Inshore Acoustic Surveys in the Eastern and Central Gulf of Alaska

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ABSTRACT

A series of daytime replicate (spring/summer/fall) acoustic surveys were conducted at 11 inshore sites along the Kodiak Island/Kenai Peninsula area and the outer coast of Southeast Alaska as part of the Gulf of Alaska Integrated Ecosystem Research Program in 2010, 2011, and 2013. A two-frequency technique was used to classify backscatter as ‘fish’ or ’macrozooplankton’ based on the observed relative frequency response, which are used as proxies for the abundance of fish with swimbladders and large-bodied zooplankton. There was a strong ‘site effect’; that is, consistent differences among sites. However, acoustic backscatter classified as fish and macrozooplankton was highly variable among repeat visits. The effects of site (i.e. sampling location) were larger than those of season or year. There were no consistent differences in backscatter between sites in the Kodiak Island/Kenai Peninsula area and Southeast Alaska. The acoustic proxies for the abundance of fish and large-bodied zooplankton increased substantially with increasing bottom depth over a depth range of 5-250 m, both within and across inshore sites. Backscatter from both fish and macrozooplankton was low at water depths < 80 m. In the inshore Gulf of Alaska, water depth appears to be a key characteristic structuring pelagic communities during daytime with sound-scattering fishes and large-bodied zooplankton being scarce in relatively shallow inshore habitats compared to adjacent deeper habitats.

Key words: Gulf of Alaska, acoustic surveys, echo surveys, fish, macrozooplankton, nearshore pelagic environment, depth.

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1. Introduction

The Gulf of Alaska (GOA) is a complex and productive environment supporting diverse fish communities and sizeable fisheries (reviewed in Hood and Zimmerman, 1987; Mundy, 2005). Compared to the eastern GOA, the western GOA exhibits a wider continental shelf (Fig. 1, Weingartner, 2005), a later spring bloom and a higher mean chlorophyll-*a* concentrations (Waite and Mueter, 2013), and a more abundant but less diverse demersal fish community (Mueter and Norcross, 2002). A primary aim of the Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP) described in this volume was to provide a synoptic view of the distribution and abundance of key species of fishes and their habitat associations from the shoreline out to beyond the shelf-break across the region (NRC, 2002; Dickson and Baker, 2016). Field sampling of fishes during this program consisted of a series of seasonal surveys from the nearshore to the offshore GOA basin. This was accomplished by sampling the offshore areas with a large survey vessel (McGowan et al., 2016) while a series of inshore sites (i.e. coastal bays and areas adjacent to islands) were sampled with a smaller survey vessel (Ormseth et al., 2017). The goals of this field sampling were to assess spatial and temporal variability of the ecosystem by comparing the east and west GOA regions across spring, summer, and fall and to determine habitat associations of key fish species. Here, we broadly characterize the relative abundance and distribution of pelagic fishes and large-bodied zooplankton at a series of inshore study sites within bays and around islands in the eastern and central GOA by means of repeated seasonal acoustic surveys.

The mountainous and glaciated coastline of the GOA is a diverse and complex coastal landscape which includes many fjords, embayments and islands, which are the result of interacting tectonic and glacial processes (Hampton et al., 1987; Weingartner, 2005). Many fishes inhabit inshore areas in the GOA, often as juveniles (Rogers et al., 1986; Johnson et al., 2012). These areas are considered important nursery grounds for juvenile fishes (Rogers et al., 1986; Manson et al., 2005; Johnson et al., 2012; Sheaves et al., 2015), exhibiting environmental and biological conditions that differ from those in more offshore areas. For example, inshore habitats in the GOA are heavily influenced by freshwater input from watersheds and glacial runoff (Royer, 1982; Weingartner, 2005). Inshore habitats are subject to substantial summer heating and winter cooling and experience higher seasonal environmental variability than deeper and more offshore habitats (Weingartner, 2005; Johnson et al., 2012). Fishes may exploit this environmental variability by occupying inshore habitats when conditions favor survival and growth (Rogers et al., 1986, Johnson et al, 2009). The dynamics of habitat choice at different life history stages thus has the potential to influence the survival and growth of fish populations. This underscores the importance of a comprehensive understanding of how inshore habitats are used by fishes in the GOA. Although there has been substantial sampling of fishes in intertidal and shallow (< 10 m) subtidal areas; e.g. Rogers et al., 1986; Johnson et al., 2012), less information is available regarding pelagic fishes and zooplankton in the adjacent inshore pelagic habitats. Surveys in these areas have generally been limited in their geographic and temporal scope, and have used different methods in shallow and deep water (e.g. Rogers et al., 1986; Sigler et al., 2004; Arimitsu et al., 2008; Witteeven et al., 2008). Thus, it remains unclear to what extent fishes use shallow inshore pelagic habitats in the GOA.

In this study, we examine the broad-scale abundance and distribution of acoustically detected fishes and macrozooplankton over a wide depth range (5-250 m) in poorly sampled inshore sites in the GOA. The primary goals of this work were to conduct a series of acoustic surveys in representative inshore study sites (Zimmermann et al., 2016 ; Ormseth et al., 2017, Zimmermann, in press) to quantify the abundance and distribution of fishes and macrozooplankton in these habitats, and to quantify seasonal, regional, and interannual patterns in abundance. We used acoustic methods to quantify the abundance of sound-scattering fish and zooplankton in coastal bays and island systems as these methods allow a large range of water depths to be sampled with consistent methods at high sampling density. In addition, acoustic methods allow for future comparison of inshore and offshore habitats (NRC, 2002), as offshore surveys have been conducted as part of this program (McGowan et al., 2016; Ormseth et al., 2017) and previous studies in the GOA have also used comparable methods (e.g. Logerwell et al., 2007; Jones et. al., 2014; Witteveen et al., 2015; Simonsen et al., 2016).

2. Methods

2.1 Inshore acoustic surveys

A series of seasonal acoustic surveys (spring, summer, fall) were conducted in 11 inshore areas of the GOA (Table 1, Fig. 1) as part of GOAIERP in 2011 and 2013. These coastal areas (bays, and waters immediately surrounding islands) were chosen as study sites representative of the diverse inshore habitats in the east and west GOA that may be important nursery areas for fishes. The study sites were selected to represent the diversity of habitats of the inshore GOA region (e.g. small bays, large bays, and island systems). The sites were selected such that to the degree possible, sites with similar characteristics were identified in the east and west study regions to allow for regional comparisons (Ormseth et al., 2017).

Surveys were conducted at five sites (Fig. 1) in the Kodiak Island/Kenai Peninsula area (hereafter referred to as the “west study region”): (1) Kiliuda Bay, (2) Izhut Bay, (3) the Barren Islands, (4) Port Dick, and (5) Aialik Bay. An additional six sites on the outer coast of Southeast Alaska (hereafter referred to as the “east study region”) were also surveyed (Fig. 1): (1) Whale Bay, (2) St. Lazaria Island, (3) Salisbury Sound, (4) Islas Bay, (5) Torch Bay, and (6) Graves Harbor. These study sites, which are described in detail elsewhere (Ormseth et al., 2017; Zimmermann et al.; 2016, and Zimmermann, in press), are summarized in Table 1.

To explore how physical differences among sites influenced fish and macrozooplankton distributions, we assigned each site to a group following Zimmermann (in press), who classified the sites into groups on the basis of 56 metrics characterizing the shoreline, bathymetry, sediments, depths and watersheds. This resulted in the following groups: east small bays (ES; Islas Bay, Torch Bay, Graves Harbor), east large bays (EL; Salisbury Sound and Whale Bay), west medium bays (WM; Port Dick, Izhut Bay, Kiliuda Bay), islands (IS; Barren Islands), and Aialik Bay (AB). Aialik Bay had a unique set of physical features and formed its own distinct group (Zimmermann, 2016). St. Lazaria, which was not considered by Zimmermann (in press), was included in the IS site group as it is also an island system.

We conducted surveys of acoustic backscatter in these sites in spring, summer, and fall of 2011 and 2013 (Table 1). In addition, surveys of 4 sites in the east study region were conducted during a summer 2010 pilot study using the same methods. Each site was sampled 4-7 times during 13 cruises of ~15 days duration. During each season, the east study region was sampled first followed by the west study region. All sites could not be sampled during the fall cruises (Table 1) due to inclement weather and a U.S. government shutdown which prematurely terminated the fall 2013 cruise. A total of 61 site-surveys covering 4100 km of acoustic transects were completed.

The surveys were conducted aboard two chartered vessels: work in the west study region was conducted on the R/V *Island C,* a 22.5 m research vessel, and surveys in the west study region were conducted aboard the F/V *Seaview*, a 16.5 m crabber/longliner. Surveys covered the inshore area, which in the case of the coastal bays was defined as the area within the mouth of the bay, and in the case of islands all transects were within 4.6 km of land (see Ormseth et al., 2017 for maps of the survey tracks). A systematic parallel transect design was used except in narrow bays where a parallel design would result in a substantial portion of effort expended on cross-transect transits (Simmonds and MacLennan, 2005). In the narrow bays of Whale Bay, the northwestern arm of Kiliuda Bay, and near the entrance to Taylor Bay in Port Dick, a zigzag transect pattern was used, with each leg of the zig-zag pattern defining a transect. The spacing of parallel transects ranged from 0.25 km apart in smaller bays such as Torch Bay and Graves Harbor to 3.7 km apart in the Barren Islands. Transects were conducted during daylight hours and extended as close to shore as safe navigation allowed and typically terminated when depths of ~15-20 m were encountered.

Acoustic backscattering was measured using calibrated Simrad EK60 38 and 120 kHz echo sounders equipped with model 38-12 and 120-7C transducers in a YSI tow body towed at speeds of 3-4 m s^{-1} from the side of the survey vessel at a depth of ~1.5 m. The echosounder, which produced conical beams of 12° at 38 kHz and 7° at 120 kHz, was operated continuously at a pulse rate of 2 s^{-1} and a pulse duration of 0.512 ms. The echosounder was calibrated 2-3 times per survey using the standard sphere method (Foote et al., 1987; Demer et al., 2015) with a 38.1 mm tungsten carbide sphere.

2.2 Skiff acoustic surveys in shallow water

Shallow areas adjacent to the shoreline (water depths of 5-30 m) were not accessible to the survey vessel (e.g. in many fjords the walls are steep and 30 m depth is very close to shore). To investigate whether high densities of fish were present in these areas, we made additional acoustic observations adjacent to the shoreline at the study sites from a 5 m inflatable boat (hereafter referred to as the ‘skiff’) powered by a 20-hp 4-stroke outboard motor. A total of 20 skiff surveys covering 381 km of trackline were conducted at 7 of the study sites starting in summer 2011 (Table 1). The skiff was equipped with a battery-powered EK60 echosounder and a 38/200 kHz combi-D single-beam transducer mounted to the transom on a 1 m pole, which was operated at a pulse rate of 2 s^{-1} and a pulse duration of 0.512 ms. The transducer used on the skiff had a 13° by 21° elliptical beam at 38 kHz, and a 7° conical beam at 200 kHz. The skiff echosounder was calibrated once per cruise using the single-beam method described in Demer et al. (2015) with a 38.1 mm tungsten carbide sphere.

2.3 Fish sampling

In acoustic surveys of fish, trawls are typically used to determine the size and species composition of acoustic scatterers (e.g. McClatchie et al., 2000; Simmonds and MacLennan, 2005). However, the vessels used for the inshore surveys were not equipped to deploy standard trawl gear. An otter trawl was modified into a small single-warp midwater trawl (3 m vertical and 6 m horizontal opening; additional detail in Ormseth et al., 2017), and deployments from the survey vessels were attempted, but due to limitations in vessel horsepower and the equipment available, we were not able to tow this net adequately in midwater. We thus attempted alternate methods to capture fishes to determine the identity of the acoustic scatters, including a gill net, cast nets, an underwater video camera, dip nets, and jigging lures with rod and reel (Ormseth et al., 2017).

