The design of a camera-based fisheries-independent survey for untrawlable habitat in the Gulf of Alaska

David R. Bryan[1,2], Kresimir Williams[1], Cecilia O'Leary[1], Christopher N. Rooper[3]

[1]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sandpoint Way N.E. Seattle, WA 98115, USA

[2] Pacific States Marine Fisheries Commission, 205 SE Spokane Street, Suite 100, Portland, OR 97202

[3] Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Rd, Nanaimo, BC V9T 6N7, CA

ABSTRACT

Biomass and size composition estimates from the fishery independent biennial Alaska Fisheries Science Center Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program Gulf of Alaska bottom trawl survey are an integral component of stock assessments and management of fishes in the region. A substantial proportion of the seafloor in the Gulf of Alaska survey area consists of rocky, high-relief habitat that is not accessible to trawl survey gear and is important habitat for many harvested fish species, especially rockfishes (*Sebastes* spp.). Survey estimates of groundfish abundance from trawlable grounds are expanded across the entire region. Therefore, survey abundance estimates could potentially be biased as a result of sampling that does not spatially represent all of the available habitat circumscribed by the Gulf of Alaska study area. Mapping the extent of the untrawlable habitat is a critical step toward understanding the scale of these potential biases and would benefit the design of a future untrawlable habitat survey. Several previous efforts have provided trawlability maps for part or all of the Gulf of Alaska based on different data inputs. In the present work, we compile two previously published untrawlable habitat maps with three other relevant data sources to create a new untrawlable habitat map, and use this map in conjunction with density estimates from existing underwater camera studies to investigate the feasibility of an untrawlable habitat rockfish survey in the Gulf of Alaska. An analysis of 1 km^2 grids sampled more than once with a lowered camera system suggested that a single-stage sampling design (one camera transect per grid) would be most effective. Post-stratification analysis showed that either a simple depth stratification or stratification based on species distribution models provided lower coefficient of variation (CV) values at a given sample size compared to random sampling. Furthermore, a target CV of 25% could be reached for a camera survey of dusky rockfish, northern rockfish, or Pacific ocean perch with less than 200 lowered camera transects if a stratification scheme based on species distribution models was used.

KEY WORDS

Gulf of Alaska, untrawlable habitat, survey design, stereo-camera, species distribution model, rockfish

INTRODUCTION

The biennial Alaska Fisheries Science Center (AFSC) Resource Assessment and Convservation Engineering Division's (RACE) Groundfish Assessment Program (GAP) Gulf of Alaska (GOA) bottom trawl survey (hereafter BTS) provides a critical fishery-independent estimate of groundfish abundance for fishery management (von Szalay and Raring 2016). This survey follows a stratified random design where biomass estimates for each species are calculated using area-swept density from trawl samples that are expanded across the entire stratum (Wakabayashi et al. 1985). However, due to the risk of gear damage or loss, the survey trawl gear used in BTS is fished to avoid sampling rocky, high-relief habitats, which are the preferred habitat of many commercially important fishes like rockfishes (*Sebastes* spp.) (Yoklavich et al. 2000). These untrawlable areas comprise approximately 18% of the BTS survey domain and are often targeted by the commercial rockfish fishery (Clausen and Heifetz 2002) (Figure 1).

Rockfish abundance estimates from the BTS may be biased if there are differences in density between trawlable and untrawlable habitat. For example, if a species has an affinity for untrawlable habitat, than the expanded BTS estimates from trawlable habitats may not accurately track changes in rockfish relative population size and length composition over time. This is especially true when there is a significant amount of fishing in areas that are considered untrawlable by the survey, since targeted fishing may cause the abundance to decline in rocky habitats while in trawlable areas there may be no detectible change in abundance (Cordue 2007). In addition, these un-surveyed areas may support different species assemblages (Matthews and Richards 1991, Jagielo et al. 2003, Zimmermann 2003), size classes (Stein et al. 1992, O'Connell and Carlile 1993, Rooper et al. 2007), and densities (Jones et al. 2021) relative to surveyed areas. Thus, monitoring fish abundance and population structure in untrawlable areas is important for providing more comprehensive estimates of rockfish populations in the GOA and other Alaskan ecosystems. Rockfishes associated with untrawlable habitat of particular interest from a commercial and management standpoint in Alaska include dusky rockfish (*Sebastes ciliatus*), harlequin rockfish (*S. variegatus*), northern rockfish (*S. polyspinis*), and Pacific ocean perch (POP) (*S. alutus*) (Fina 2007).

The distributions of demersal and semi-demersal rockfishes are strongly driven by habitat preference, and the cost-effectiveness of sampling can typically be improved with habitat-based stratification (O'Connell and Carlile 1993, Ault et al. 1999, Yoklavich et al. 2007, Smith et al. 2011, Xu et al. 2015). Recently, several projects have focused on defining untrawlable habitat in the GOA with the aim of eventually producing GOA-wide estimates of the amount of untrawlable habitat. In these studies, habitat classification has been explored using several methods, including single beam acoustics (von Szalay and Somerton 2017), multibeam acoustics (Weber et al. 2013, Pirtle et al. 2015), and modeling bathymetry data (Zimmermann and Prescott 2015, Baker et al. 2019). These different approaches provide predictions that may not be directly comparable or compatible. Each of these studies, with the exception of the Baker et al. (2019), covers only a portion of the GOA survey area, and some of these areas are non-overlapping. To date, the results from these studies have not been consolidated. Here we combine the results to create a new, untrawlable habitat map to investigate the feasibility of an untrawlable habitat survey of rockfish in the GOA.

One of the difficulties in developing a new survey is determining appropriate strata. Sampling of spatially heterogeneous populations, including many rockfishes, is most efficient when a stratified survey design that reflects ecologically meaningful spatial distributions is used. Within untrawlable areas, there can be a wide range of habitat types and physical characteristics that can be highly influential on the occurrence and density of rockfish (O'Connell and Carlile 1993, Yoklavich et al. 2007, Rooper 2008, Rooper et al. 2010, Greene et al. 2011, Jones et al. 2012). Post-stratification analysis, in which estimated variances are compared between different stratification schemes, can be used to evaluate potential survey designs if relevant data are available.

AFSC researchers have spent the last decade developing innovative camera tools and analytic methods that can be used to survey fish in untrawlable habitat (Williams et al. 2010, Jones et al. 2012, Rooper et al. 2012, Williams et al. 2014). These tools include stereo-camera technology, towed and stationary camera platforms, and optic-acoustic survey methodology. Lowered stereo camera (LSC) transects have been conducted throughout the Aleutian Islands in Alaska to investigate the spatial distributions of corals and fishes in a variety of habitat types (Goddard et al. 2017, Bryan et al. 2018) and have been used to estimate rockfish abundance in small, localized study sites, with high concentrations of sampling effort (Rooper et al. 2012). In addition to these projects, LSC transects have been conducted every two years during the AFSC's GOA acoustic-trawl survey (hereafter ATS) (Jones et al. 2021). Data from the LSC transects include size and density estimates of multiple fish species on both trawlable and untrawlable habitat throughout the GOA. These data are ideal for evaluating the feasibility of a LSC survey on untrawlable habitat. Researchers in GAP have also recently produced a detailed bathymetric map of the GOA (Zimmermann and Prescott 2015) and several species distribution models of rockfish abundances in the GOA (Rooney et al. 2018). The production of these two new data products at a GOA-wide spatial scale provides a unique opportunity to investigate new stratification schemes for a LSC survey of fishes over untrawlable habitat.

Overall, the availability of these diverse data sources has provided a unique opportunity to assess the feasibility of conducting region-wide fishery-independent surveys in untrawlable habitat for several important rockfish species. The goal of this research was to evaluate the feasibility of a LSC survey in untrawlable habitat in the Gulf of Alaska. As a first step we combined several existing mapping products, including habitat information from previous LSC transects to create a new untrawlable habitat map with grid cells at a 1 km^2 spatial scale intended for LSC survey. We then divided this sampling frame into two different stratification schemes; one based on depth and a second from existing species distribution models. Data from LSC transects over untrawlable habitat was used to calculated species-specific estimates of density and variance for four rockfish species for each strata within these schemes. This post stratification analysis allowed for a comparison of stratification schemes with a random sample design along with an estimation of the required number of samples needed to achieve a range of confidence intervals for estimates of rockfish abundance for untrawlable habitat in the GOA for each stratification scheme.

METHODS

I. Development of composite untrawlable habitat map

Survey Frame

The first step in developing a composite untrawlable habitat map for the GOA was to create a grid that could accommodate the length of LSC transects and was on a spatial scale similar to the resolution of available trawlable/untrawlable habitat information. The average LSC transect length was 353 m (range 42 to 1132 m), while the types of data used to create the new composite untrawlable habitat map had spatial scales that ranged from 6 m^2 to 25 km^2 with a majority comprised of 100 m^2 grid cells. A 1 km^2 grid would be large enough encompass the length of most transects, and small enough that a single LSC transect might be expected to accurately represent the density of rockfishes in the grid cell. Furthermore, a 1 km2 grid was a reasonable compromise among the spatial scales (6 m^2 to 25 km^2) of the existing untrawlable habitat maps. Thus, we decided that a 1 km^2 grid was most appropriate for a camera-based survey of untrawlable habitat in the GOA. The grid covered the entire BTS sampling frame from the Islands of Four Mountains (170 W) to Dixon Entrance in southeast Alaska (133 W) at charted depths from 10 to 1000 m (von Szalay and Raring 2016) (Figure 1). A total of 322,134 individual 1 km^2 grid cells were created.

Data Sources

Five data sources were compiled to create the new composite untrawlable habitat map for the GOA. Data from each source was summarized at the 1 km^2 spatial scale through either aggregation or interpolation to create independent layers used to create the composite map. The first layer came from the BTS grid and represents the historical assessment of charter vessel captains of the trawlability of the survey trawl locations. The BTS grid is divided into 5 x 5 km^2 grid cells (25 km^2) that sometimes contain multiple irregularly shaped bathymetric strata (von Szalay and Raring 2018) (Figure 1). Prior to the survey, a stratified random design is used to choose grid cells that will be sampled using the bottom trawl. During the survey, each of these randomly chosen grid cells is examined by the charter vessel captain with their echosounder to determine if a 1.5 km tow with less than 20 m change in depth can be conducted inside the grid cell over trawlable bottom. A two-hour time limit is set for searching, and a minimum of 50% of the tow path needs to be within the grid cell (Stauffer 2004, von Szalay and Raring 2018). Grid cells where a survey tow can be conducted are deemed trawlable. If no suitable tow path is found at the end of 2 hours of searching, that grid cell is deemed untrawlable. Grid cells deemed untrawlable are not included in the allocation process in the subsequent surveys. This process has been in place since 1996. Grid cells that have not been visited are classified as uncertain. Based on historical BTS trawling efforts of the in the GOA, 38% of the grid cells by area have been defined as trawlable, 8% as untrawlable, and 54% have not been assessed (uncertain). We overlaid our 1 km^2 grid on the BTS grid and used the BTS classification under the center of each 1 km^2 grid cell to classify that cell (Figure A1). This layer is referred to hereafter as BTSH (the H signifying the higher 1 km^2 resolution).

