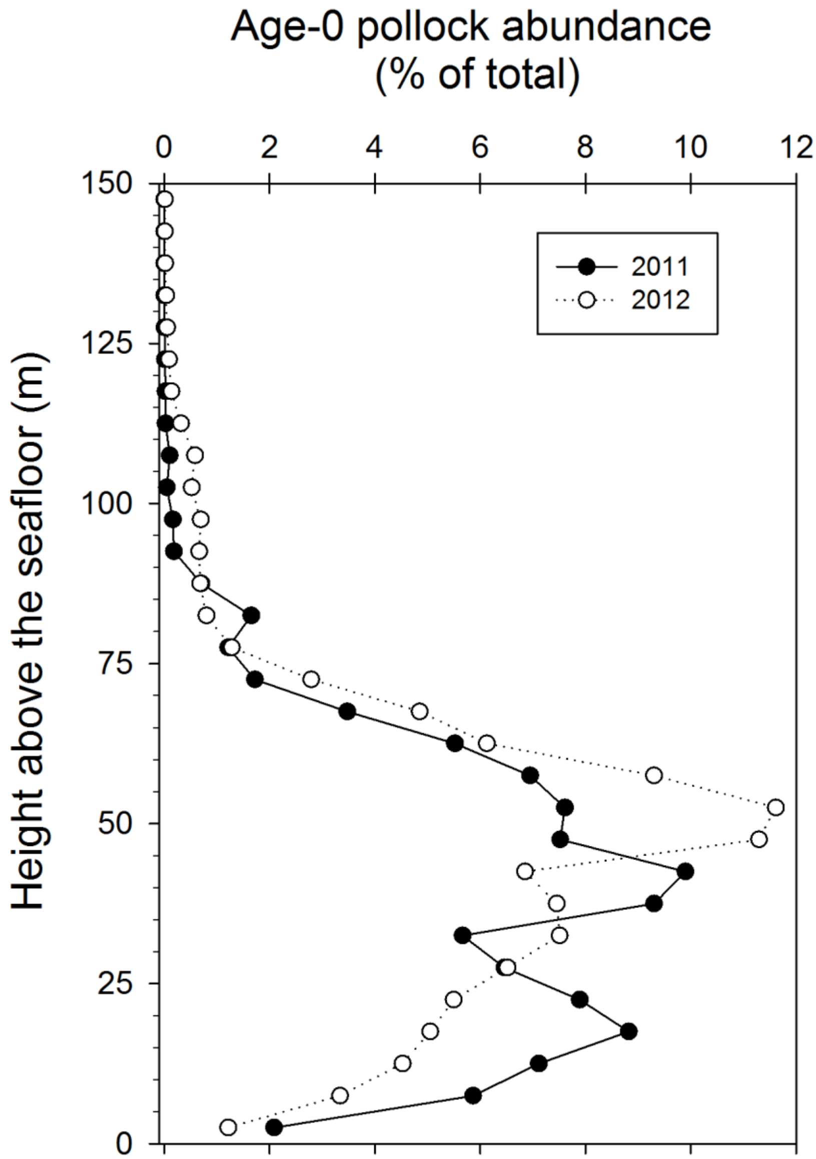


Figure 13. -- Vertical distribution of age-0 walleye pollock in the 2011 and 2012 surveys expressed as height of the fish above the seafloor.

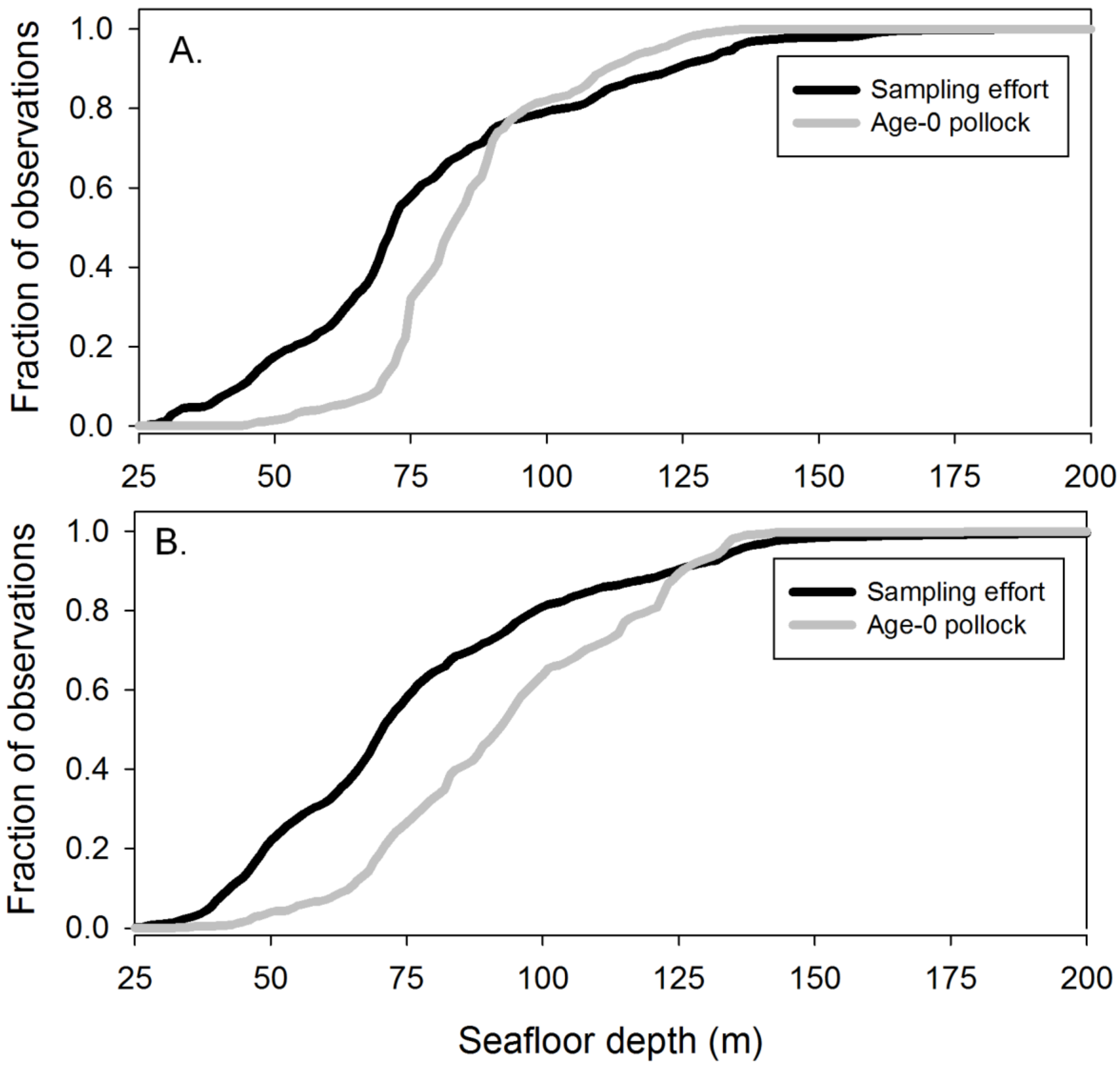


Figure 14. -- Cumulative sum of sampling effort and estimated age-0 pollock abundance as a function of seafloor depth in A) 2011 and B) 2012.

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