Jigging lures was the only method to consistently capture fishes and was thus adopted as the primary method to sample fish during the acoustic surveys. As time allowed, the acoustic survey was interrupted to deploy lures at the depths of scattering layers, which in some instances resulted in fish catches. We used small multi-hook herring lures (Sabiki rigs) which were more successful for capturing smaller species such as Pacific herring (*Clupea pallasii*), as well as dart lures resembling forage fishes which were more successful for capturing larger fishes such as rockfishes (*Sebastes* spp) and walleye pollock (*Gadus chalcogrammus*). Typically, both lure types were used at a location until it was determined which was most effective.

2.4 Post-processing methods

The spring and summer 2011 38 kHz data from the tow body were compromised due to undiscovered damage caused by flexing of the conductors in the transducer cable, which intermittently impacted the observations. These data were corrected for this bias by using both the transmit pulse and the bottom echo as a reference (see Ormseth et al., 2017, appendix D), which are useful measures of instrument performance (e.g. Ryan and Kloser, 2004; Hjellvik and De Robertis, 2007; Shabangu et al., 2014). After correction, residual uncertainty for 38 kHz backscatter was estimated as ~0.5 dB (~12 % in linear terms), while the fish/macrozooplankton classification used in this study is robust to errors of ± 3 dB (Ormseth et al., 2017). Consequently, the unaffected 120 kHz data are used as an index of abundance, and the 38 kHz data, which are subject to more uncertainty due to the correction, are used only for classification of backscatter, which is robust to residual errors remaining after correction. Data from the 2010 pilot study and after summer 2011 were not subject to biases introduced by the damaged cable. After the damage was discovered, more robust armored data cables were used with the tow body and the instrumentation was carefully monitored during surveys for any signs of cable damage by 1) continuously monitoring the strength of the transmit pulse, 2) monitoring the resistance across transducer quadrants, and 3) conducting more frequent sphere calibrations.

Acoustic backscatter was processed in Echoview 5.4 (Myriax Pty Ltd, Hobart, Tasmania, Australia). Backscatter from the survey vessel was partitioned into signals consistent with either fish or macrozooplankton (Fig. 2) based on their relative frequency response, using a two-frequency variant of the method described in De Robertis et al. (2010). The water column data from the acoustic records (i.e. samples > 1 m from the transducer and 1 m above the first bottom echo) were smoothed with a 5 ping by 0.5 m sample sliding window (using a 'top hat' convolution algorithm, i.e. with equal weights of 1), and the frequency response ($S_{V,120kHz} - S_{V,38kHz}$) in each cell was computed. This spatial averaging increased the spatial overlap of the backscatter measurements (i.e. as 38 and 120 kHz had different beam widths), and reduced the variability in frequency response. Analysis cells with a frequency response in the range of -16 to 8 dB were assigned to the "fish" category and those in the range of 8 to 30 dB were assigned to the "macrozooplankton" category (cf. De Robertis et al., 2010, their Fig. 2). In some instances (6.2% of observations), a continuous, diffuse, and low-backscatter near-surface scattering layer with a frequency response partially overlapping with that of the fish category was evident. Although the scatterers constituting this layer are unknown (e.g. Wolliez et al., 2012), the backscatter is not consistent with juvenile or adult fishes in terms of aggregation behavior, scattering strength, and frequency response. This backscatter (3.5% of total 120 kHz backscatter) was manually excluded.

The 120 kHz backscatter data from 6 m below the surface to 0.5 m above the sounder-detected bottom were echo-integrated as the nautical area scattering coefficient (s_A, m^2 nmi^{-2}) or the volume backscattering coefficient (s_v, m^{-1}), which are linear measures of total water column (i.e. integrated over the water column) or backscatter per unit volume, respectively (MacLennan et al., 2002). The data were averaged in 100 m along-track units and 5 m depth bins. A –67 dB re 1 m^{-1} minimum S_v integration threshold was used for the fish category, and -75 dB re 1 m^{-1} for the macrozooplankton category. Data were summarized by transect by first excluding observations while the vessel transited between transects and then computing the mean backscatter for each transect by averaging all 100 m along-track samples on that transect. The mean backscatter per unit area for each site sampled on a given cruise was computed by averaging the observations over all transects consistently visited on all cruises (Table 1).

The backscatter measurements from the skiff's 38/200 kHz system were processed in an analogous manner to those from the survey vessel except that 200 kHz was used in place of 120 kHz. Analysis cells from skiff acoustic data with a $S_{V,200kHz}$ - $S_{V,38kHz}$ frequency response in the range of -16 to 8 dB were assigned to the "fish" category and those in the range of 8 to 30 dB were assigned to the "macrozooplankton" category (De Robertis et al., 2010). The skiff transducer is subject to ringing of the transmit pulse which masks echoes from organisms at short ranges (Knudsen and Larsson, 2009). Therefore, backscatter with the skiff system could be measured from a depth of 5 m below the surface to 0.5 m above the sounder-detected bottom.

2.5 Statistical analysis

To identify spatial and temporal differences in backscatter at the scale of repeated visits to each study site, we conducted a series of paired t-tests that tested for differences in the mean log-transformed backscatter observed at each site (i.e. $\log_{10}[s_A]$). We limited these comparisons to the years and seasons where all study sites were sampled (spring/summer and 2011/2013).

To examine the relative importance of various descriptors of broad spatial scale (region [east/west], group [site grouping, see Table 1], site [sampling location, see Table 1]) and time (year, season) on fish and macrozooplankton backscatter, we conducted a series of 2-factor analyses of variance (ANOVAs) on the log-transformed site-visit average backscatter ($\log_{10}[s_A]$). Tests for homogeneity of variance (Levene's test; Levene, 1960) revealed that for both fish and macrozooplankton backscatter, variances were unequal among site groups ($p < 0.05$) but that all other factors met the assumption of equal variance ($p > 0.05$). Therefore, ANOVA was conducted using generalized least squares and models that included site group as a factor were weighted by the site-group variances (Pinheiro et al., 2017). We sequentially tested a single combination of spatial and temporal variables in each analysis (i.e. 6 combinations of spatial and temporal predictors were tested separately, see Table 2). Explanatory factors and their interactions were considered significant at $p < 0.05$. Pairwise comparisons were performed to identify differences among site groups when significant differences were observed.

Acoustic data aggregated at the scale of a transect were used to explore potential factors influencing fish and macrozooplankton backscatter at a finer scale. We used generalized additive models (GAMs; Hastie and Tibshiriani, 1990) to evaluate the relative importance of site, season, year, and bottom depth on the acoustic backscatter categorized as fish and macrozooplankton. In this method, the functional relationship between each covariate and the response variable is estimated by simultaneously fitting multiple covariates to the data as categorical variables or nonlinear functions under the assumption that the covariates have an additive effect on the response variable. An advantage of the GAM method is that it does not require *a priori* designation of the functional form of the relationship among variables, and the model considers multiple variables simultaneously. A GAM was fit to the 'fish' and 'macrozooplankton' backscatter as a means to interpret how backscatter changes with the covariates. In contrast to the statistical tests described above, this analysis used all available data as it does not require a balanced design.

The following model was fit to the transect-averaged acoustic measurements:

$$b = \mathrm{s}(depth) + \mathrm{f}(season) + \mathrm{f}(site) + \mathrm{f}(year) + \mathrm{error}, \qquad (1)$$

where b is the $\log_{10}$-transformed transect-average acoustic backscatter ($s_{A,fish}$ or $s_{A,zooplankton}$), *depth* is the mean seafloor depth observed on all echosounder observations on a given transect, *season* (i.e. spring, summer, fall), *site* (see Fig. 1), *year* (i.e. 2010, 2011, 2013), and *error* is a normally distributed error term. The function *s* represents a nonlinear regression spline, and *f* represents a factor accounting for categorical differences. Models were fit using the MGCV library (1.8-10, Wood, 2006) for R (R Core Team, 2015), using the Gaussian family model and identity link function. The depth effect was fit with a penalized regression spline with the shape of the spline constrained to 3 knots (Wood and Augustin, 2002). Generalized cross-validation

(GCV) was used to select the covariates included in the final models. The model variables were reduced by sequentially eliminating covariates whose partial effect had the lowest significance level. This process was repeated until all non-significant terms were removed and further elimination of a covariate increased the model GCV. To achieve approximately normally distributed residuals as assumed by the model, transformations were applied to transect-level fish and macrozooplankton backscatter [$b = \log_{10}(s_A+0.1)$]. We excluded 68 of 1772 transects from the analysis as the maximum depth on these transects exceeded the 250 m maximum data collection range (i.e. areas with unobserved portions of the water column were excluded).

3. Results

3.1 Fish and macrozooplankton backscatter

Water column backscatter classified as either fish or macrozooplankton varied substantially among sites and seasons (Fig. 3). Backscatter varied with season and year although temporal trends were generally not consistent among sites. The observed backscatter was highly variable, with changes of more than an order of magnitude among repeat visits to a single site (Fig. 3). However, some patterns are evident in the data. Fish backscatter was greater than macrozooplankton backscatter during most of the surveys. Fish and macrozooplankton backscatter was low at the Islas Bay and Barren Islands sites (i.e. the IS group) during all surveys. The paired t-tests indicated that year and season had a limited effect on site-visit mean backscatter. Fish backscatter did not vary significantly with year or season ($p > 0.05$ in both cases). Macrozooplankton backscatter was significantly lower in 2013 relative to 2011 ($p < 0.05$) but spring and summer were not significantly different ($p > 0.05$).

The two-way ANOVA revealed significant differences in site-mean water column backscatter among sites and site groups. In all combinations tested, fish backscatter differed among study sites and groups (Table 2, models 2a-f, Fig. 4a). Year and season did not significantly affect fish backscatter but the interaction terms were significant for all models where season was included (models 1d-f in Table 2), indicating that while seasonal differences exist, they are not consistent at the study sites. Pairwise comparisons revealed that fish backscatter in east large bays (EL) was higher than in east small bays (ES; $p < 0.05$). Similarly, west medium bays (WM) exhibited higher fish backscatter than ES ($p < 0.05$). The EL-WM and ES-IS pairwise comparisons were not significantly different and Aialik Bay (AB) was not different from other groups.

Macrozooplankton backscatter was also significantly different for all tests considering site and site groups, but not for comparisons of the east and west regions (Table 2, models 2a-2f; Fig. 4 b). Macrozooplankton water column backscatter was higher in 2011 than in 2013 when group and site were tested, but not when region was included (Table 2, model 2a). When season and group were included in a model, both were significant (Table 2, model 2e). No interaction terms were significant for the macrozooplankton analysis. Pairwise comparisons indicated that macrozooplankton backscatter was higher at WM bays relative to IS ($p < 0.05$), and that the sites in the EL group exhibited higher zooplankton backscatter than the ES ($p < 0.05$) and IS ($p < 0.01$) sites.

The acoustic observations exhibited a strong and consistent relationship between water column backscatter and seafloor depth. Backscatter from both fish and macrozooplankton was substantially higher in deeper areas, with low water column backscatter in areas with bottom depths < 80 m and increasing with depth until bottom depths of ~175 m (Fig. 5a-b). The skiff surveys indicated that water column backscatter from both fish and macrozooplankton was low in the shallow areas adjacent to shore which where inaccessible to the survey vessel (Fig. 5c-d). Site-mean water column backscatter was also correlated with mean site depth for both fish and macrozooplankton (Fig. 6), indicating that despite the variability among sites (Fig. 4), on average, water column backscatter from fish and macrozooplankton was higher at the deeper study sites.