The second mapping layer was developed by Pirtle et al. (2015). In this study, metrics derived from a Simrad ME70 multibeam echosounder (Kongsberg, Inc.) were tested for their ability to discriminate between trawlable and untrawlable seafloor types. Using a 6 m^2 grid for the predictions, backscatter strength data in combination with bathymetric position index and seafloor ruggedness explained over 54% of the variation between trawlable and untrawlable seafloor types. A model probability threshold of 0.5 was then used to discriminate between trawlable and untrawlable areas. We used the mean value from all of the 6 m^2 grid cells within our 1 km^2 grid to determine if each grid cell was trawlable or untrawlable. If the mean was ≥ 0.5, the grid cell was classified as trawlable. Data from Pirtle et al. (2015) only covered a small portion of our 1 km^2 grid (7.3%) (Figure A2). This layer is referred to hereafter as ME70.

The third layer was from Baker et al. (2019). They developed maps predicting trawlability from several benthic terrain or oceanographic variables using random forest outputs. They then integrated all individual variable responses and breakpoints to develop an estimate of the cumulative impact of multiple factors. The integrated layer delineated areas unsuitable to bottom trawl surveys as a spatial union of areas that exceed a critical threshold for any individual predictive variable. Their analysis was performed at a 100 m^2 grid cell size. Depth, bathymetric position index (BPI), slope, rugosity, vector ruggedness measure (VRM), and curvature were informative in predicting trawlable areas; current and sediment grade were less informative. If 10% or greater of their 100 m^2 cells within our 1 km^2 grid were predicted as untrawlable, the 1 km^2 grid cell was classified as untrawlable. This low barrier for untrawlable classification was chosen to minimize the loss of any potential untrawlable habitat from the survey frame. In particular, patchy and edge habitat that constitutes a small percentage of a grid cell can still be important for certain species, and the elimination of this habitat from a survey domain could result in bias. This layer included information for the entire survey domain (Figure A4) and is referred to hereafter as BOV.

Data from the LSC transects conducted in 2013, 2015, 2017, and 2019 were used to help determine trawlable/untrawlable thresholds in the fourth layer described below as well as for survey design analysis. These transects were conducted primarily during nighttime as part of the acoustic trawl survey ATS for pelagic fish in the GOA (Jones et al. 2021) (Figure 2). Transect locations were haphazardly selected throughout the central and western GOA as part of a project to quantify fish species observed with acoustic backscatter and to characterize seafloor topographic features and trawlability. Specific sampling locations were chosen from trawlable and untrawlable grid cells that were adjacent to or nearby the position where the vessel ended operations at the end of each day (see Jones et al. 2021 for detailed description). A total of 363 LSC transects were conducted during this period throughout the central and western GOA from 19 m to 255 m bottom depth. During the analysis of these transects, if any image frame within a transect contained substrate (e.g., rocks and boulders) larger than 25 cm in height, the transect was considered to be untrawlable. The presence of benthic fauna, such as corals or sponges, or changes in depths were not considered for the LSC untrawlable classification. If no large substrate were encountered, the transect was considered to have taken place over trawlable substrate (Jones et al. 2021). Any of the 1 km^2 grid cells that contained an untrawlable LSC transect were classified as untrawlable. Likewise, any 1 km^2 grid cell that contained a trawlable LSC transect was classified as trawlable. In 2019, there were multiple transects (2-5) in 40 different 1 km^2 grid cells. If any of those transects was considered to be untrawlable, the grid cell was classified as untrawlable. Overall, 49% of LSC transects (179 out of 363) were conducted over untrawlable habitat. This layer is referred to hereafter as CAM.

The fourth layer consisted of a seafloor rockiness surface that was based on a compilation of rock features and sediment attributes from several data sources (Pirtle et al. 2019, Harris et al. 2022). Their substrate data came from Golden et al. (2016), where estimates of shear stress were derived through empirical relationships with seafloor hardness assessments. Rocky areas were defined as those with substrate greater than 20 cm or hard bottom (shear stress value >1.8). Additional substrate data from compiled bathymetric soundings from NOS smooth sheets were also used (Zimmermann and Benson 2013, Zimmermann and Prescott 2015) along with centroid locations of BTS grid cells in which rocky substrate features were found. These data sources were engineered into a combination 100 m^2 cell resolution raster grid using natural neighbor interpolation to create a continuous surface (1-0) that delineated the rocky to not-rocky habitat for the GOA (Pirtle et al. 2019). The trawlable or untrawlable classification process for this data layer required 2 steps. First, we calculated the mean value of all 100 m^2 grid cells within each of our 1 km^2 grid cells. For each grid cell where a LSC survey had taken place, we searched for a threshold in which agreement between the LSC classification and the mean values from the rocky to not-rocky layer was highest. We found that a 0.85 threshold, in which cells with a value ≥0.85 were classified as untrawlable, had the highest agreement with LSC data. We next reclassified each of the 100 m^2 grid cells as either trawlable or untrawlable based on this threshold. If 10% or greater of these 100 m^2 grid cells within our 1 km^2 grid were predicted as untrawlable, the 1 km^2 grid cell was classified as untrawlable (Figure A3). This layer is referred to hereafter as RNR.

A fifth layer came from Vessel Monitoring Systems (VMS) data collected from 2003-2016. The track lines for all commercial fishing trawl tows targeting flatfish were plotted, assuming that flatfish trawling is not likely to take place in rocky habitats. If one of the 1 km^2 grid cells had 5 or more trawl tows within it, that grid was considered trawlable (Figure A5). No grid cells were classified as untrawlable in this layer. This layer is referred to hereafter as VMS.

The five data layers described above were combined to create the composite untrawlable habitat map at the 1 km^2 resolution. For each layer, untrawlable grid cells were scored as -1, grid cells that were unclassified as 0, and trawlable grid cells as 1. The scores from each layer had equal weighting. Scores from each layer within a grid cell were added to create a composite score for that grid. Grids with a score less than 0 were considered untrawlable, those with a score of 0 as uncertain, and those with a score greater than 0 as trawlable.

II. Density Estimates of Key Species

Camera Data

We used data from LSC transects conducted in 2013, 2015, 2017, and 2019 in the GOA to produce density and variance estimates for four key species: dusky rockfish, harlequin rockfish, northern rockfish, and Pacific ocean perch. These estimates were used to predict the survey effort that would be required to reach target levels of uncertainty in mean abundance across the GOA. Target levels of uncertainty were based on historic coefficient of variation (CV) values estimated from the BTS. There were several upgrades to the stereo camera systems during this time period, but the deployment methodology remained the same (Jones et al. 2021). Each transect was 15 minutes long with a vessel speed close to 1 knot. The goal was to keep the LSC within 1 m of the bottom during the transect. Most transects took place at night when these species were more likely to be near the bottom (Brodeur 2001, Rooper et al. 2010). The still images collected by the LSC were reviewed with AFSC's SEBASTES software (Williams et al. 2016). All fish that were encountered along the transect were recorded, and care was taken to avoid double counting fish by tracking each fish through all frames in which it was visible. Primary and secondary substrate information was also recorded.

Density Calculations

Density per transect was calculated by dividing the total number of fish observed on a transect by the area swept. The area swept was calculated by multiplying the visual swath by the distance covered. The equation for calculating swath can be found in Rooper et al. (2016) and considers the field of view of both cameras. The distance covered was calculated by multiplying the transect distance (great circle distance between the position of first view of the seafloor to the position when the LSC retrieval was initiated) by the proportion of image frames in which the seafloor was clearly visible. In 2019, multiple LSC transects were conducted in 40 of the 1 km^2 grids. For these data, individual species density per transect was calculated, and a weighted mean density per species based on area swept was calculated from all transects within that grid. The weighted mean density from grids sampled more than once in 2019 was treated as a single transect for subsequent survey design and sample size estimation calculations. Mean density and variance were estimated for each species for each year, for all years combined, for all years combined grouped by depth category (see below), and for all years combined grouped by species-specific essential fish habitat (EFH) score (see below). Species and length-specific selectivity of LSC transects in the form of either attraction or avoidance has not been well studied, so density estimates presented here should be considered in that light.

III. Untrawlable Habitat Survey Design and Sample Size Estimations

Selecting a stratification scheme

Two stratification schemes were compared with a simple random design in which the transect densities were pooled across locations for a single density estimate for each species. The first stratification scheme was based on bottom depth. The average depth for each grid cell was calculated from the Zimmermann and Prescott (2015) 100 m resolution bathymetric map of the GOA. Each grid was then classified as either shallow (< 100 m depth) or deep (> 100 m and < 300 m depth) (Figure A5). This cutoff depth (100 m) was chosen based on previous research on the four rockfish species of interest that indicated these species were most likely to be abundant at shelf break depths > 100 m (Rooper 2008).

The second stratification scheme was based on the predicted abundances for each of the four rockfish species used to create essential fish habitat (EFH) maps (Rooney et al. 2018). A generalized additive model (GAM) was used to predict the abundance and distribution of Pacific ocean perch, and a hurdle model (hGAM) was used for dusky, harlequin, and northern rockfish predictions (Rooney et al. 2018). Each model relied on fish abundance data collected during the summer BTS (1993-2013) and incorporated oceanographic (ocean current and temperature from the regional ocean modeling system (ROMS)), bathymetric (slope and depth from Zimmermann and Prescott (2015)), and biogenic habitat-related variables (occurrence of structure-forming invertebrates modeled from the BTS catch with methods from Rooper et al. (2016)). The maps of predicted abundance used for this study were constructed by Rooney et al. (2018) at the 1 km^2 scale with the same extent as the composite trawlable/untrawlable habitat map. Each grid cell was scored with the relative abundance of each species on a range from 0 to 5, with 0 indicating no abundance and 5 indicating the highest predicted abundance per grid cell across the map. Although the maps were developed from BTS data that did not include untrawlable habitat, they provided the best available estimate of regional patterns in abundance.

Optimal number of samples per grid cell

In 2019, forty 1 km^2 grid cells were sampled more than once by the LSC. Of these grid cells, 121 transects were conducted within 21 unique grid cells that were classified as untrawlable. The sampling frequency ranged from 2-5 transects per grid cell. The replicated transects were selected by computing a set of uniform random offsets bounded by 0.5 km intervals to either side of a line through the grid cell center for the transect starting point while maintaining the same transect heading, resulting in a set of randomly spaced parallel transects (Figure 3). We used Cochran (1977) equation for m* (overall sample standard deviation) to determine the optimal number of samples that should be drawn from each grid cell:

$$m^* = \frac{\sqrt{s_2^2}}{s_u} \quad (1)$$

s_2^2 is the sample variance within each grid cell (equation 2) and s_u is the overall sample standard deviation (equation 3).

$$s_2^2 = \frac{1}{n}\sum_i \left[\frac{\sum\left(D_{ij} - \bar{D}_i\right)^2}{m_i - 1}\right] \quad (2)$$

n is the total number of transects, D_{ij} is the density in transect j in grid cell i, $\bar{D}_i$ is the mean density (individuals/ha) in grid cell i, and m_i is the number of transects in grid cell i.

$$s_u = \sqrt{s_1^2 - \frac{s_2^2}{M}} \quad (3)$$

$$s_1^2 = \frac{\sum_i\left(\bar{D}_i - \bar{\bar{D}}_{2019}\right)^2}{n-1} \quad (4)$$

s_1^2 is the sample variance among grid cells. M is the total number of possible non-overlapping samples in a grid cell, which, based on the mean area swept in 2019, equaled 627. $\bar{\bar{D}}_{2019}$ is the mean density for all transects in year 2019.

To test whether multiple transects were needed per grid cell we compared the variance within grid cells to the variance among grid cells. If the ratio of the sample standard deviation within grid cells compared to the overall sample standard deviation (m*) is greater than one, then there is a larger variation in the abundance counts within a grid cell than across grid cells. In this situation, more than one sample (i.e., transect) can be taken from within each grid cell to lower the variance of the overall abundance estimate.

Survey Design Comparisons

Data from the LSC transects were used to conduct post-stratification analysis to compare a simple random survey design to a depth and EFH stratification scheme (Pfeffermann and Rao

2009). Species-specific survey design comparisons were based on the number of samples estimated to meet a range of coefficient of variation (CV) values for a GOA-wide untrawlable habitat survey (Bryan et al. 2016). The CV was defined as the ratio of the standard error to the GOA-wide mean density for a stratified random survey ($\bar{\bar{D}}_{st}$) (equation 5).

$$CV\left[\bar{\bar{D}}_{st}\right] = \frac{SE\left[\bar{\bar{D}}_{st}\right]}{\bar{\bar{D}}_{st}} \quad (5)$$

The GOA-wide mean density for a stratified random survey was the area-weighted mean of all stratum densities (equation 6).

$$\bar{\bar{D}}_{st} = \sum_h w_h \bar{\bar{D}}_h \quad (6)$$

$$\bar{\bar{D}}_h = \frac{1}{n_h} \sum_i \bar{D}_{hi} \quad (7)$$

Where w_h was the stratum weighting factor and $\bar{\bar{D}}_h$ was the mean density (individuals per ha) in stratum h (equation 7). n_h was the number of transects in stratum h and $\bar{D}_{hi}$ was the density of transect i in stratum h.

The relationship between CV and sample size was estimated using standard sampling theory and data from LSC transects (Cochran 1977). Sample size to CV relationships were developed separately for the four rockfish species of interest. The initial target CV for a GOA-wide survey of untrawlable areas was 25% because it is the typical lower CV bound for dusky (CV ~0.2 – 0.5) and northern (CV ~0.3 – 0.6) rockfish bottom trawl estimates (Heifetz et al. 2009).

Sample size projections needed to reach the desired variance for a simple random and stratified random sampling designs were calculated based on the performance measure, n^* (Cochran 1977):

$$n^* = \frac{\left(\sum_h w_h s_h\right)^2}{V\left(\bar{\bar{D}}_{st}\right) + \frac{1}{N} \sum_h w_h s_h^2} \quad (8)$$

Where s_h was the sample standard deviation (equation 3) and s_h^2 was variance of density in stratum h (equation 9), w_h was the stratum weighting factor, $V\left(\bar{\bar{D}}_{st}\right)$ was the desired variance for the domain-wide mean density for a stratified random survey ($\bar{\bar{D}}_{st}$) (equation 6), and *N* was the total number of possible sample units in the survey frame (37,519 untrawlable grid cells).

$$s_h^2 = \frac{\sum_i \left(\bar{D}_{hi} - \bar{\bar{D}}_h\right)^2}{n_h - 1} \quad (9)$$

Only untrawlable grid cells based on the composite trawlable/untrawlable habitat map with a mean depth less than 300 m were included in the survey frame. This depth limit focuses the survey effort on shelf habitats where the rockfish species of greatest commercial importance are historically found (Brodeur 2001, Clausen and Heifetz 2002, Rooper et al. 2007). All years of camera surveys were used to generate sample size estimates for a camera survey. Estimations of n^* assume that sampling effort will be allocated among strata following an optimal Neyman allocation scheme in which stratum variance and the number of grids is taken into consideration.

When the EFH stratification scheme was used for post-stratification analysis, the estimated density and variance of a rockfish population/stock based on LSC transects was zero for 33% of strata. Although it is possible that a particular rockfish species does not occur within those strata, the estimates of zero were more likely due to low abundance and a relatively small LSC sample size. Thus, for the post-stratification analysis, we replaced the stratum density($\bar{D}_h$), standard deviation of density s_h, and the sample variance of density s_h^2 for zero occurrence strata with the estimates from the stratum with the lowest density ($\bar{D}_h$), for that species. This was required to ensure that during the post-stratification analysis a minimum number of samples were projected into each stratum.

RESULTS

I. Development of Composite Untrawlable Habitat Map

In the composite map, 17% of grid cells were classified as untrawlable, 66% as trawlable, and 17% as uncertain (composite score of 0) (Table 1, Figure 4). A majority of the grid cells had data from either 2 layers (46% of grid cells) or 3 layers (43% of grid cells). Overall, the trawlable/untrawlable scores among data layers within a grid cell were the same in 60% of the grid cells. However, the percentage of grid cells showing agreement in classification differed substantially amongst data sources (Figure 5). The VMS layer (which only included trawlable cells) had the highest agreements: 96% with the BTSH layer, 88% with the CAM layer, and 86% with the BOV layer. The CAM layer had 70% agreement with all data sources except BOV in which there was only a 52% agreement. Forty-four percent of the grid cells classified by the BOV layer as trawlable were untrawlable in the CAM layer and 59% of the grid cells that were untrawlable in the BOV layer were classified as trawlable in the CAM layer. The BOV layer also had low agreement (56%) with the ME70 layer.

In the BTSH grid layer, 52% of the grid cells were unclassified (i.e., have not been visited). In the composite map, 17% were classified as uncertain; the scores of trawlable or untrawlable from the various data layers were even within a grid cell (i.e., 2 data layers scored as trawlable, 2 scored as untrawlable, and 2 with no data in that grid). This is a significant improvement over the current BTSH grid. In the BTSH grid, when unclassified grid cells were removed, 18% of the survey domain was considered untrawlable. In the composite untrawlable habitat map, when uncertain grids were removed, 20% of the survey domain was classified as untrawlable. In the BOV layer, 18% of the survey domain was classified as untrawlable. There were some minor differences in the classification of grid cells between the BTSH and the composite untrawlable habitat map; there were disagreements in 4% of the grid cells that had either a trawlable/untrawlable classification. The majority of these disagreements were BTSH trawlable grid cells that were classified as untrawlable in the composite map. Of the unclassified grid cells in the BTSH layer, 55% were classified as trawlable in the composite map and 15% as untrawlable.

II. Density Estimates of Key Species

Of the 363 LSC transects conducted between 2013 and 2019, 179 occurred in untrawlable habitat as defined by the LSC transect data. A total of 5463 fish were observed on this habitat; 32.3% were the four key species used for this analysis, 23.7% were unidentified rockfish, and 6.4% were unidentified fish. The mean density of the key species along these untrawlable transects varied among years, with considerable variance associated with each annual estimate (CV range 28% – 98%) (Figure 6). With all years combined, the mean density on untrawlable substrate was 11% to 175% higher for all key species at depths between 100 and 300 m (deep) compared to depths less than 100 m (shallow), suggesting that a depth stratification could be beneficial in lowering the variance of population estimates. There were also differences in mean density for all species among EFH score-based strata, with generally higher mean densities from LSC transects associated with grids with higher EFH scores (Figure 7).

Optimal number of samples per grid cell

In 2019, the sample variance of mean density was greater among grid cells than within grid cells for all species (Figure 8). The m* value for dusky rockfish was 0.74, 0.63 for harlequin rockfish, 0.57 for northern rockfish and 0.46 for Pacific ocean perch. These values suggest that one sample (i.e., transect) per grid cell is optimal for a LSC survey on untrawlable habitat when the goal is to reduce population estimate CVs.

III. Untrawlable Habitat Survey Design and Sample Size Estimations

CV values for untrawlable habitat abundance estimates from camera data were relatively high when all years were combined (n = 123, dusky – 32%, harlequin – 41%, northern – 30%, and POP – 51%). N* curves suggest that with a simple random design, under 200 LSC transects would be needed to reach a target CV of 25% for dusky (196) and northern rockfish (180), over 300 LSC transects would be needed for harlequin rockfish (324), and over 500 for POP (507) (Table 2, Figure 9 and 10). The depth stratification (shallow (< 100m) and deep (100-200m)) along with an optimal allocation of sample sites could reduce the number of samples needed to reach a target CV (25%) by 35% for dusky, 19% for northern rockfish, and 31% for POP (Table 2, Figure 9 and 10). Harlequin rockfish did not have a large difference in density or variance based on depth, so this stratification scheme did not help improve sampling efficiency. The deep strata comprised 41% of the grids in the sample frame, but the optimal allocation of sites by strata suggested that 84%, 63%, and 85% of sampling effort should be taken within the deep strata for dusky, northern, and POP, respectively.

The stratification scheme based on model-based estimates of EFH reduced estimated sample size estimates for all species, but the gains for harlequin rockfish were minimal; a 4% reduction in estimated sample size. The number of LSC transects estimated to provide an abundance estimate on untrawlable habitat for dusky rockfish was reduced by 41% as compared to a simple random sample design. Northern rockfish estimated sample size was reduced by 46% to reach a target CV, and POP estimated sample size was reduced by 63%. Sampling efficiency was gained by oversampling grid cells with an EFH score of 4 and 5 for those dusky and northern rockfish and grid cells with a score of 5 for harlequin rockfish and Pacific ocean perch.

DISCUSSION

A better understanding of the amount and location of untrawlable habitat in the Gulf of Alaska is paramount for designing and assessing the practicality of a fishery-independent survey of untrawlable habitat. For this study, we combined several data layers to produce a new composite untrawlable habitat map for the Gulf of Alaska at a 1 km^2 scale. In general, there was between 52% to 96% agreement among data sources on where untrawlable habitat exists, but more habitat mapping is needed. Although the results of this study showed 17% of the total area remained unclassified, this is a great improvement over the BTS map where an estimated 52% of GOA is unclassified. Despite some possible limitations of this composite map, we were able to investigate the feasibility of conducting an untrawlable habitat survey with LSCs. We found that the use of either depth or model-based estimates of fish abundance were beneficial in stratifying the survey domain and reduced the number of samples estimated to reach target CVs for 3 out of the 4 considered rockfish species.

I. Development of Composite Untrawlable Habitat Map

The combination of data from different spatial scales required several decisions. These included grid cell size and how to aggregate or downscale data from the various habitat layers to fit within the predetermined grid. First, we considered three factors when choosing the grid cell size; 1) ability to encompass the length of a single LSC transect, 2) small enough so that density estimates from a LSC transect or transects would be representative of the grid, and 3) size compatible with the spatial resolution of untrawlable habitat layers. The BTS surveys in the GOA and Aleutian Islands utilize large grids (25 km^2) to ensure that a successful trawl tow can be conducted within a sample unit. A visual inspection of untrawlable habitat predictions from the RNR and BOV data layers suggested some heterogeneity of trawlable/untrawlable habitat within the 25 km^2 grid used by the BTS in the GOA. Since the area swept of the LSC transects were much smaller than those of a trawl tow, we were able to use a much smaller grid size. A reduced grid cell area should contain more homogenous habitat and thus require fewer samples within each grid cell to obtain a representative sample. The results from our 2019 investigation into the optimal number of LSC transects per grid cell, in which we found that one transect per grid cell was optimal for a 1 km^2 grid cell, supported this theory and supported the use of a 1 km^2 grid size for LSC transects.