One potential explanation for the increase in water column backscatter with depth is the larger observation volume as site depth increases (as this is a measure of backscatter per unit area and the volume sampled increases in proportion to depth). However, measures of backscatter per unit volume were low in the upper 80 m and increased substantially at greater depth for both fish and macrozooplankton, with the highest values in the depth range of 110-150 m (Fig. 7). Thus, the observed increase in water column backscatter with seafloor depth (Figs 5-6) is primarily attributable to higher abundances of organisms at depths >80 m.

The GAM models fitted to the transect-average data sets supports the relationship between water column backscatter and depth. In the best-fitting fish backscatter model (Table 3, model 1a) fish backscatter was strongly associated with mean transect depth, increasing by more than an order of magnitude (i.e. 1 $\log_{10}$ unit) between 10 and 100 m (Fig. 8a). Fish backscatter was lower in 2011 compared to other years (Fig. 8b), and there was a strong site effect (Fig. 8c) with higher backscatter at St. Lazaria, Torch Bay, and Kiliuda Bay, and lower backscatter at Graves Harbor and the Barren Islands. In addition, there was a seasonal effect with higher average backscatter in summer and fall than in spring (Fig. 8d). Analysis of macrozooplankton backscatter (Table 3, model 2a) revealed increased backscatter with mean transect depth (Fig. 9a), with a ~300-fold (i.e. 2.5 $\log_{10}$ units) predicted change in total water column backscatter as depth increases from 10-200 m, lower abundance in 2013 compared to other years (Fig. 9b), differences among sites (Fig. 8c), and higher macrozooplankton backscatter in summer than spring, and lower backscatter in fall (Fig. 9d).

Of the factors considered, depth had the largest effect on transect-mean fish and macrozooplankton water column backscatter (i.e. compare the magnitudes of the partial effects in Figs. 8 and 9). To gauge the importance of the depth effect, we fit alternative models. When depth is excluded from consideration in the transect-level GAM, performance drops substantially for both fish and macrozooplankton backscatter (i.e. compare models 1a-b and 2a-b in Table 3). When only depth is used to predict backscatter, the resulting models explain more of the deviance with many fewer degrees of freedom and lower GCV scores than when season or year are considered (i.e. compare models 1b-c and 2b-c in Table 3). Thus, depth was a better predictor of fish and zooplankton backscatter than season or year at the transect level.

3.2 Fish catches

A total of 302 fishes were captured when targeting fish aggregations observed acoustically by jigging lures on survey transects (Table 4). The primary species captured were rockfishes, Pacific herring, walleye pollock, and Pacific cod (*Gadus macrocephalus*). Walleye pollock, and Pacific cod were more abundant in the west study region sites, and rockfishes tended to be more abundant in the catches in the east study region (e.g. rockfishes were the most common species at 5 of 6 sites). In some cases, the jig catches likely reflected the primary sources of the acoustic backscatter observed with the echosounder. For example, rockfishes were readily captured when targeting demersal schools at the Saint Lazaria Island site, and it is likely that the fish in this area are dominated by demersal rockfish. In addition, jigging on high-backscatter schools in Kiliuda and Aialik bays suspected to be Pacific herring based on their aggregation behavior confirmed that these were schools of herring. However, it was clear that jigging was highly selective and often inefficient as it was not always effective in identifying sound-scattering aggregations (e.g. sampling of near-bottom aggregations in rocky areas often confirmed the presence of rockfishes, but jigging on midwater scattering layers often yielded no catch).

4. Discussion

Acoustic backscatter from fish and macrozooplankton at the 11 inshore study sites sampled in the GOA was highly variable but exhibited consistent differences among sites, both when study sites were considered individually and when the sites were grouped based on physical similarities (Zimmermann et al., 2016; Zimmermann, in press). These site effects were stronger than the temporal changes attributable to season or year across the habitats. Backscatter did not differ consistently between sites in the west (Kodiak Island/Kenai Peninsula) and east (Southeast Alaska) study regions. This contrasts with observations of groundfish distribution on the GOA shelf where biomass was higher in the western GOA (Mueter and Norcross, 2002). It is possible that the difference in the habitats sampled in the two regions increases variability and masks (the smaller) differences in abundance between the two regions. The east large (Salisbury Sound, Whale Bay) and west medium (Port Dick, Izhut Bay, Kiliuda Bay) sites tended to exhibit higher fish and macrozooplankton backscatter than the smaller, shallower bays. These larger bays tend to be similar: they cluster together in an analysis of the physical characteristics of the bays (Zimmermann, in press). Thus, although fish and zooplankton backscatter was highly variable, on average, there were consistent differences in backscatter across sites.

We relied on a two-frequency acoustic discrimination method to classify acoustic backscatter as consistent with either ‘fish’ or ‘macrozooplankton’. The method allows for fishes to be discriminated from smaller fluid-like scatters (i.e. zooplankton) as there is a sizeable and consistent difference in frequency-dependent scattering for many zooplankton-like targets but not for fishes with swimbladders (e.g. Kang et al., 2002; Lavery et al., 2007; De Robertis et al., 2010; Lezama-Ochoa et al., 2011). Although this technique allows for large areas to be surveyed using acoustic-based proxies of abundance in a consistent fashion, it does not produce species-level or size information. Small fishes with swimbladders are strong acoustic scatters and cannot be distinguished from larger individuals with any confidence based on differences in frequency or amplitude at the frequencies used in this study (Horne et al., 2000; Gauthier and Horne, 2004; De Robertis et al., 2010). Thus, the fish backscatter cannot be attributed to a given species or size class of fish based on the acoustic signal. In contrast, at the frequencies used in this study, scattering from zooplankton is highly dependent on material properties and size (Kang et al., 2002; Lavery et al., 2007). At these frequencies, the backscatter from many zooplankton taxa (e.g. crustaceans) scales roughly as the fourth power of length (Greenlaw, 1979). Thus, the index of macrozooplankton backscatter is likely dominated by the contributions from the largest organisms such as amphipods and euphausiids as is the case in other areas (e.g. Ballón et al., 2011; Ressler et al. 2012) including the offshore GOA (Simonsen et al., 2016).

There was a strong depth gradient in acoustically determined fish and macrozooplankton abundance in inshore bays in the GOA, with much higher abundance in deeper habitats. Water depth was an important factor at all three scales considered (100 m along-track interval, transect, study site), and depth likely explains some of the differences in fish and zooplankton abundance across sites and site groups. A similar increase in fish abundance with depth has been noted by Mueter and Norcross (2002) and Rooper and Martin (2012), who demonstrated that bottom trawl catches of adult fishes on the GOA shelf increased substantially with water depth over the ~20-200 m depth range. Our observations are also consistent with the distribution of age 1^+ walleye pollock, which are the dominant sound scatterers in daytime acoustic surveys of the offshore GOA shelf: pollock are abundant at depths > 75 m (Jones et al., 2014). The largest zooplankton in the GOA tend to vertically migrate, avoiding surface waters during daytime (Mauchline, 1980; Coyle and Pinchuk, 2005). This is consistent with our observations of low macrozooplankton backscatter in near-surface waters during daytime. However, an acoustic index of total water-column euphausiid abundance derived from these offshore GOA surveys was not significantly related to bottom depth (Simonsen et al., 2016). This discrepancy may be because this offshore study did not sample the shallow areas (< 80 m) where backscatter from large zooplankton was lowest in our inshore measurements.

Backscatter observed in shallow water sampled with the skiff was low compared to that observed in deeper water farther from shore with the larger survey vessel. It should be noted that the skiff and survey vessels used different high frequencies (120 vs 200 kHz). The difference in frequency combined with frequency-dependent scattering of biological scattering means that the results from the skiff and the survey vessel are not directly comparable. The macrozooplankton index from the 200 kHz skiff observations will be higher 120 kHz index from larger survey vessel when small zooplankton are dominant as small zooplankton will contribute more to the higher-frequency observations (Lavery et al., 2007). For fishes and large-bodied zooplankton such as adult euphausiids, the difference in frequencies used is expected to account for backscatter differences of approximately a factor of 2 (Gauthier and Horne, 2004, De Robertis et al., 2010). Given that very low backscatter was observed by the skiff, biases of this magnitude would not invalidate the conclusion that during daytime, acoustically detectable juvenile and adult fish and large-bodied zooplankton are scarce in shallow inshore pelagic habitats (i.e. areas with water depths of 5-80 m) including those adjacent to the shoreline.

Acoustic backscatter with a frequency response consistent with macrozooplankton (i.e. $Sv,_{120\ \mathrm{kHz}} >> Sv,_{38\mathrm{khz}}$) varied spatially and temporally, and was highly depth-dependent. On average, macrozooplankton backscatter was lower in 2013 relative to 2011, and tended to be higher in summer than in the fall. It is possible that the reduced macrozooplankton backscatter in fall results from mortality or transport during summer months: for example, the transect-mean GAM indicated that on average, fish abundance was higher in the summer and fall than in spring. This seasonal pattern is consistent with previous sampling in the nearshore GOA (Rogers et al., 1986; Johnson et al., 2009), and the reduction in zooplankton biomass may result from predation by fishes during the summer. We did not sample acoustically-detected zooplankton aggregations and thus cannot determine the identity of the species in these sound-scattering layers. Despite the uncertainties in the species causing the ‘macrozooplankton’ backscatter, it is clear that backscatter with a frequency response consistent with large-bodied zooplankton is strongly depth-dependent. Very little zooplankton backscatter was observed in shallow water (< 80 m deep) during daytime. Large zooplankton in shallow water can be associated with the seafloor (e.g. Kringel et al., 2003), where they would be less detectable with acoustic methods (Ona and Mitson, 1996). However, the most likely explanation is that macrozooplankton in these inshore areas adjacent to deep water are avoiding surface waters during the day. Planktivorous fishes are highly effective predators in well-lit environments even at low density (e.g. Brooks and Dodson, 1965; Gliwicz, 1986; Aksnes et al, 2004), and large zooplankton likely avoid near-surface pelagic habitats to minimize predation risk. Many optically conspicuous (i.e. large-bodied and pigmented) species of zooplankton engage in diel vertical migration behavior to deep, poorly illuminated midwater habitats during the day (e.g. Mauchline, 1980; Ohman and Romagnan, 2015), including the largest large zooplankters in the GOA (euphausiids and amphipods, Coyle and Pinchuk, 2005)

Acoustic methods offer only indirect measures of abundance and acoustic surveys typically rely on trawl sampling to attribute acoustic backscattering to organisms of a given species and size (e.g. McClatchie et al., 2000; De Robertis et al., 2017). A limitation of this study is that trawl-capable vessels were not available for this study: these vessels tend to be larger, costlier, and less able to access shallow areas than those used in this study. The lack of trawl fisheries in the east study region made the availability of such vessels extremely limited. We were not successful in initial attempts with a single-warp trawl (e.g. Sarda et al., 2002) and prioritized other aspects of the multidisciplinary GOAIERP project over developing this method during this study. Development of midwater trawls that can be reliably used to target a broad size range of pelagic fishes from small, non-specialized vessels will greatly improve acoustic surveys of this type.

Although we attempted several methods to identify the size and species composition of fish aggregations observed acoustically, these attempts were met with limited success. Jigging proved to be the most effective method of capturing fishes. However, jigging is selective in terms of which species and size/age classes are captured (Ralston, 1990; Millar and Fryer, 1999). In addition, a large fraction of the backscatter could not be identified with confidence (i.e. in many instances no fish were captured, particularly in midwater, and the probability of capture as a function of species and size remains unknown). Despite these limitations, some general trends are evident from the jig catches: walleye pollock and Pacific cod were more abundant in the west study region, particularly at the deeper sites, and rockfishes were consistently captured in the east study region. This is consistent with previous sampling of nearshore fishes (Rogers et al., 1986) and acoustic-trawl surveys of the GOA shelf, which include Kiliuda Bay and Kenai Peninsula bays (including Port Dick, and Aailik Bay) where adult pollock were the primary sound-scattering organisms detected (Wilson et al., 2003, Guttormsen and Jones, 2010). In some situations, jigging confirmed suspected species aggregations inferred from the shapes of schools observed on the echosounder (Horne, 2000; Reid et al., 2000). For example, at the St. Lazaria Island site, backscatter was observed as near-bottom schools where rockfishes were readily captured, and very dense midwater schools in Kiliuda Bay yielded Pacific herring. Because we were often unable to identify the scatterers in our surveys, we focused on drawing broad-scale inferences based on abundance proxies (i.e. backscatter with a frequency response consistent with fish and macrozooplankton, Lezama-Ochoa et al., 2011; De Robertis and Cokelet, 2012) as this allows for the data to be considered in a consistent manner.