Once the grid size was chosen, the next set of decisions involved how to aggregate the finer spatial resolution of habitat data into the 1 km^2 grid cell. For each layer, we decided to average all of the finer resolution data within a grid cell and then set a threshold for the percentage of untrawlable that would be used to classify each grid cell. These thresholds varied depending on the underlying data. In general, we wanted an untrawlable habitat map and sampling frame that would minimize potential biases caused by omitting certain habitats while simultaneously maximizing survey efficiency. From a sampling efficiency standpoint, if a trawlable grid cell is misclassified as untrawlable, there is the potential to lose untrawlable habitat survey samples as the result of a LSC transect being conducted over the wrong habitat. If an untrawlable grid cell is misclassified as trawlable, then this grid cell is dropped from the sampling frame, which can be problematic if there is a bias in the classification process. For example, edge or sparsely patchy rocky habitat that is untrawlable may only constitute a small percentage of total habitat within a grid cell, but likely has a great influence on the abundance of some rockfish (Anderson et al. 2009). If thresholds are set too high, the grid cells that contain this habitat type would be misclassified as trawlable, which could bias abundance estimates. For this reason, we consciously tried to minimize misclassifying untrawlable grid cells as trawlable knowing that we might overestimate untrawlable habitat. For example, all 1 km^2 BTHS grid cells within a 25 km^2 BTS grid cell were given the same classification as the parent cell. BTS grid cells may include a variety of habitats (Jones et al. 2021), and some BTS untrawlable grid cells were classified as untrawlable based on a single tow. It is therefore possible that some of the 25 1 km^2 grid cells on either side of that tow may be trawlable. A more accurate method could be to use the BTS tow paths and their designation as a successful and unsuccessful tow to classify the 1 km^2 grid cell instead of the entire 25 km^2 grid cell. This would lead to more unknown grid cells, but would be more accurate. We also classified a grid cell as untrawlable if 10% of the BOV 100 m^2 grids were classified as untrawlable. Fifty-seven percent of the 1 km^2 BOV grid cells that were classified as untrawlable were comprised of all untrawlable 100 m^2 grid cells. The remainder of the 1 km^2 grid cells had a mixture of trawlable and untrawlable 100 m^2 grid cells within them.

These mixed 100 m^2 grid cells and our method of classification may have been the reason for the large discrepancy (only 52% agreement) between the CAM and the BOV layer. For the ME70 layer, a 0.5 threshold was set based on the probability threshold used for their model to delineate untrawlable from trawlable habitat (Pirtle et al. 2015). A 0.85 threshold was chosen for reclassifying the 100 m^2 grid cells in the RNR layer as trawlable or untrawlable followed by the same 10% cutoff of untrawlable cells within 1 km^2 grid cells as used for the BOV layer. Both the ME70 and RNR layers had high agreement with the LCS data (80% and 70%, respectively) as it was used in either the model fitting process of creating the layer (ME70 layer) or used directly to set thresholds (RNR layer).

The composite untrawlable habitat map was primarily created to allow us to evaluate the feasibility of a fishery-independent LCS survey and should not be considered static. Instead, the map can be updated when new data sources become available, and thresholds can be revisited for existing layers. We chose equal weighting for each data layer; however, using the inverse of the variance associated with each layer might be more appropriate. The variance for each layer is currently unavailable and would be an interesting challenge for future research. Some of the layers were dependent upon the same underlying data (i.e., bathymetry, BTS surveys, or LSC surveys) and thus are not 100% independent. Although we believe there were enough differences in the methods used to create each layer to warrant their use as separate layers, this choice could be revisited. Our method for combining layers meant that those with a larger spatial coverage had a greater influence on the overall composite untrawlable habitat map. However, we believe that the layers with smaller spatial coverage are still informative and useful to include, based on the higher resolution of the trawlability designations that were possible with these methods.

For this study, we restricted the survey domain to only untrawlable habitat (as predicted in the composite untrawlable habitat map) and depths less than 300 m. All of our data from the LSC transects came from depths less than 300 m, and the range of the four rockfish species is also typically shallower than 300 m (Clausen and Heifetz 2002). This restricted survey domain (untrawlable and shallower than 300 m) was 13% of the area included in the BTS. New LSC systems have deeper ratings and as new LSC data are collected, the max depth of the survey domain could be expanded.

II. Density Estimates of Key Species

We combined 4 years of data (2013, 2015, 2017, and 2019) to increase the sample size for making projections on the sampling effort required to reach a target CV, but there was significant variability in annual density estimates from LSC transect data. These rockfish are generally long-lived with a low natural mortality rate, and though it is difficult to discern, this variability may be more reflective of our low sample size than a change in abundance. However, by combining years, we have assumed that there has been no underlying population change. If a historical change in abundance occurred, for example harlequin rockfish or Pacific ocean perch abundance declined, the number of samples needed to provide abundance estimates may have also changed. Thus, the estimates presented here for predicted CVs and sample sizes are dynamic and should be revisited with new data prior to initiation of a new survey.

The LSC density data used for analysis was collected at night. Previous research in the GOA (Jones et al. 2012, Jones et al. 2021) found no significant difference in total rockfish backscatter and the heights of backscatter between day and night over rocky habitat, however, in the Bering Sea diel patterns for both POP and northern rockfish have been observed, with rockfish nearer to the seafloor during nighttime hours (Brodeur et al. 2001, Rooper et al. 2010). Species-specific diel movement patterns for the rockfish analyzed here are generally not well known. Any diel change in density would affect the estimates provided if a LSC survey was to take place during the daytime.

Species identification for the pelagic shelf rockfish complex examined here can be difficult using image data alone. Since physical specimens are not collected, reviewers can only use external cues such as color patterns and body shapes to make proper species identification. Even with recently published guides to underwater identification (Butler et al. 2012), this can be challenging; 24% of fish observed during LSC transects could only be classified as rockfish unidentified. The four species chosen for this analysis are relatively easy to identify compared to other rockfish species, but it is likely that many were not classified to species, and thus reported densities are lower than the actual density. With ongoing improvements in cameras and lighting it is possible that the number of unidentified species can be reduced. Future work should consider conducting double reads of images to minimize potential reader bias.

III. Untrawlable Habitat Survey Design and Sample Size Estimations

Both a two-depth stratification and a post-stratification based on the distribution models of fish abundance would improve the precision of abundance estimates for untrawlable habitat based on LSCs. The depth-based post-stratification was best for dusky rockfish, while the modeled abundance (EFH) stratification worked best for the other species. Overall, there were minimal differences (<5%) in the estimated number of samples to reach a target CV of 25% for harlequin rockfish between stratified and simple random designs. Harlequin rockfish are generally less abundant in the GOA than the other species examined here, and they also have a stronger affinity to untrawlable habitat (Jones et al. 2021). Of the species examined, they are also less likely to be observed in large schools (Rooper, unpublished data).

Model-based abundance estimates for northern rockfish and Pacific ocean perch correlated well with LSC density estimates within the 1 km^2 grids (Figure 6). This correlation meant that EFH maps of modeled abundance were ideal for post stratifying the survey domain for these two species and resulted in a significant reduction in the predicted sampling effort required to reach a target CV. This reduction in predicted sampling effort was possible by oversampling (compared to proportional) predicted high abundance grids.

The use of species distribution models for optimizing survey stratification has not been widely used to date, but clearly could be advantageous (Peterman et al. 2013). Here the model-based estimates of abundance were based on a different data set than the LSC data used for actual density and variance estimates, but as more LSC data are collected, they could be incorporated into species distribution models. An iterative process where each year species distribution models are updated, post-stratification analysis is conducted, and sampling allocation is revised would likely either lower sample size requirements for target CVs or reduce the variance around abundance estimates if the effort remained the same. This multi-level framework, including the creation and assessment of species distribution models and optimization of sampling, could be beneficial for management (Neto et al. 2020), and we envision it would work well in the GOA.

Understanding changes in rockfish abundance over time in untrawlable habitat is critical to supporting their assessment in population models. The definition of untrawlable habitat in the BTS differs from the definition for commercial fishers. Commercial fisheries in GOA use larger and more robust gear than the current BTS trawl net and are capable of capturing rockfish from rougher habitats. If the movement of rockfish between trawlable and untrawlable habitat is limited, this mismatch in the spatial coverage of trawl hauls means that the survey is likely sampling a different portion of the rockfish population than is captured by the commercial fishing gear. Given the affinity of rockfish for rocky habitat, the BTS may not accurately track rockfish populations, potentially introducing bias into stock assessment population estimates and management reference points. For example, if the population of rockfish is increasing overall, yet the number of fish inhabiting trawlable habitat is stable due to their habitat preferences, then the BTS would likely perceive no increase in the stock size. Conversely, the opposite effect could occur if rockfish are disproportionately harvested from untrawlable habitats. Thus, tracking the temporal trend in the rockfish stocks in the GOA requires sampling the entire population in both trawlable and untrawlable habitats (Cordue 2007).

In our post-stratification analysis, we assumed Neyman optimal allocation of samples for each species. Furthermore, EFH maps for each species were used for post-stratification analysis. In practice, a fishery-independent LSC survey on untrawlable habitat would be based on a single sampling frame (map), and sampling allocation would need to be based on multiple species. Optimizing LSC transect surveys for untrawlable habitat would likely require prioritizing species for which precise estimates are most important. For example, in the BTS, sampling allocation is based on a Neyman allocation across ~20 species of groundfish with sampling weights applied according stratum area, to ex-vessel value from the most recent BTS year (Oyafuso et al. 2022). In Florida and the U.S. Caribbean, multispecies fishery-independent surveys are optimized based on the density and variance of a few ecologically and economically important species that represent a range of life history strategies (Smith et al. 2011, Bryan et al. 2016). The inclusion of multiple species in the survey design improves community-level estimates at the cost of higher variance for some individual species. To account for possible changes in fish density, the allocation of sampling effort is reassessed prior to each survey to incorporate the data from the previous survey.

Selectivity of Cameras

Surveys of untrawlable habitat require innovative instrumentation and methods to provide species and size-specific abundance estimates that can be used in a similar manner as the BTS in stock assessment models. All survey gears are likely to elicit some level of behavioral response that may differ by species (e.g., avoidance or attraction) or be unable to accurately sample the entire extent of the species distribution (e.g., vertical distribution in the water column). At the beginning of a potential new survey time series using LSC technology, it is critical to identify and quantify potential biases resulting from LSC transects, and provide estimates that are as close to the true abundance as possible. Selectivity of camera systems is a topic of ongoing research at NOAA in order to operationalize visual surveys for groundfish in the USA (Somerton et al. 2017, Stimpert et al. 2019, Campbell et al. 2021).We encourage future research into the assessment of fish behavior responses to moving camera systems and methods for incorporating that knowledge into density estimates. This work could help improve the accuracy of camera surveys and allow for their incorporation into the stock assessment process.

CONCLUSION

The relatively large amount of untrawlable habitat in the GOA (17% as predicted by the composite map) and potential differences in estimates of size-structured abundance of species between trawlable and untrawlable habitats highlight the importance of investigating the feasibility of a fisheries-independent survey over untrawlable habitat. Our new composite untrawlable habitat map and the density data collected for four rockfish species during several years of LSC transects provided a unique opportunity to examine the possibility of conducting a untrawlable habitat survey. Post-stratification analysis suggested that the use of species distribution models to stratify the GOA could lead to abundance estimates with CV values less than 25% for 3 rockfish species with sample sizes less than 200. These estimates were for surveys optimized for a single species but generally show that a GOA-wide LSC survey of untrawlable habitat is possible. Continued research on optimizing multispecies surveys, along with potential improvements in distribution models, including incorporating LSC data could lead to further reductions in sample size requirements.