Juvenile fishes are often abundant close to shore in complex structured habitats (e.g. vegetation such as eelgrass and kelp beds) which may serve as nursery grounds (Johnson et al., 2009; Laurel et al., 2007; Johnson et al., 2012). Fishes likely use these habitats as a refuge from predation (Gregory and Levings, 1996; Laurel et al., 2007; Anderson et al., 2007). Although sampling with a purse seine during these cruises indicated that fish were abundant in vegetated nearshore habitats at these study sites (Ormseth et al., 2017), our acoustic surveys of inshore bays and island systems in the GOA indicate that fish backscatter was low in the shallow pelagic habitats adjacent to the shoreline. These exposed shallow pelagic habitats are likely to be risky, and fishes likely either distribute themselves in habitats with cover (e.g. near bottom or very close to shore) or in deeper poorly-lit waters where visual predators will be less efficient (Brodeur and Wilson, 1996, Lewin et al., 2004). Patterns of habitat use are linked to the trade-off between feeding and predation risk (Lima and Dill, 1990), and fishes are likely avoiding well-lit pelagic waters where predication risk is high, and/or following their vertically migrating zooplankton prey to depth or occupying vegetated habitats during daytime. Fishes and zooplankton often exhibit diel patterns in habitat use and aggregation behavior, (e.g., Kaltenberg and Benoit-Bird, 2009), and likely make use of these shallow inshore pelagic habitats more extensively at night (Keats, 1990).

5. Summary

The primary finding of this study is that the abundance of fishes and large-bodied zooplankton in inshore habitats during daytime is highly depth-dependent: these organisms are scarce in shallow habitats in (< 80 m) in GOA bays and around islands compared to adjacent deeper habitats. Water depth appears to be a key characteristic structuring inshore pelagic habitats in the GOA, as backscatter per unit volume was low at depths < 80 m, and water column backscatter (a proxy for abundance per unit area) increased dramatically from the shallowest depths sampled to ~ 150-200 m. Acoustic methods are well-suited for detecting aggregations of fishes with swimbladders, which are strong sound scatterers (e.g. Gauthier and Horne, 2004; Parker-Stetter et al., 2013; De Robertis et al., 2017), and allow for efficient sampling of large areas. If fish aggregations had been abundant in the shallow pelagic habitats in these daytime surveys, they would have been detected using acoustic methods. For example, we did not observe the shallow sound-scattering layers dominated by age-0 pollock that were observed throughout the offshore GOA in 2013 (McGowan et al., 2016). Similarly, we did not detect fish aggregations in pelagic habitats adjacent to the vegetated shoreline. The distributions of macrozooplankton backscatter were similar to those of fish: there was little evidence for sound-scattering aggregations of macrozooplankton in pelagic habitats at depths of < 80 m. Although in most instances, we were unable to distinguish among backscatter from different species and size classes in this study, it is clear from backscatter measurements that overall, at the inshore sites sampled in the GOA, fishes and large-bodied zooplankton are relatively scarce in shallow inshore pelagic habitats compared to the adjacent deeper habitats.

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References

Aksnes, D.L., Nejstgaard, J., Soedberg, E., Sornes, T., 2004. Optical control of fish and zooplankton populations. Limnol. Oceanogr. 49, 233–238.

Anderson, J. L., Laurel, B. J., and Brown, J. A. 2007. Diel changes in behaviour and habitat use by age-0 Atlantic cod (*Gadus morhua* L.) in the laboratory and field. J. Exp. Mar. Biol. Ecol., 351: 267-275.

Arimitsu, M.L., Piatt, J.F., Litzow, M.A., Abookire, A.A., Romano, M.D., Robards, M.D., 2008. Distribution and spawning dynamics of capelin (*Mallotus villosus*) in Glacier Bay, Alaska: a cold water refugium. Fish. Oceanogr. 17 (2), 137-146.

Ballon, M., Bertrand, A., Lebourges-Dhaussy, A., Gutierrez, M., Ayon, P., Grados, D., and Gerlotto, F. 2011. Is there enough zooplankton to feed forage fish populations off Peru? An acoustic (positive) answer. Prog. Oceanogr. 91, 360-381.

Brodeur, R. D., and Wilson, M. T. 1996. Mesoscale acoustic patterns of juvenile walleye pollock (*Theragra chalcogramma*) in the Western Gulf of Alaska. Can. J. Fish. Aquat. Sci., 53: 1951-1963.

Brooks, J.L., Dodson, S.I., 1965. Predation, body size, and composition of plankton. Science 150, 28-35.

Coyle, K. O., and Pinchuk, A. I. 2005. Seasonal cross-shelf distribution of major zooplankton taxa on the northern Gulf of Alaska shelf relative to water mass properties, species depth preferences and vertical migration behavior. Deep-Sea Res. II, 52: 217-245.

De Robertis, A., McKelvey, D., Ressler, P.H., 2010. Development and application of empirical multi-frequency methods for backscatter classification. Can. J. Fish. Aquat. Sci. 67, 1459–1474.

De Robertis, A., Cokelet, E.D., 2012. Distribution of fish and macrozooplankton in ice-covered and open-water areas of the eastern Bering Sea. Deep-Sea Res. II (65-70), 217-229.

De Robertis, A., Taylor, K., Wilson, C., Farley, E., 2017. Abundance and distribution of Arctic cod (*Boreogadus saida*) and other pelagic fishes over the U.S. continental shelf of the northern Bering and Chukchi seas Deep-Sea Res. II 135: 51-65

Demer, D.A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R. et al., 2015. Calibration of acoustic instruments. ICES Cooperative Research Report No. 326, 130 pp.

Dickson, D. M. S., and Baker, M. R. 2016. Introduction to the North Pacific Research Board Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP): Volume I Introduction. Deep-Sea Res. II, 132: 1-5.

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., Simmonds, E.J., 1987. Calibration of acoustic instruments for fish density estimation. ICES Cooperative Research Report No. 144, 81 pp.

Gauthier, S., Horne, J.K., 2004. Acoustic characteristics of forage fish species in the Gulf of Alaska and Bering Sea based on Kirchhoff-approximation models. Can. Journal of Fisheries and Aquatic Sciences 61 (10), 1839-1850.

Gliwicz, M.Z., 1986. A lunar cycle in zooplankton. Ecology 67 (4), 883-897.

Guttormsen, M.A., Jones, D., 2010. Results of the acoustic-trawl surveys of walleye pollock (*Theragra chalcogramma*) in the Gulf of Alaska, February-March 2010 (DY2010-01 and

DY2010-02). AFSC Processed Rep. 2010-05, 85 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Greenlaw, C.F., 1979. Acoustical estimation of zooplankton populations. Limnol. Oceanogr. 24 (2), 226-242.

Gregory, R. S., and Levings, C. D. 1996. The effects of turbidity and vegetation on the risk of juvenile salmonids, *Oncorhynchus* spp to predation by adult cutthroat trout, *O. clarkii*. Envir. Biol. Fish., 47: 279-288.

Hampton, M.A., Carlson, P.R., Lee, H.J., Feely, R.A., 1987. Geomorphology, sediment, and sedimentary processes. P 93-133 in Hood, D. W. and Zimmerman, S. T. , The Gulf of Alaska: Physical Environment and Biological Resources. United States. Ocean Assessments Division. Alaska Office; United States Minerals Management Service. Alaska OCS Region. 653 pp.

Hastie, T.J., Tibshirani, R.J., 1990. Generalized Additive Models. Chapman and Hall, London. 335 pp.

Hjellvik, V., De Robertis, A., 2007. Vessel comparison on the seabed echo: Influence of vessel attitude. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-171, 34 p.

Hood, D.W., Zimmerman, S.T., 1987. The Gulf of Alaska: Physical environment and biological resources. United States. Ocean Assessments Division. Alaska Office; United States Minerals Management Service. Alaska OCS Region. 653 pp.

Horne, J.K., 2000. Acoustic approaches to remote species identification: a review. Fish. Oceanogr. 9 (4), 356-371.

Johnson, S.W., Neff, A.D., Thedinga, J.F., Lindeberg, M.R., Maseko, J.M., 2012. Atlas of nearshore fishes of Alaska: A synthesis of marine surveys from 1998 to 2011. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-239, 261 pp.

Johnson, S.W., Thedinga, J.F., Neff, A.D., 2009. Invasion by saffron cod *Eleginus gracilis* into nearshore habitats of Prince William Sound, Alaska, USA. Mar. Ecol. Prog. Ser. 389, 203-212.

Jones, D.T., Resssler, S.C., Steinessen, S.C., McCarthy, A., Simonsen, K.A., 2014. Results of the acoustic-trawl survey of walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska, June-August 2013 (DY2013-07). AFSC Processed Report. 2014-06, 95 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Kaltenberg, A. M., and Benoit-Bird, K. J. 2009. Diel behavior of sardine and anchovy schools in the California Current System. Mar. Ecol. Prog. Ser., 394: 247-262.

Kang, M., Furusawa, M., Miyashita, K., 2002. Effective and accurate use of difference in mean volume backscattering strength to identify fish and plankton. ICES J. Mar. Sci. 59, 794-804.

Keats, D. 1990. A nocturnal inshore movement of juvenile cod *Gadus morhua* L. in eastern Newfoundland. J. Exp. Mar. Biol. Ecol., 139: 167-173.

Knudsen, F. R., and Larsson, P. 2009. Discriminating the diel vertical migration of fish and *Chaoborus flavicans* larvae in a lake using a dual-frequency echo sounder. Aquat. Living Resour., 22: 1-8.

Kringel, K., Jumars, P. A., and Holliday, D. V. 2003. A shallow scattering layer: High-resolution acoustic analysis of nocturnal vertical migration from the seabed. Limnol. Oceanogr., 48: 1223-1234.

Laurel, J., Stoner, A. W., Ryer, C. H., Hurst, T. P., and Abookire, A. A. 2007. Comparative habitat associations in juvenile Pacific cod and other gadids using seines, baited cameras and laboratory techniques. J. of Exp. Mar. Biol. Ecol., 351: 42-55.

Lavery, A.C., Wiebe, P.H., Stanton, T.K., Lawson, G.L., Benfield, M.C., Copely, N., 2007. Determining dominant scatterers of sound in mixed zooplankton populations. J. Acoust. Soc. Am. 122, 3304-3326.

Levene, H., 1960. Robust tests for equality of variances, in: Olkin, I., Ghurye, S.G., Hoeffding, W., Madow, W.G., Mann, H.B. (Eds.) Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling. Stanford University Press, Redwood City, CA, pp. 278–292.

Lewin, W. C., Okun, N., and Mehner, T. 2004. Determinants of the distribution of juvenile fish in the littoral area of a shallow lake. Freshwater Biol., 49: 410-424.

Lezama-Ochoa, A., Ballon, M., Woillez, M., Grados, D., Irigoien, X., Bertrand, A., 2011. Spatial patterns and scale-dependent relationships between macrozooplankton and fish in the Bay of Biscay: an acoustic study. Mar. Ecol. Prog. Ser. 439, 151-168.