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TABLES

Table 1. The percentage of grids (322,134) classified as either trawlable, untrawlable, or uncertain for five data layers and the composite untrawlable habitat map. Data layers were derived from: BTHS – Alaska Fisheries Science Center’s Gulf of Alaska bottom trawl survey map, ME70 – multibeam ecosounder data (Pirtle et al. 2015), RNR– a model derived substrate predictor (Pirtle et al. InPress), BOV- trawlability model based on benthic terrain and oceanic variables (Baker et al. 2019), VMS – commercial fish locations for flatfish hauls.

Layer	**Trawlable**	**Untrawlable**	**Uncertain**
BTSH	40%	9%	52%
RNR	59%	34%	7%
BOV	77%	23%	0%
ME70	4%	3%	93%
VMS	6%	0%	94%
Composite	66%	17%	17%

Table 2. Estimated total number of samples (i.e., LSC transects) and optimal allocation of sample effort within strata required to reach a target CV of 25% for each post-stratification scheme that was considered.

Scheme	Strata	Dusky Rockfish	Harlequin Rockfish	Northern Rockfish	Pacific Ocean Perch
Simple Random	All	196	324	180	507
Stratified Random - Depth	Deep	108	141	90	303
Stratified Random - Depth	Shallow	20	165	54	52
Stratified Random - Depth	All	128	306	144	355
Stratified Random – EFH	0	72	238	42	3
Stratified Random – EFH	1	1	1	1	1
Stratified Random – EFH	2	4	9	2	1
Stratified Random – EFH	3	4	1	2	2
Stratified Random – EFH	4	26	1	12	10
Stratified Random – EFH	5	10	60	31	172
Stratified Random – EFH	All	117	310	90	189

Table 3. Total number of possible grid cells for each strata. The number and location of EFH grid cells are different for each species as they are based on individual species distribution models.

Scheme	Strata	Dusky Rockfish	Harlequin Rockfish	Northern Rockfish	Pacific Ocean Perch
Simple Random	All	37824	37824	37824	37824
Stratified Random - Depth	Deep	15426	15426	15426	15426
Stratified Random - Depth	Shallow	22398	22398	22398	22398
Stratified Random - Depth	All	37824	37824	37824	37824
Stratified Random – EFH	0	29956	27794	30076	9703
Stratified Random – EFH	1	613	764	287	1247
Stratified Random – EFH	2	1699	1857	1368	4903
Stratified Random – EFH	3	1803	1678	1578	7017
Stratified Random – EFH	4	1421	2731	1275	5362
Stratified Random – EFH	5	2332	3000	3240	9592
Stratified Random – EFH	All	37824	37824	37824	37824

FIGURES

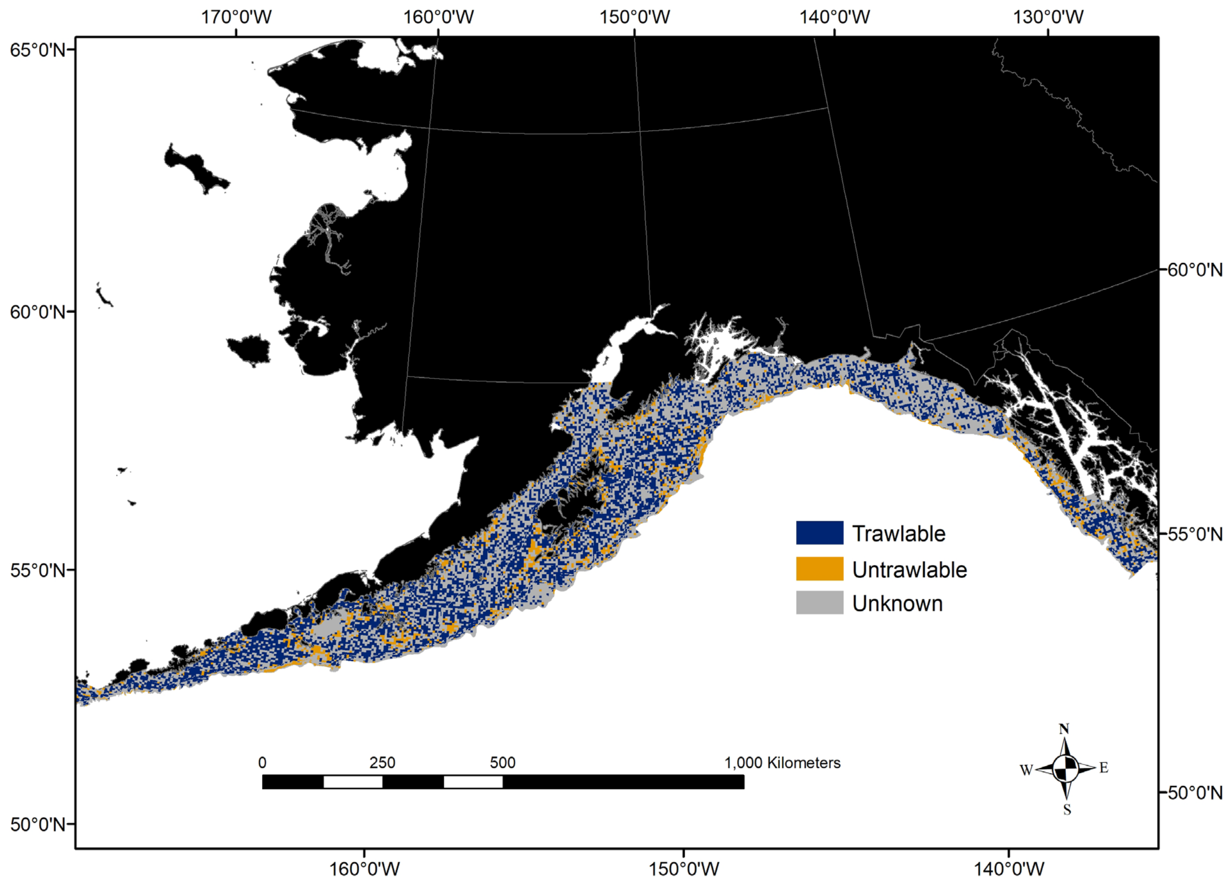

Figure 1. The Alaska Fisheries Science Center Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program 2019 Bottom Trawl Survey (BTS) map of trawlable, untrawlable, and unknown stations.

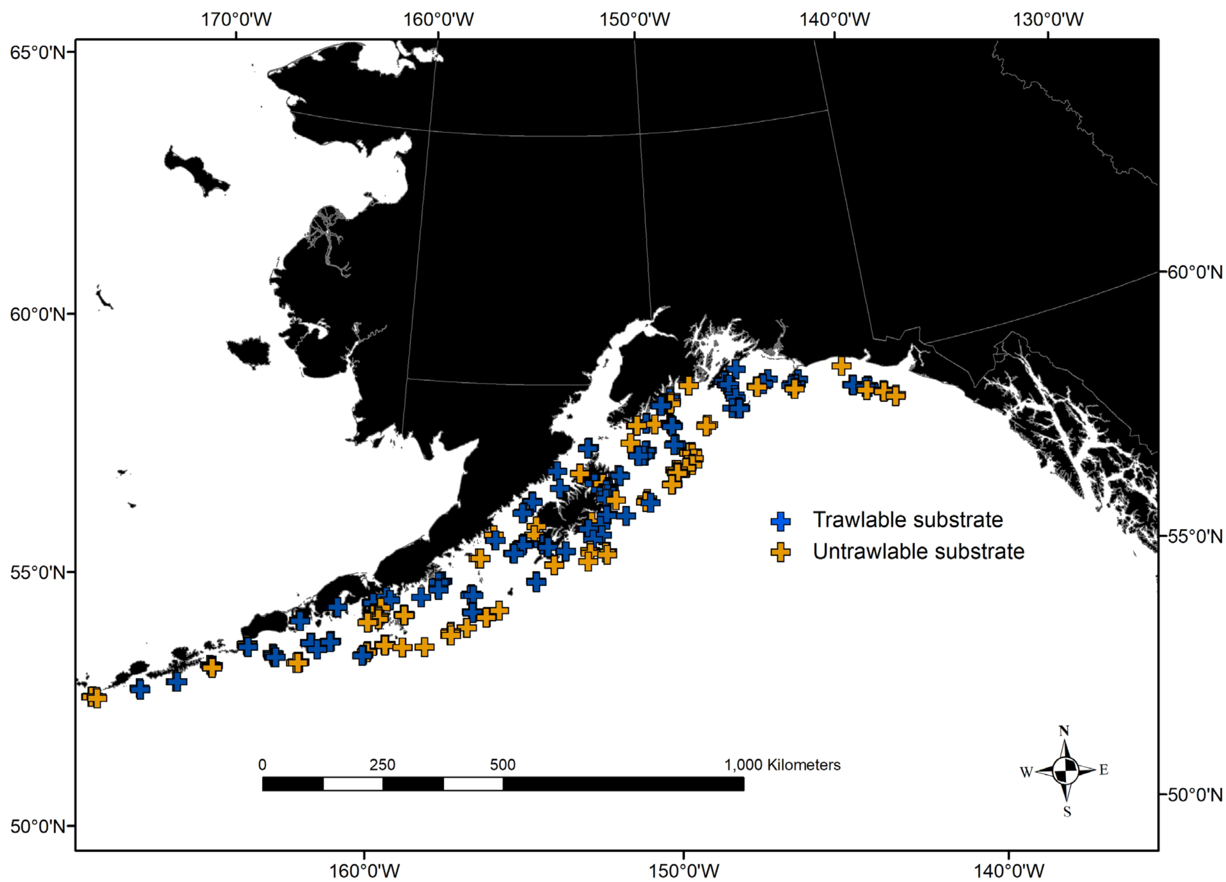

Figure 2. Locations of 2013, 2015, 2017 and 2019 Lowered Stereo Camera (LSC) transects. Locations that were classified as trawlable are marked in blue and those that were untrawlable are in orange.