Lima , S. L., and Dill, L. M. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. Can. J. Zool., 68: 619-640.

Logerwell, E.A., Stabeno, P.J., Wilson, C.D., Hollowed, A.B., 2007. The effect of oceanographic variability and interspecific competition on juvenile pollock (*Theragra chalcogramma*) and capelin (*Mallotus villosus*) distributions on the Gulf of Alaska shelf. Deep-Sea Res. II, 54 (23-26), 2849-2868.

MacLennan, D.N., Fernandes, P.G., Dalen, J., 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES J. Mar. Sci., 59, 365-369.

Manson, F.J., Loneragan, N.R., Harch, B.D., Skilleter, G.A., Williams, L., 2005. A broad-scale analysis of links between coastal fisheries production and mangrove extent: A case-study for northeastern Australia. Fish. Res., 74 (1-3), 69-85.

Mauchline, J., 1980. The biology of mysids and euphausiids Adv. Mar. Biol., 18, 1-677.

McClatchie, S., Thorne, R.E., Grimes, P., Hanchet, S., 2000. Ground truth and target identification for fisheries acoustics. Fish. Res., 47 (2-3), 173-191.

McGowan, D. W., Horne, J. K., and Parker-Stetter, S. L. 2016. Variability in species composition and distribution of forage fish in the Gulf of Alaska. Deep-Sea Res. II, doi.org/10.1016/j.dsr2.2016.11.019.

Millar, R.B., Fryer, R.J., 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. Rev. Fish. Biol. Fisher. , 9 (1), 89-116.

Mueter, F.J., Norcross, B.L., 2002. Spatial and temporal patterns in the demersal fish community on the shelf and upper slope regions of the Gulf of Alaska. Fish. Bull., 100 (3), 559-581.

Mundy, P.R., Ed., 2005. The Gulf of Alaska: biology and oceanography. Alaska Sea Grant College Program report AK-SG-05-01, University of Alaska Fairbanks. 214 pp.

NRC, 2002. A century of ecosystem science: Planning long-term research in the Gulf of Alaska. National Research Council, National Academy Press, Washington, D.C. 108 pp. Available at http://www.nap.edu/catalog/10469.html.

Ohman, M.D., Romagnan, J.-B., 2015. Nonlinear effects of body size and optical attenuation on diel vertical migration by zooplankton. Limnol. Oceanogr. 61, p 765-770. doi: 10.1002/lno.10251.

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

Ormseth, O. A., Rand, K., and De Robertis, A. 2017. Fishes and invertebrates in Gulf of Alaska bays and islands: Results from inshore ecosystem surveys in 2011 and 2013. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-344, 140 p. www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-344.pdf

Parker-Stetter, S., Horne, J.K., Farley, E., Barbee, D.H., Andrews, A.G., Eisner, L.B., Nomura, J.M., 2013. Summer distributions of forage fish in the eastern Bering Sea. Deep-Sea Research II 94, 211-230.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. and R Core Team (2017). nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-131, https://CRAN.R-project.org/package=nlme.

R Core Team, 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Ralston, S., 1990. Size selection of snappers (*Lutjanidae*) by hook and line gear. Can. J.Fish. Aquat. Sci., 47 (4), 696-700.

Reid, D., Scalabrin, C., Petigas, P., Masse, J., Aukland, R., Carrera, P., Gregorakarakos, S., 2000. Standard protocols for the analysis of school based data from echo sounder surveys. Fish. Res., 47, 125-136.

Ressler, P.H., De Robertis, A., Warren, J.D., Smith, J.D., Kotwicki, S., 2012. Developing an acoustic index of euphausiid abundance to understand trophic interactions in the Bering Sea ecosystem. Deep-Sea Research II, 65-70, 184-195.

Rogers, D.E., Rogers, B.J., Rosenthal, R.J., 1986. The nearshore fishes. P 399-415 in Hood, D. W. and Zimmerman, S. T. The Gulf of Alaska Physical Environment and Biological Resources. United States. Ocean Assessments Division. Alaska Office; United States Minerals Management Service. Alaska OCS Region. 653 pp.

Rooper, C. N., and Martin, M. H. 2012. Comparison of habitat-based indices of abundance with fishery-independent biomass estimates from bottom trawl surveys. Fish. Bull., 110: 21-35.

Royer, T.C., 1982. Coastal fresh-water discharge in the northeast Pacific. J. Geophys. Res. – Oceans, 87 (Nc3), 2017-2021.

Ryan, T. E., and Kloser, R. J. 2004. Quantification and correction of a systematic error in Simrad ES60 echosounders. ICES FAST white paper, Gdansk. Copy available from CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, Australia.

Sarda, F., Recasens, L., Abello, P., Rotllant, G., Moli, B., 2002. Commercial feasibility trial for a single-warp deep-water "Maireta" (OTMS) trawl gear. Fish. Res., 55 (1-3), 121-130.

Shabangu, F.W., Ona, E., Yemane, D., 2014. Measurements of acoustic attenuation at 38 kHz by wind-induced air bubbles with suggested correction factors for hull-mounted transducers. Fish. Res., 151, 47-56.

Sheaves, M., Baker, R., Nagelkerken, I., Connolly, R.M., 2015. True Value of Estuarine and Coastal Nurseries for Fish: Incorporating Complexity and Dynamics. Estuaries and Coasts, 38 (2), 401-414.

Simmonds, E.J., MacLennan, D.N., 2005. Fisheries Acoustics 2nd. Ed. Blackwell Science LTD, Oxford, UK 437 p.

Simonsen, K.A., Ressler, P.H., Rooper, C., Zandor, S.G., 2016. Spatio-temporal distribution of euphausiids: an important component to understanding ecosystem processes in the Gulf of Alaska and eastern Bering Sea. ICES J. Mar. Sci., doi:10.1093/icesjms/fsv1272.

Sigler, M.F., Womble, J.N., Vollenweider, J.J., 2004. Availability to Steller sea lions (*Eumetopias jubatus*) of a seasonal prey resource: a prespawning aggregation of eulachon (*Thaleichthys pacificus*). Can. J. Fish. Aquat. Sci., 61 (8), 1475-1484.

Waite, J. N., and Mueter, F. J. 2013. Spatial and temporal variability of chlorophyll-a concentrations in the coastal Gulf of Alaska, 1998–2011, using cloud-free reconstructions of SeaWiFS and MODIS-Aqua data. Prog. Oceanogr., 116: 179-192.

Weingartner, T.C., 2005. Physical and Geological Oceanography: Coastal Boundaries and Coastal and Ocean Circulation. P 35 -48 in Mundy, P. R, ed. The Gulf of Alaska: Biology and Oceanography. Alaska Sea Grant College Program report AK-SG-05-01, University of Alaska Fairbanks. 219 pp.

Wilson, C.D., Hollowed, A.B., Shima, M., Walline, P., Stienessen, S., 2003. Interactions between commercial fishing and walleye pollock. Alaska Fishery Research Bulletin 10, 61-77.

Witteeven, B.H., Foy, R.J., Wynne, K.M., Tremblay, Y., 2008. Investigation of foraging habits and prey selection by humpback whales (*Megaptera novaeangliae*) using acoustic tags and concurrent fish surveys. Mar. Mammal Sci. 24, 516-534.

Witteveen, B.H., De Robertis, A., Guo, L., Wynne, K.M., 2015. Using dive behavior and active acoustics to assess prey use and partitioning by fin and humpback whales near Kodiak Island, Alaska. Mar. Mammal Sci. 31 (1), 255-278.

Woillez, M., Ressler, P.H., Wilson, C.D., 2012. Multifrequency species classification of acoustic-trawl survey data using semi-supervised learning with class discovery. J. Acoust. Soc. Am. 131, EL184-EL190.

Wood, S.N., 2006. Generalized additive models: An introduction with R. Chapman and Hall, Boca Raton, Florida, 392 pp.

Wood, S.N., Augustin, N.H., 2002. GAMs with integrated model selection using penalized regression splines and applications to environmental modelling. Ecol. Model., 157, 157-177.

Zimmermann, M., in press, this issue. Comparison of central and eastern Gulf of Alaska study sites. Deep-Sea Research II.

Zimmermann, M., Reid, J.A., Golden, N., 2016. Using smooth sheets to describe groundfish habitat in Alaskan waters, with specific application to two flatfishes. Deep-Sea Research II, http://dx.doi.org/10.1016/j.dsr2.2015.02.020i.

Table 1. Inshore surveys and sampling effort at each site listed from west to east. The study region and group each site was assigned to (see text), the area of the bay, the number of survey transects that were consistently visited, the total distance surveyed in a single survey, and the mean depth observed along the survey trackline is given. The date each survey started (duration was 1-3 days) is given. The ‘*’ indicates that skiff sampling of shallow (< 30 m) nearshore areas occurred at the site, the ‘x’ indicates that a site was not sampled, and *n/a* indicates that the area is not reported for islands as there is no clear demarcation of surface area in this case.

Study site	**Region**	**Site group**	**Latitude (°N)**	**Longitude (°W)**	**Area (km^2)**	**# transects per survey**	**Survey length (km)**	**Mean depth (m)**	**2010 summer**	**2011 spring**	**2011 summer**	**2011 fall**	**2013 spring**	**2013 summer**	**2013 fall**
Kiliuda Bay	West	WM	57.308	153.048	93.5	28	86.9	66.3	x	5/7	8/7*	10/16*	5/11*	8/15	11/3*
Izhut Bay	West	WM	58.205	152.266	89.5	30	69.1	71.9	x	5/10	8/3	10/21*	5/21	8/18*	x
Barren Islands	West	IS	58.948	152.159	n/a	5	29.4	79.21	x	5/14	8/11	10/23	5/15	8/21	x
Port Dick	West	WM	59.279	151.133	64.4	21	50.1	116.2	x	5/14	8/12	10/25*	5/17*	8/22*	11/7
Aialik Bay	West	AB	59.775	149.657	239.1	16	50.2	119.4	x	5/17	8/15	x	5/19	8/25	x
Graves Harbor	East	ES	58.284	136.736	12.6	16	23.9	74.8	x	4/29	7/18	x	4/27*	8/4*	x
Torch Bay	East	ES	58.322	136.808	7.5	24	23.1	52.8	7/16	4/27	7/17	x	4/27	8/3	x
Islas Bay	East	ES	57.808	136.384	7.3	27	31.7	41.3	7/14	4/25	7/14	9/30	4/25*	8/1	x
Salisbury Sound	East	EL	57.332	135.696	70.2	22	53.8	106.2	x	4/22	7/11	9/21*	4/22*	7/30*	9/22*
Saint Lazaria Island	East	IS	56.980	135.702	n/a	11	51.4	38.6	7/20	4/21	7/10	9/24	4/21	7/28	9/25
Whale Bay	East	EL	56.655	134.951	71.5	76	57.1	100.2	7/22	4/17	7/7	9/25*	4/18*	7/24*	9/26*

Table 2. Results of a series of 2-factor ANOVAs with interactions exploring the effects of time and space on site-mean fish and macrozooplankton backscatter. For each model the table indicates the response variable and the predictor variables used. The time predictors considered are year (2011/2013), season (spring/summer), and the space predictors are region (east GOA/west GOA), group (see Table 1), and study site (see Table 1). P-values and predictors in bold indicate significance at the $p < 0.05$ level. df = denominator degrees of freedom.

Model	Response	Predictors		df	F			p-value		
		time	space		time	space	int.	time	space	int.
1a	$\log_{10}(s_{A,fish})$	year	region	40	0.50	1.04	0.97	0.482	0.313	0.330
1b	$\log_{10}(s_{A,fish})$	year	**group**	34	0.44	8.14	1.03	0.512	**0.000**	0.407
1c	$\log_{10}(s_{A,fish})$	year	**site**	22	0.89	4.93	0.28	0.356	**0.001**	0.978
1d	$\log_{10}(s_{A,fish})$	season	region	40	0.08	1.13	4.63	0.782	0.295	**0.038**
1e	$\log_{10}(s_{A,fish})$	season	**group**	34	3.84	8.75	3.52	0.058	**0.001**	**0.017**
1f	$\log_{10}(s_{A,fish})$	season	**site**	22	0.23	8.74	2.34	0.638	**0.000**	**0.047**
2a	$\log_{10}(s_{A,zp})$	year	region	40	2.976	0.018	0.077	0.092	0.894	0.782
2b	$\log_{10}(s_{A,zp})$	**year**	**group**	34	4.630	10.150	0.619	**0.039**	**0.000**	0.652
2c	$\log_{10}(s_{A,zp})$	**year**	**site**	22	6.399	5.992	0.431	**0.019**	**0.000**	0.916
2d	$\log_{10}(s_{A,zp})$	season	region	40	0.171	0.017	0.402	0.681	0.897	0.530
2e	$\log_{10}(s_{A,zp})$	**season**	**group**	34	4.335	12.252	0.423	**0.045**	**0.000**	0.791
2f	$\log_{10}(s_{A,zp})$	season	**site**	22	0.323	4.965	0.478	0.575	**0.001**	0.887

Table 3. Results of generalized additive model selection for the transect-averaged data. The ‘full model’ refers to the model considering all variables, the ‘depth excluded’ model considers all variables but transect mean depth, and the ‘depth only’ model considers only transect depth. The generalized cross-validation (GCV) score, effective degrees of freedom of the model (Total DF), and the p value from approximate F or t tests (Wood and Augustin, 2002) for each covariate remaining in the models are listed. The notation *ex* denotes covariates excluded from the model during model selection, and *n/a* denotes covariates that were not considered in the model.

Model	n	GCV score	Total DF	Deviance explained	Site	Depth	Season	Year
1a: $s_{A,fish}$ full model	1704	0.67	16.99	25.1 %	< 0.001	< 0.001	< 0.001	< 0.05
1b: $s_{A,fish}$ depth excluded	1704	0.79	13	10.9 %	< 0.001	*n/a*	< 0.001	*ex*
1c: $s_{A,fish}$ depth only	1704	0.73	2.98	17.1 %	*n/a*	< 0.001	*n/a*	*n/a*
2a: $s_{A,zp}$ full model	1704	0.49	16.96	49.9 %	< 0.001	< 0.001	< 0.001	< 0.001
2b: $s_{A,zp}$ depth excluded	1704	0.79	15	17.8 %	< 0.001	*n/a*	< 0.001	< 0.001
2c: $s_{A,zp}$ depth only	1704	0.62	2.97	34.2 %	*n/a*	< 0.001	*n/a*	*n/a*

Table 4. Catches from jig fishing summarized by study site. The species captured (where at least two individuals of a given species were captured) are listed from most to least common. Sites are listed from west to east. The term 'rockfishes' is used to describe members of the genus *Sebastes*.

Study Region	Site	# cruises with catch	# individuals captured	Species captured
West	Kiliuda Bay	3	53	walleye pollock, Pacific cod, Pacific herring, sandfish, Pacific halibut
West	Izhut Bay	2	29	rockfishes, Pacific cod , Atka mackerel
West	Barren Islands	1	6	rockfishes
West	Port Dick	3	41	walleye pollock, rockfishes
West	Aialik Bay	2	14	Pacific herring, walleye pollock, Pacific cod, rockfishes
East	Graves Harbor	1	4	rockfishes
East	Torch Bay	2	24	Pacific herring, rockfishes
East	Islas Bay	0	0	n/a
East	Salisbury Sound	5	32	rockfishes, sablefish
East	Saint Lazaria	5	31	rockfishes
East	Whale Bay	5	68	rockfishes, Pacific herring, walleye pollock

Figure legends

Fig. 1. May of study area with boxes indicating the nearshore sampling sites in the Gulf of Alaska. Acoustic surveys were conducted in bays and in the immediate vicinity of islands. As can be seen from the 200 m depth contour (light grey line) the continental shelf is wider in the west study region.

Fig. 2. Example of the dual-frequency classification method used to classify volume backscatter into 'fish' and 'macrozooplankton' categories. a) Raw 38 kHz echogram showing backscatter from fishes. b) Raw 120 kHz echogram showing backscatter from fish similar to the 38 kHz in addition to a dense band of macrozooplankton backscatter between 70-120 m which is not evident at 38 kHz. c) Post-processed 120 kHz backscatter with a frequency response consistent with fish (i.e. 38 kHz is similar to 120 kHz). d) Post-processed 120 kHz backscatter with a frequency response consistent with zooplankton (i.e. 120 kHz >> 38 kHz).

Fig. 3. Mean site-visit water column backscatter at 120 kHz classified as fish (left side, panels a, c, e) and zooplankton (right side, panels b, d, f) for inshore sites sampled in 2010, 2011, and 2013 by season. Black bars represent spring, white bars represent summer, gray bars represent fall. Sites (see Table 1 and Figure 1) are listed from west to east. Some locations were not sampled in the summer of 2010, and fall of 2011 and 2013 (see Table 1).

Fig. 4. Box plots of a) $\log_{10}$ transformed fish and b) macrozooplankton water column backscatter by study site groups (see text and Table 1 for explanation). Filled circle indicates median; lower and upper box bounds indicate 25th and 75th percentiles, and bar ends indicate 1.5 times the inter-quartile range.

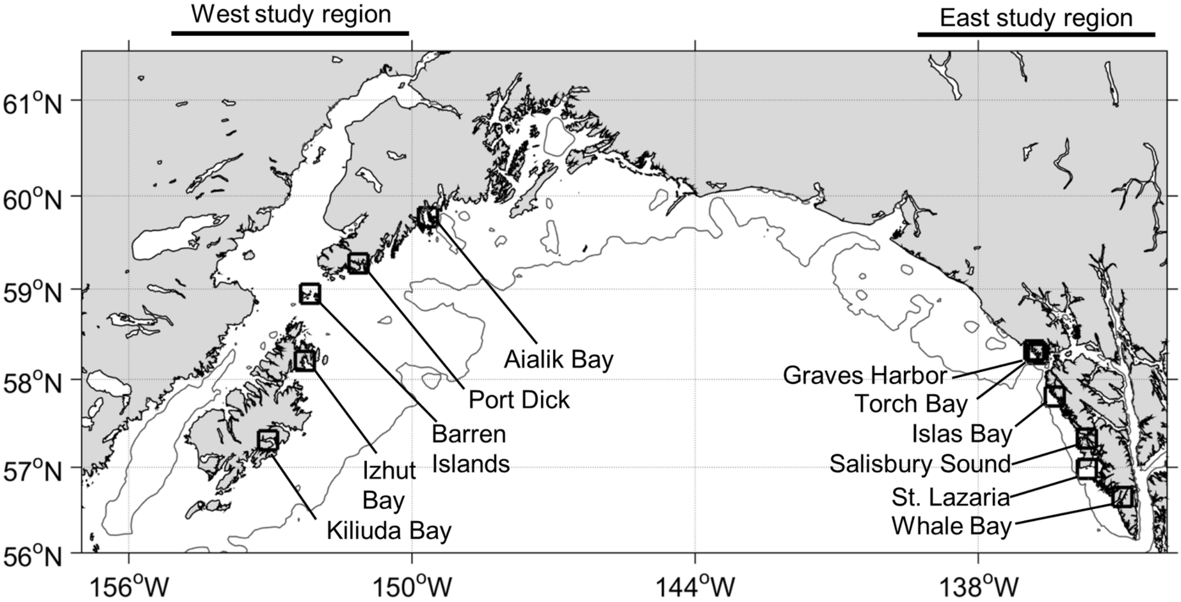
Fig. 5. Fish and zooplankton total water column backscatter is low and less variable in shallow water and increases substantially with water depth. Top panels show a) 38 kHz fish backscatter and b) 120 kHz macrozooplankton from the larger vessel used to survey inshore areas. Bottom panels show shallow-water backscatter recorded in areas adjacent to the shoreline with the skiff c) 38 kHz fish backscatter and d) 200 kHz macrozooplankton backscatter. Box plots summarize the distribution of vertically integrated backscatter for all 100 m along-track observations in a given depth range where > 25 observations were made. The box plots depict the 10th, 25th, 50th, 75th and 90th percentiles of the observations. Note that the y-axis scales for the survey vessel (a-b) are 50 times greater than those of the skiff (c-d).

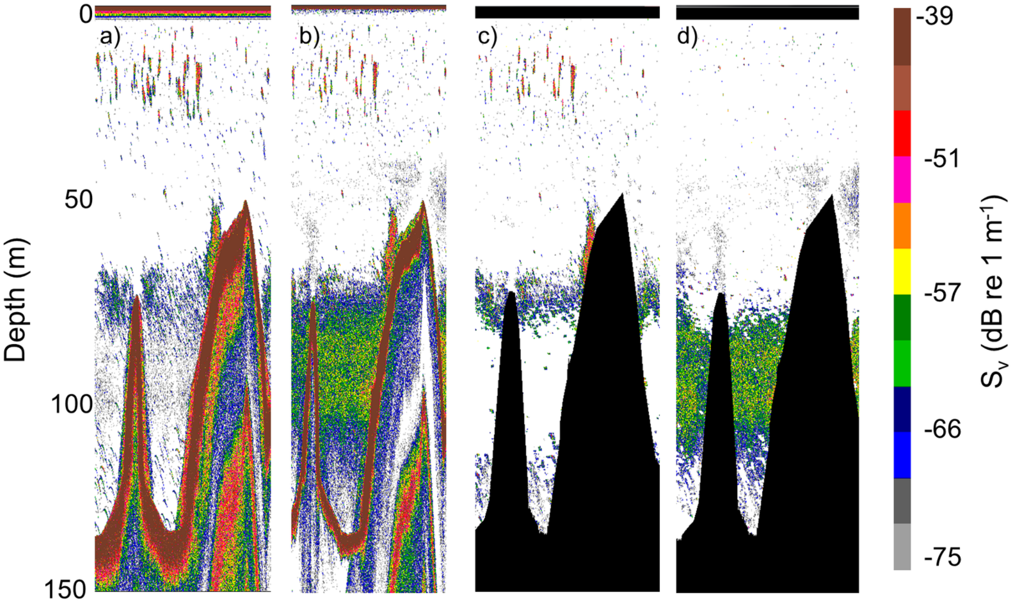
Fig. 6. Site-mean water column acoustic backscatter classified as a) fish and b) macrozooplankton plotted against to the average depth from all observations each time a given site was surveyed. A least-squares line is fit to the data points, and the correlation coefficient and the p-value for the hypothesis test of no correlation is given.