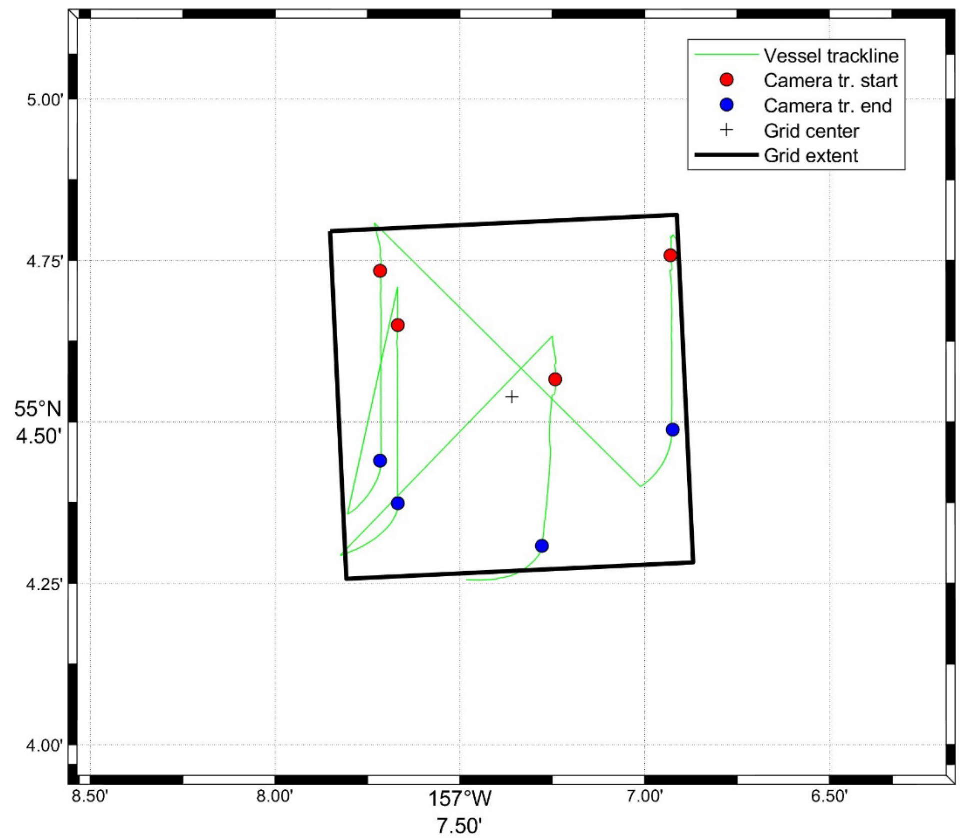

Figure 3. An example of randomly chosen LSC transect start points along with the vessel track line and endpoints during the 2019 oversampling grid project.

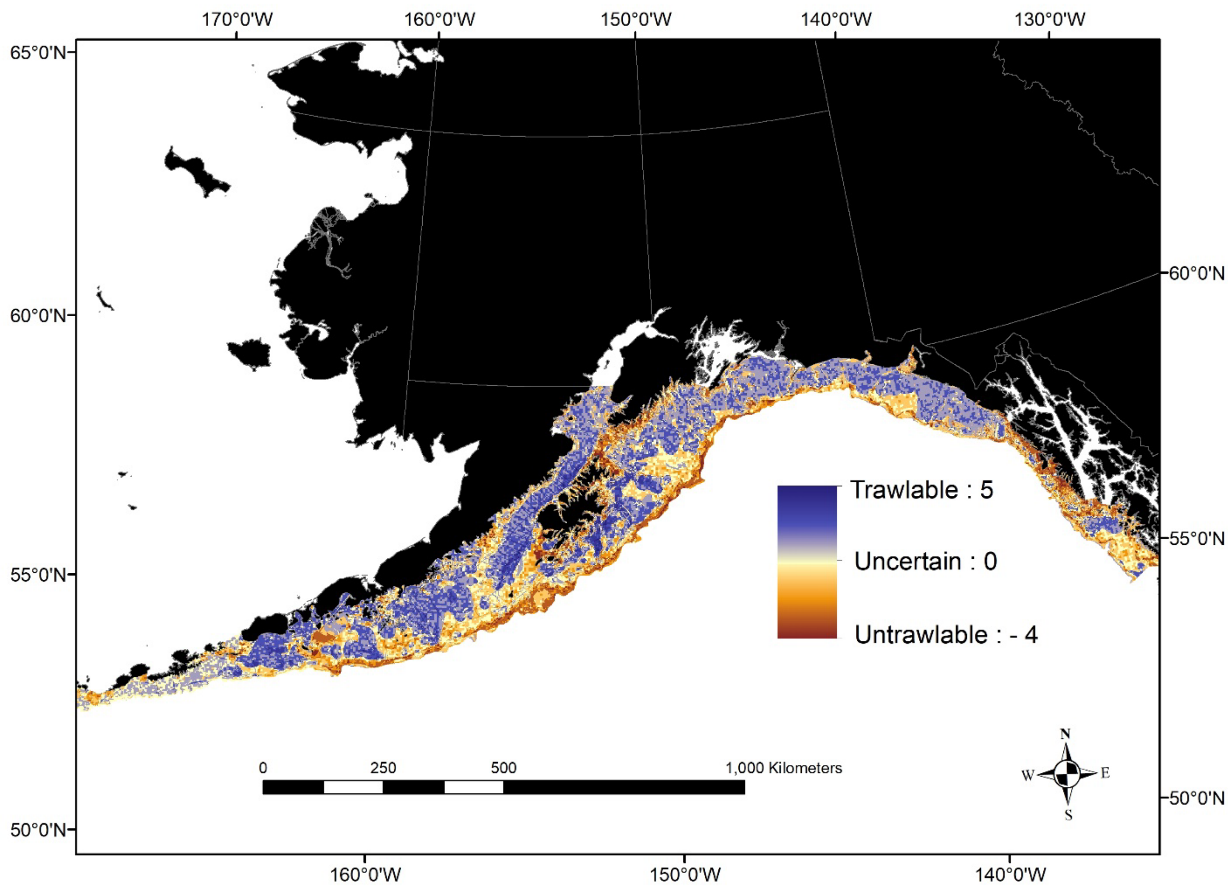

Figure 4. Composite untrawlable habitat map. Negative values (orange) indicate where more trawlability map layers classified the 1 km^2 grid as untrawlable and positive values (blue) where more data sources classified a grid as trawlable.

	BTSH	ME70	RNR	BOV	VMS	CAM
BTSH		0.629	0.677	0.75	0.955	0.717
ME70	0.629		0.657	0.564	0.713	0.796
RNR	0.677	0.657		0.643	0.724	0.698
BOV	0.75	0.564	0.643		0.859	0.52
VMS	0.955	0.713	0.724	0.859		0.882
CAM	0.717	0.796	0.698	0.52	0.882	

Figure 5. Proportion of grid cells with agreement on trawlable or untrawlable classification among the 6 different data layers used to create the composite untrawlable habitat map. Data layers were derived from: BTHS – Alaska Fisheries Science Center Resource Assessment and Convservation Engineering Division’s Groundfish Assessment Program Gulf of Alaska bottom trawl survey map, ME70 – multibeam ecosounder data (Pirtle et al. 2015), RNR– a model derived substrate predictor (Pirtle et al. InPress), BOV- trawlability model based on benthic terrain and oceanic variables (Baker et al. 2019), VMS – commercial fish locations for flatfish hauls, and CAM – habitat data from lowered stereo camera transects (Jones et al. 2021).

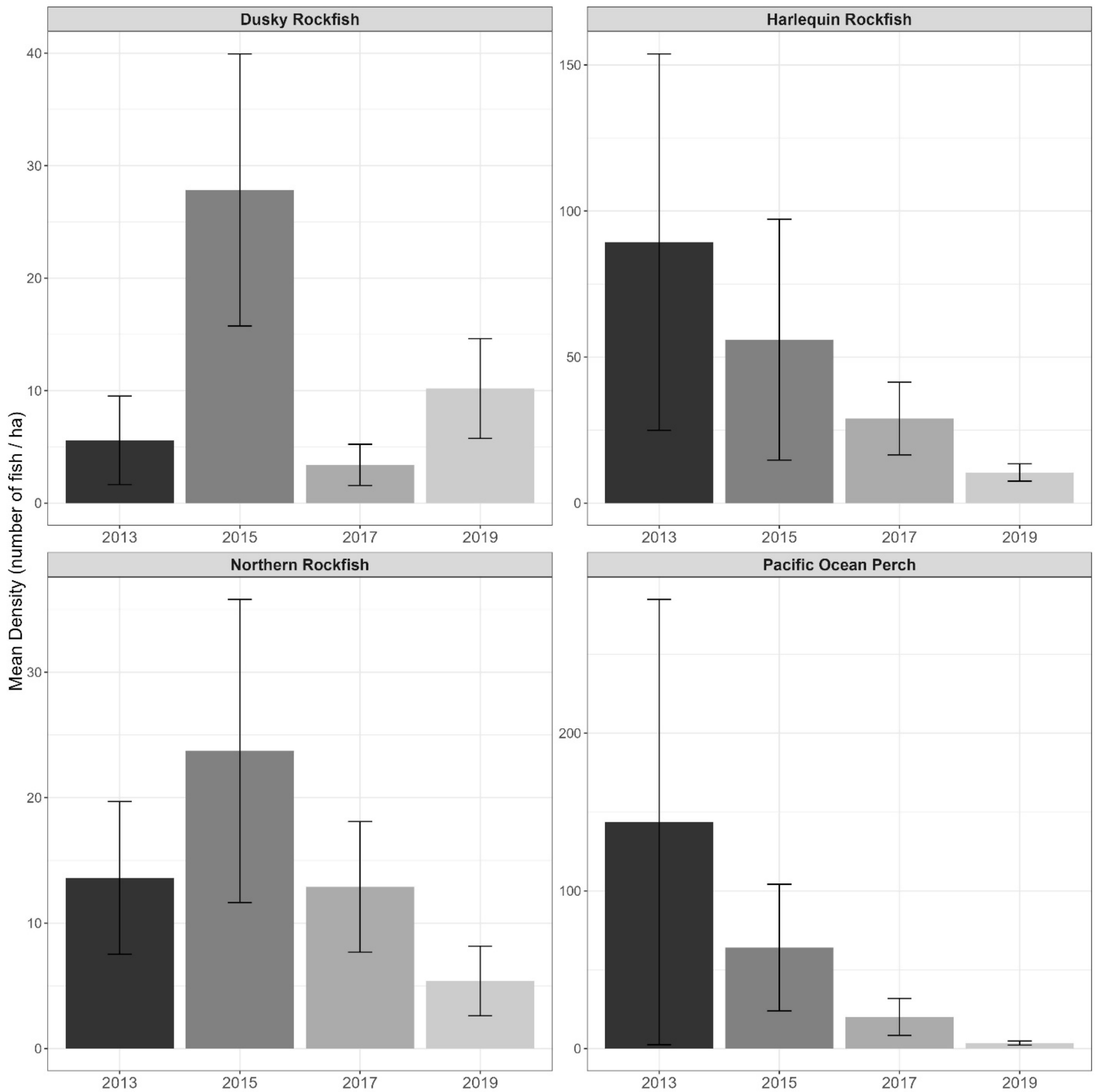

Figure 6. Mean density (number of fish/ha) estimated from LSC transects on untrawlable habitat by year for dusky rockfish, harlequin rockfish, northern rockfish, and Pacific ocean perch. Vertical bars represent +/- 1 standard error.