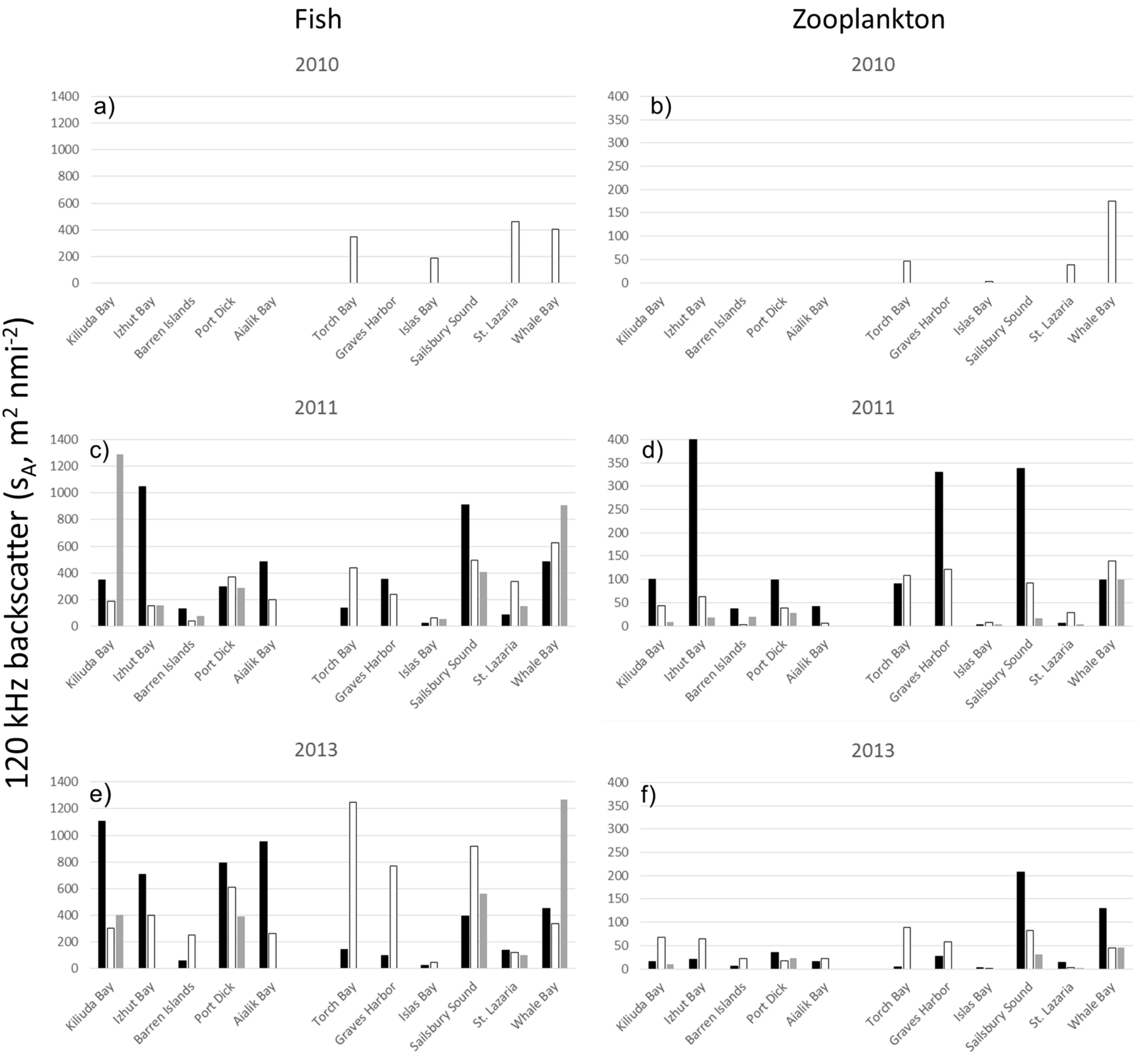
Fig. 7. Volume backscatter increases substantially with depth, indicating that acoustic backscatter from both a) fish and b) macrozooplankton is low in shallow water, and increases at greater depths (all survey vessel observations pooled). In both cases, backscatter is low and less variable at depths < 80 m. The box plots depict the 10th, 25th, 50th, 75th and 90th percentiles of all 120 kHz observations.

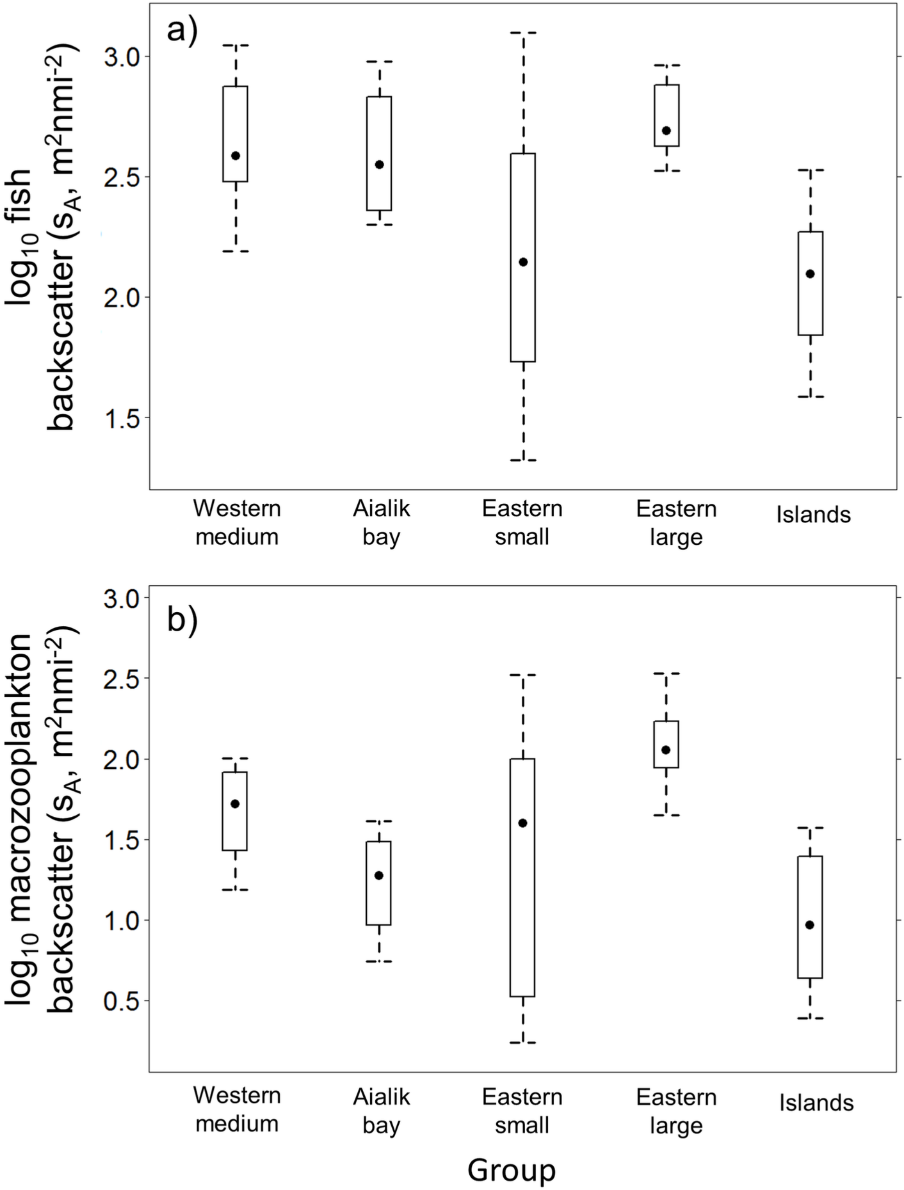
Fig. 8. Effects of explanatory variables on transect-mean water column fish acoustic backscatter resulting from the best-fitting generalized additive model. The significant effects in the best-fitting model were a) depth, b) year, c) site, and d) season (see Table 4). The symbols are the partial residuals (i.e. the residuals after removing the mean effects of the other covariates) for each data point. The units of the y-axis are the additive effect on $\log_{10}(s_A+0.1)$; that is, a 1 unit change reflects a 10-fold change in acoustic backscatter. Factor coefficients determined to be significant ($p < 0.05$) are indicated with an asterisk.

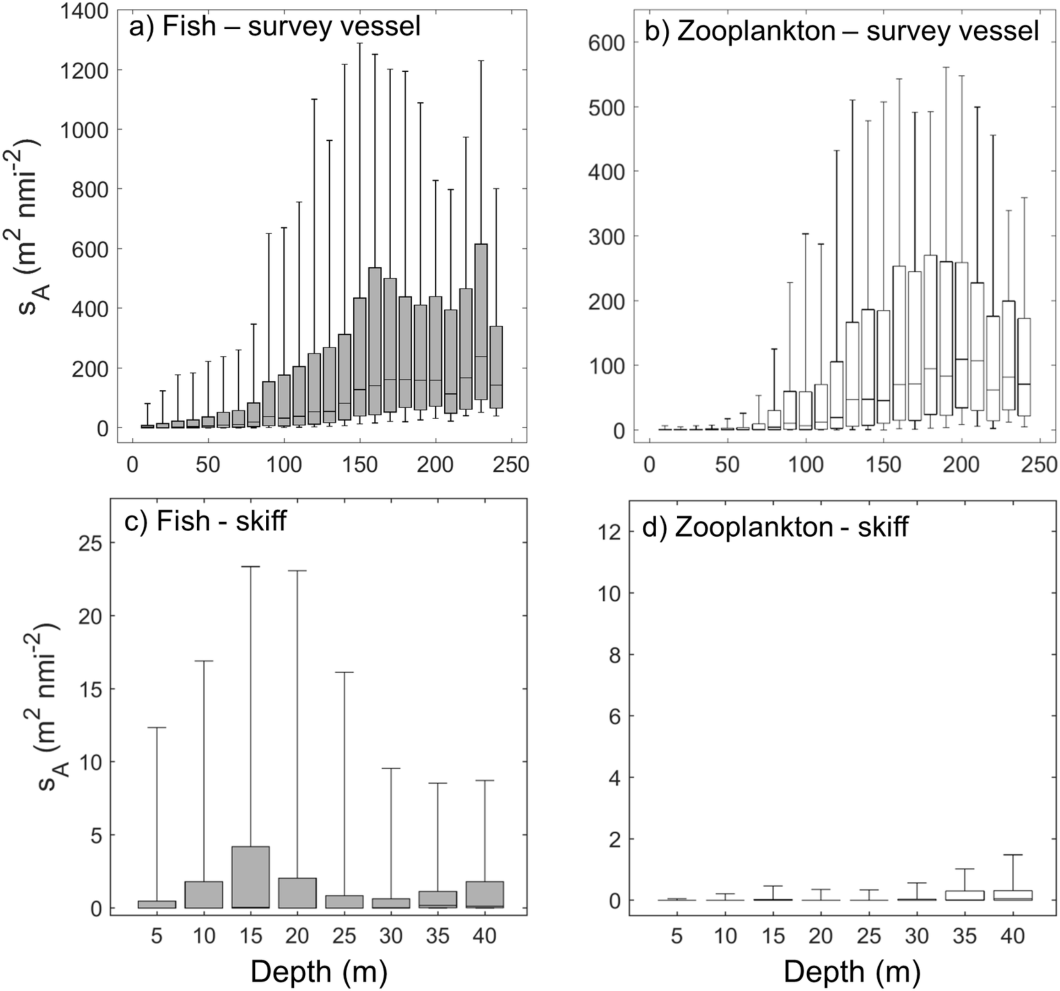
Fig. 9. Effects of explanatory variables on transect-mean water column macrozooplankton acoustic backscatter resulting from the best-fitting generalized additive model. The significant effects in the best-fitting model were a) depth, b) year, c) site, and d) season (see Table 4). The symbols are the partial residuals (i.e. the residuals after removing the mean effects of the other covariates) for each data point. The units of the y-axis are the additive effect on $\log_{10}(s_A+0.1)$; that is, a 1 unit change reflects a 10-fold change in acoustic backscatter. Factor coefficients determined to be significant ($p < 0.05$) are indicated with an asterisk.

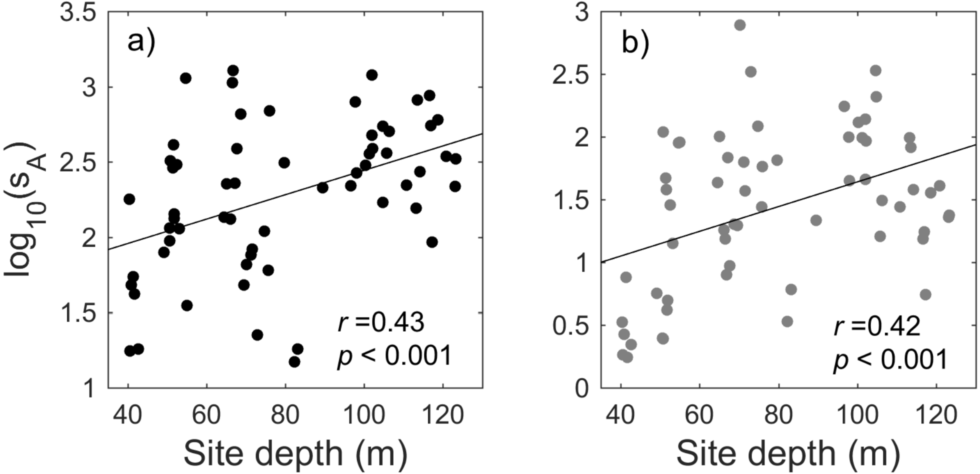

West study region
East study region
61°N
60°N
59°N
58°N
57°N
56°N
156°W
150°W
144°W
138°W
Aialik Bay
Port Dick
Barren Islands
Izhut Bay
Kiliuda Bay
Graves Harbor
Torch Bay
Islas Bay
Salisbury Sound
St. Lazaria
Whale Bay

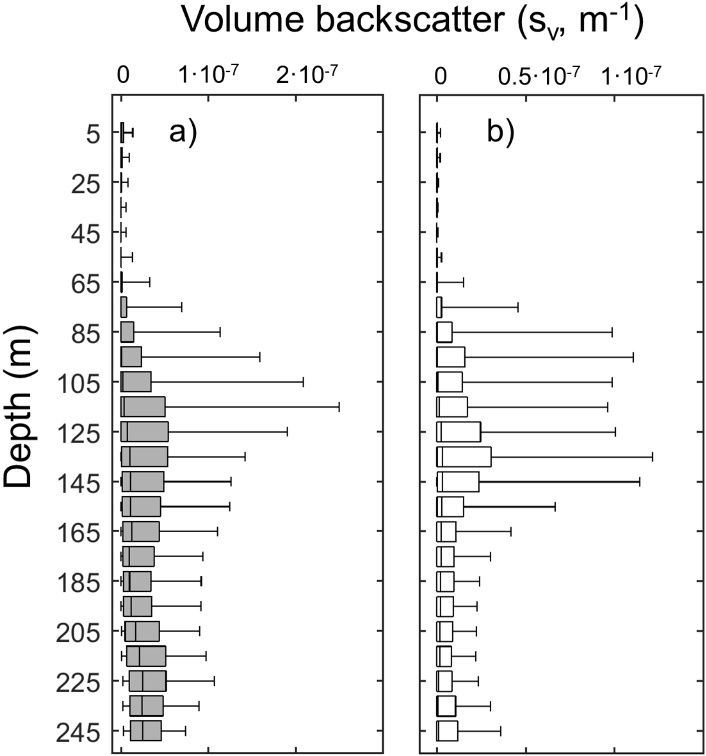

0
50
100
150
Depth (m)
a)
b)
c)
d)
-39
-51
-57
-66
-75
S_v (dB re 1 m^{-1})

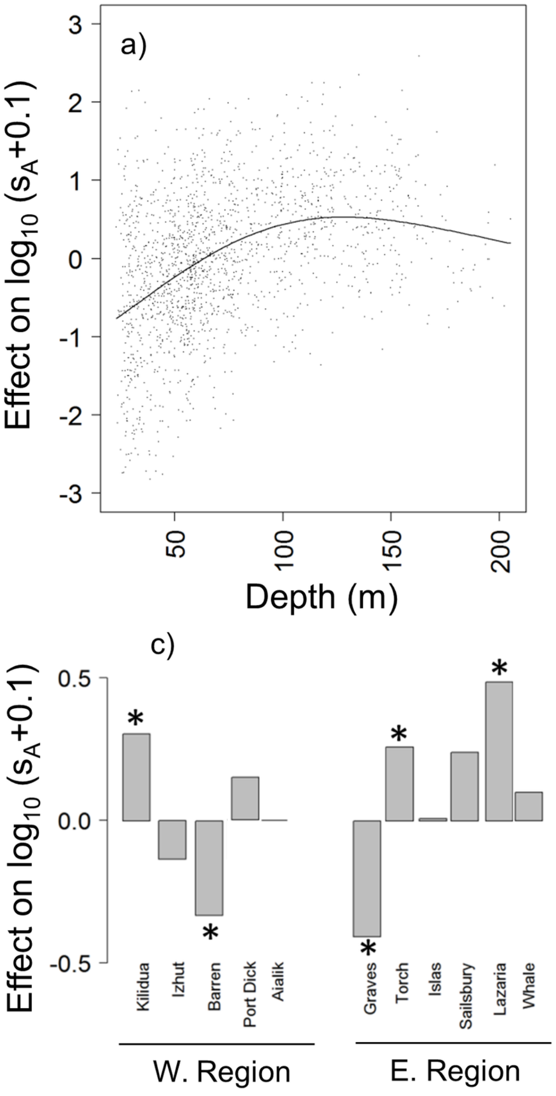

Fish
Zooplankton
120 kHz backscatter (s_A, m^2 nmi^{-2})
2010
a)
b)
2011
c)
d)
2013
e)
f)
0
200
400
600
800
1000
1200
1400
0
50
100
150
200
250
300
350
400
Kiliuda Bay
Izhut Bay
Barren Islands
Port Dick
Aialik Bay
Torch Bay
Graves Harbor
Islas Bay
Sailsbury Sound
St. Lazaria
Whale Bay

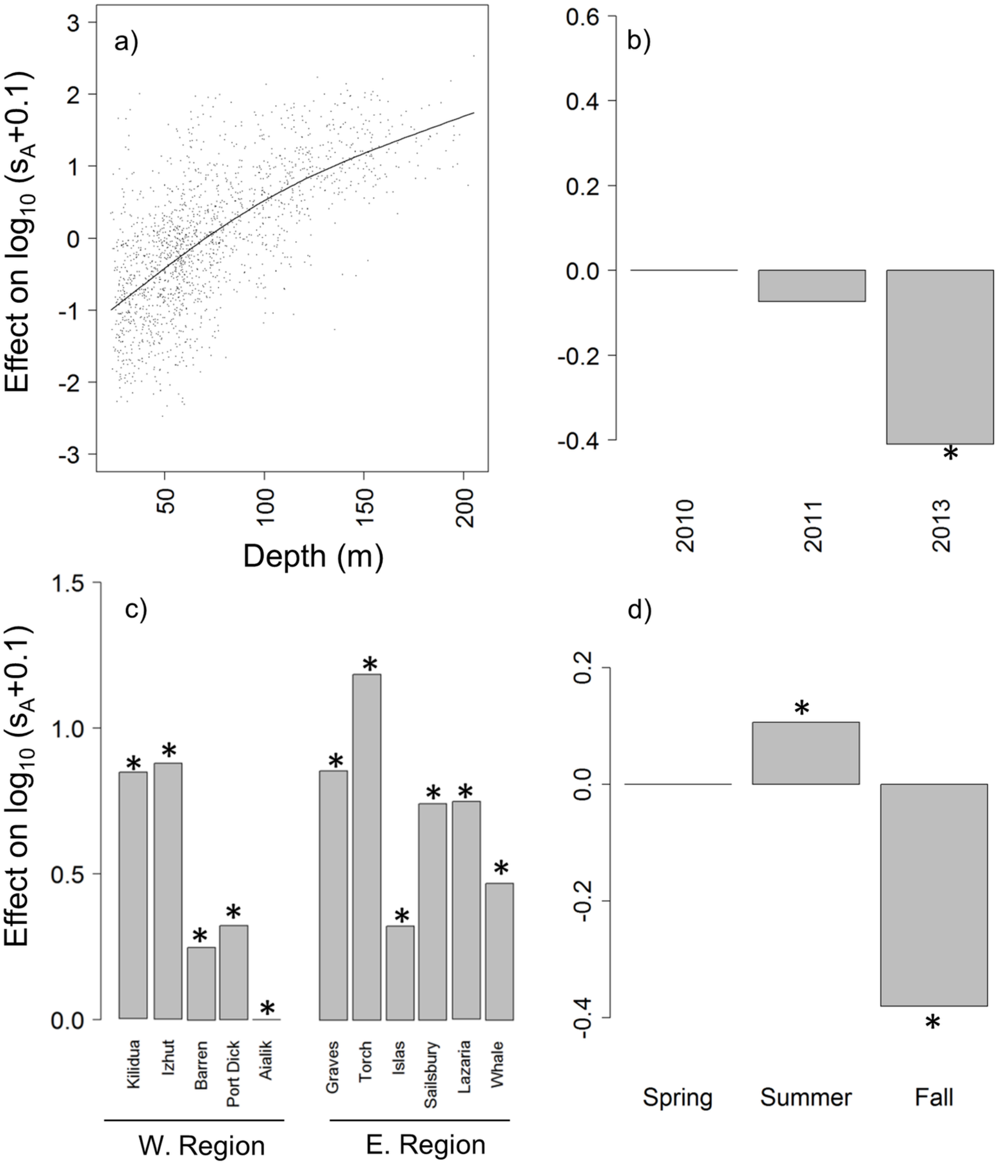

a)
$\log_{10}$ fish backscatter (s_A, m^2nmi^{-2})
3.0
2.5
2.0
1.5
Western medium
Aialik bay
Eastern small
Eastern large
Islands
b)
$\log_{10}$ macrozooplankton backscatter (s_A, m^2nmi^{-2})
3.0
2.5
2.0
1.5
1.0
0.5
Western medium
Aialik bay
Eastern small
Eastern large
Islands
Group


a) Fish – survey vessel
b) Zooplankton – survey vessel
c) Fish - skiff
d) Zooplankton - skiff
s_A (m^2 nmi^{-2})
s_A (m^2 nmi^{-2})
1400
1200
1000
800
600
400
200
0
600
500
400
300
200
100
0
0
50
100
150
200
250
0
50
100
150
200
250
25
20
15
10
5
0
12
10
8
6
4
2
0
5
10
15
20
25
30
35
40
5
10
15
20
25
30
35
40
Depth (m)
Depth (m)


a)
b)
$\log_{10}(s_A)$
Site depth (m)
Site depth (m)
r =0.43
p < 0.001
r =0.42
p < 0.001
3.5
3
2.5
2
1.5
1
0.5
0
40
60
80
100
120


Volume backscatter (s_v, m^{-1})
0
1·10^{-7}
2·10^{-7}
0
0.5·10^{-7}
1·10^{-7}
a)
b)
Depth (m)
5
25
45
65
85
105
125
145
165
185
205
225
245


a)
Effect on $\log_{10}(s_A+0.1)$
3
2
1
0
-1
-2
-3
50
100
150
200
Depth (m)
b)
0.6
0.4
0.2
0.0
-0.2
-0.4
*
2010
2011
2013
c)
Effect on $\log_{10}(s_A+0.1)$
0.5
0.0
-0.5
*
*
*
*
*
Kilidua
Izhut
Barren
Port Dick
Aialik
Graves
Torch
Islas
Sailsbury
Lazaria
Whale
W. Region
E. Region
d)
0.4
0.2
0.0
-0.2
*
*
Spring
Summer
Fall


a)
b)
c)
d)
Effect on $\log_{10}(s_A+0.1)$
Depth (m)
3
2
1
0
-1
-2
-3
50
100
150
200
0.6
0.4
0.2
0.0
-0.2
-0.4
2010
2011
2013
*
1.5
1.0
0.5
0.0
Kilidua
Izhut
Barren
Port Dick
Aialik
Graves
Torch
Islas
Sailsbury
Lazaria
Whale
W. Region
E. Region
0.2
0.0
-0.2
-0.4
Spring
Summer
Fall