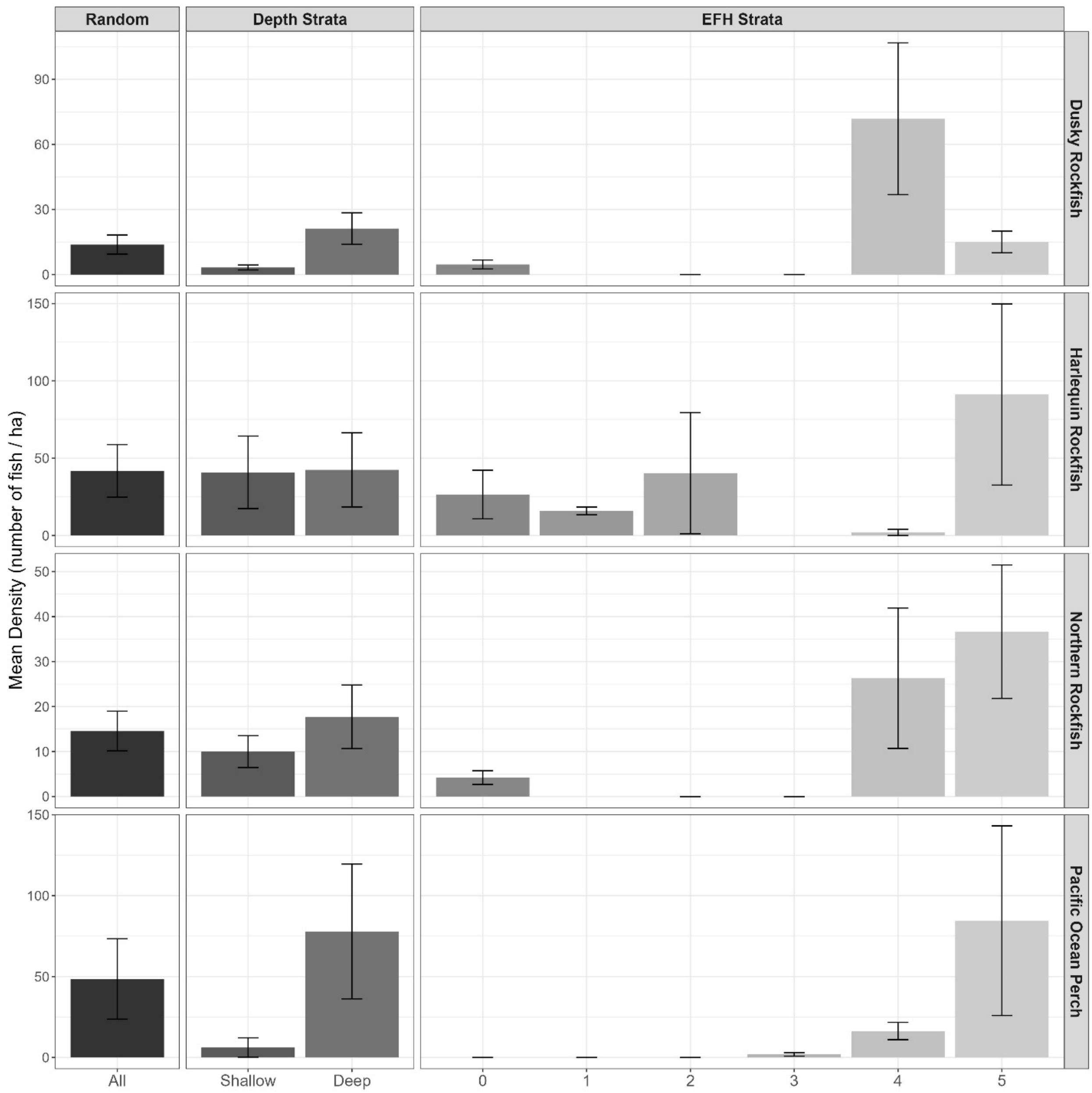

Figure 7. Mean density (number of fish/ha) estimated from LSC transects on untrawlable habitat for all years combined (Random), grouped by depth category (Depth Strata), and grouped by modeled relative abundance score (EFH Strata, 0=no abundance, 5=high abundance) for dusky rockfish, harlequin rockfish, northern rockfish, and Pacific ocean perch. Vertical bars represent +/-1 standard error.

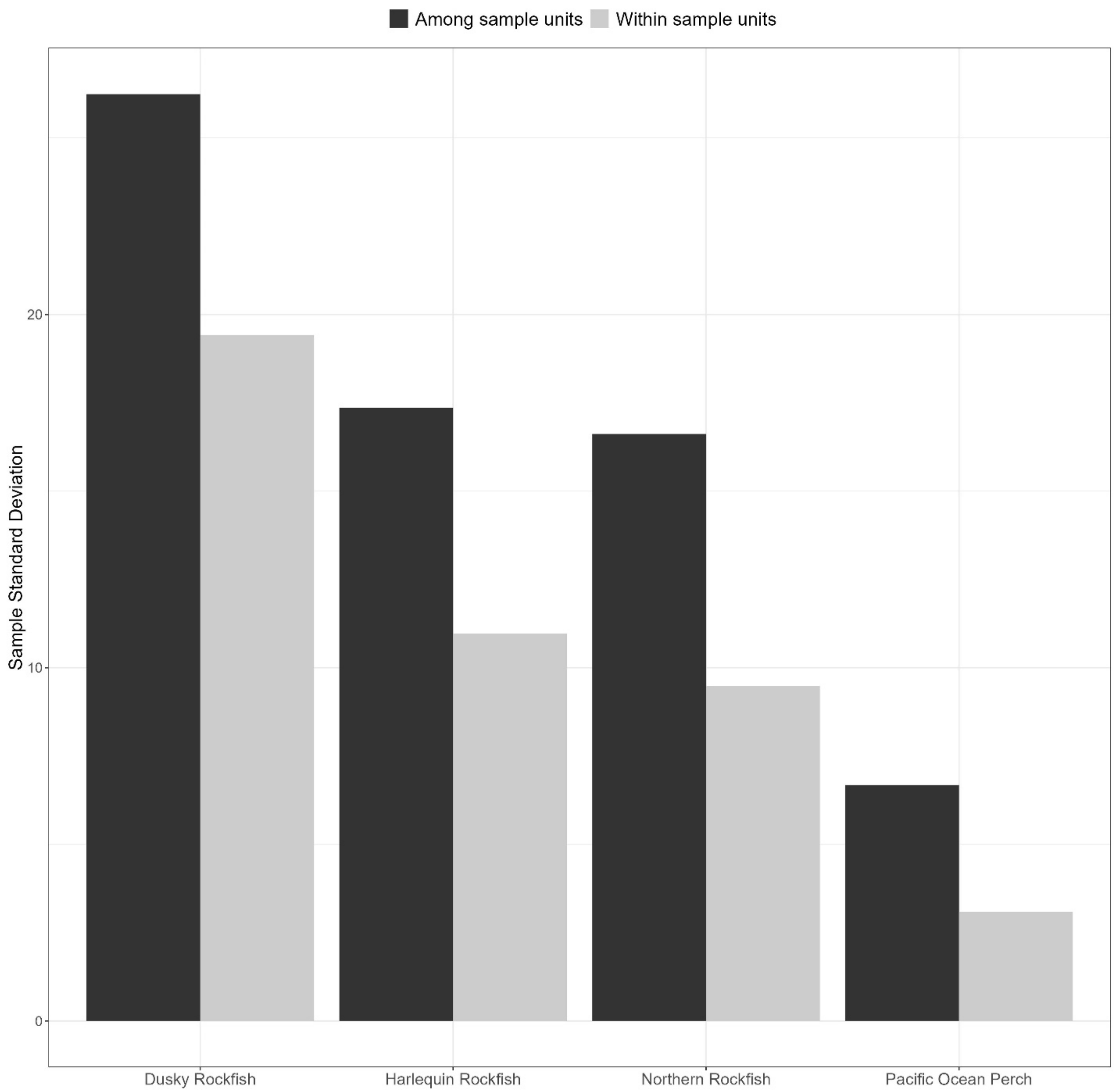

Figure 8. Sample standard deviation of mean density on untrawlable habitat compared from 2019 LSC transects among and between 1 km^2 sampling units for dusky rockfish, harlequin rockfish, northern rockfish, and Pacific ocean perch.

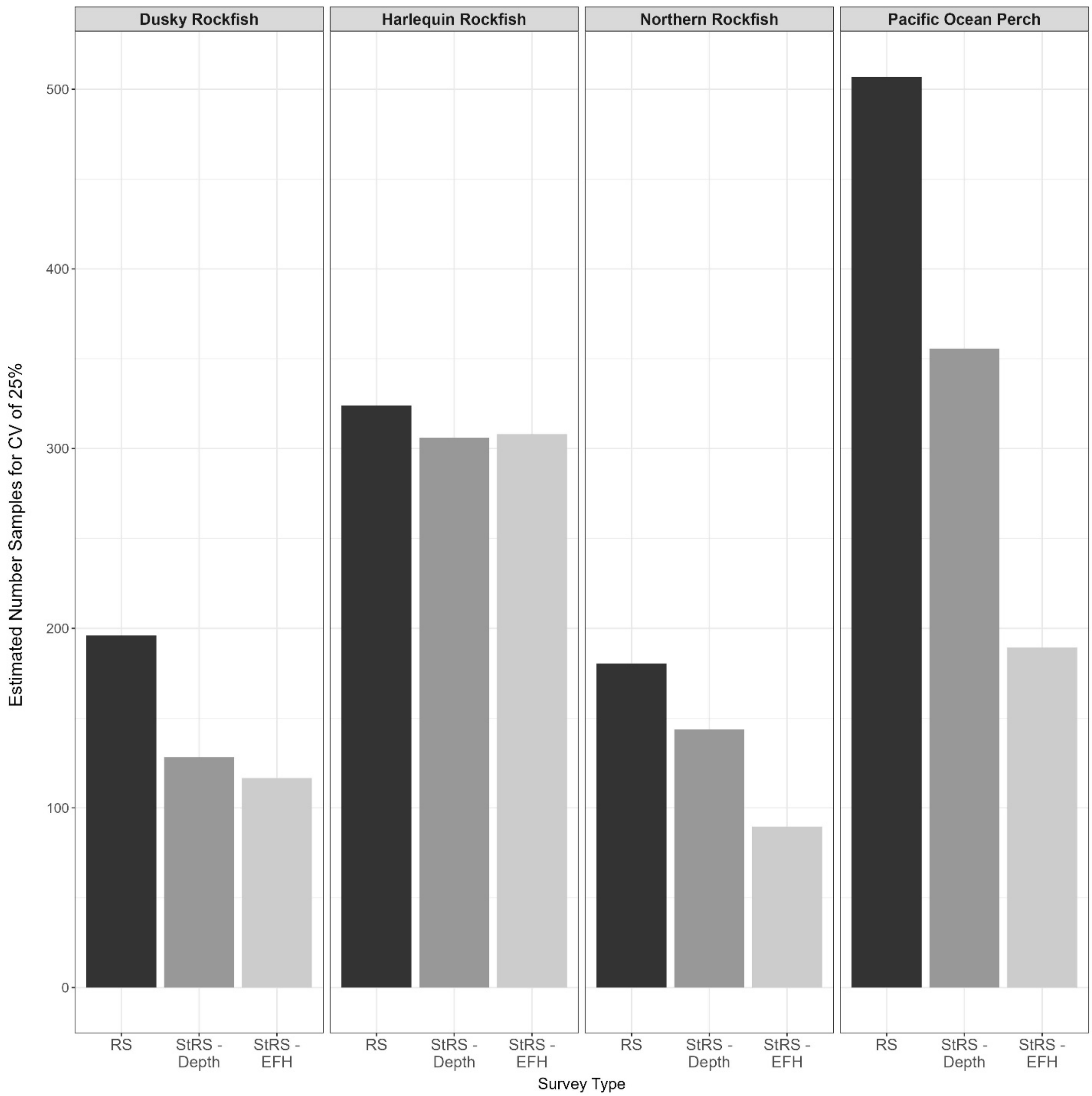

Figure 9. Estimated number of samples to reach a target CV of 25% for a simple random survey (RS), a stratified random survey (StRS-Depth) with two depth categories, and a stratified random survey with scores from a model-based estimate of abundance (StRS-EFH) used for stratification. Estimated number of samples are shown for dusky rockfish, harlequin rockfish, northern rockfish, and Pacific ocean perch.

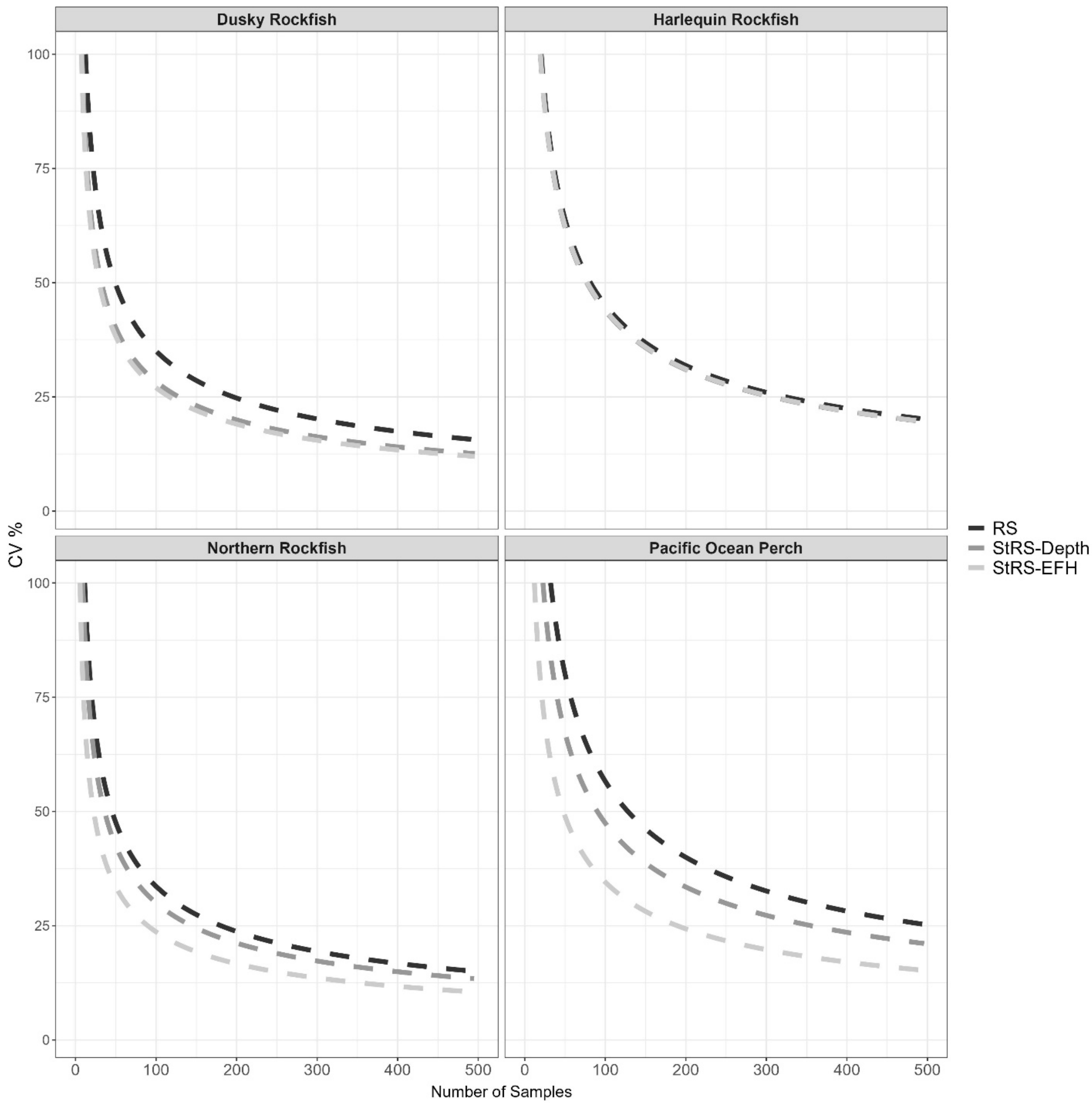

Figure 10. Estimated number of camera tow samples needed to reach a given coefficient of variation (CV) of mean density for a simple random design (RS) and stratified random sample design based on depth (StRS – Depth) and model-based estimate of abundance (StRS – EFH). Estimated are shown for dusky rockfish, harlequin rockfish, northern rockfish, and Pacific ocean perch.

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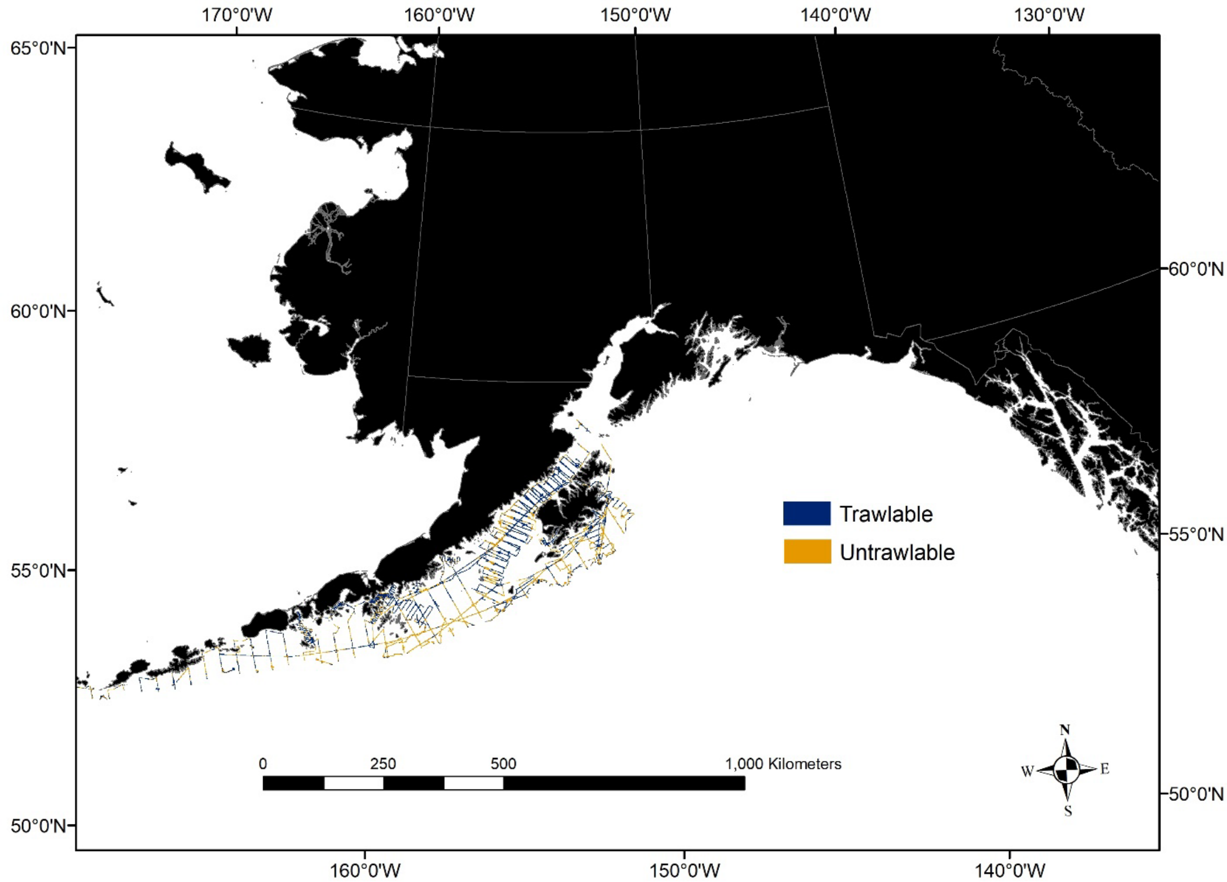
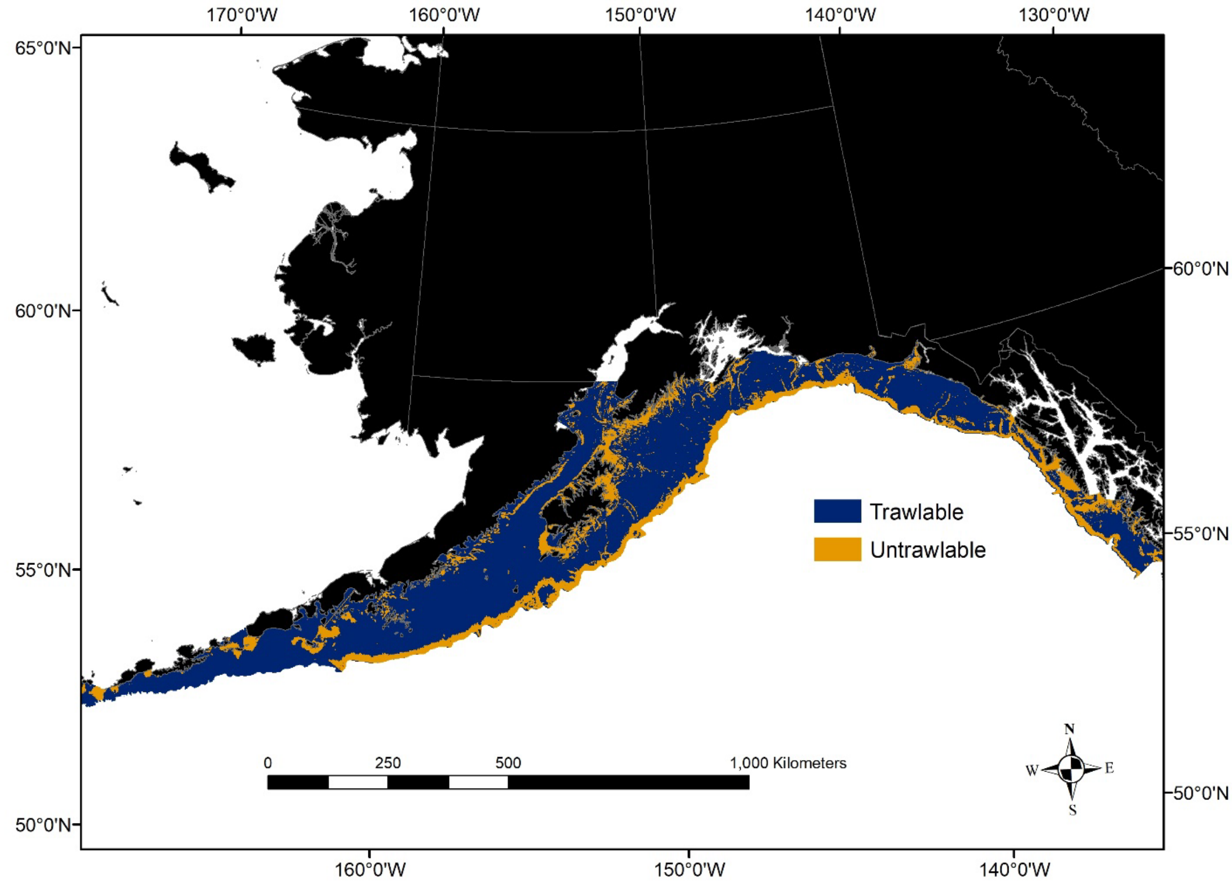
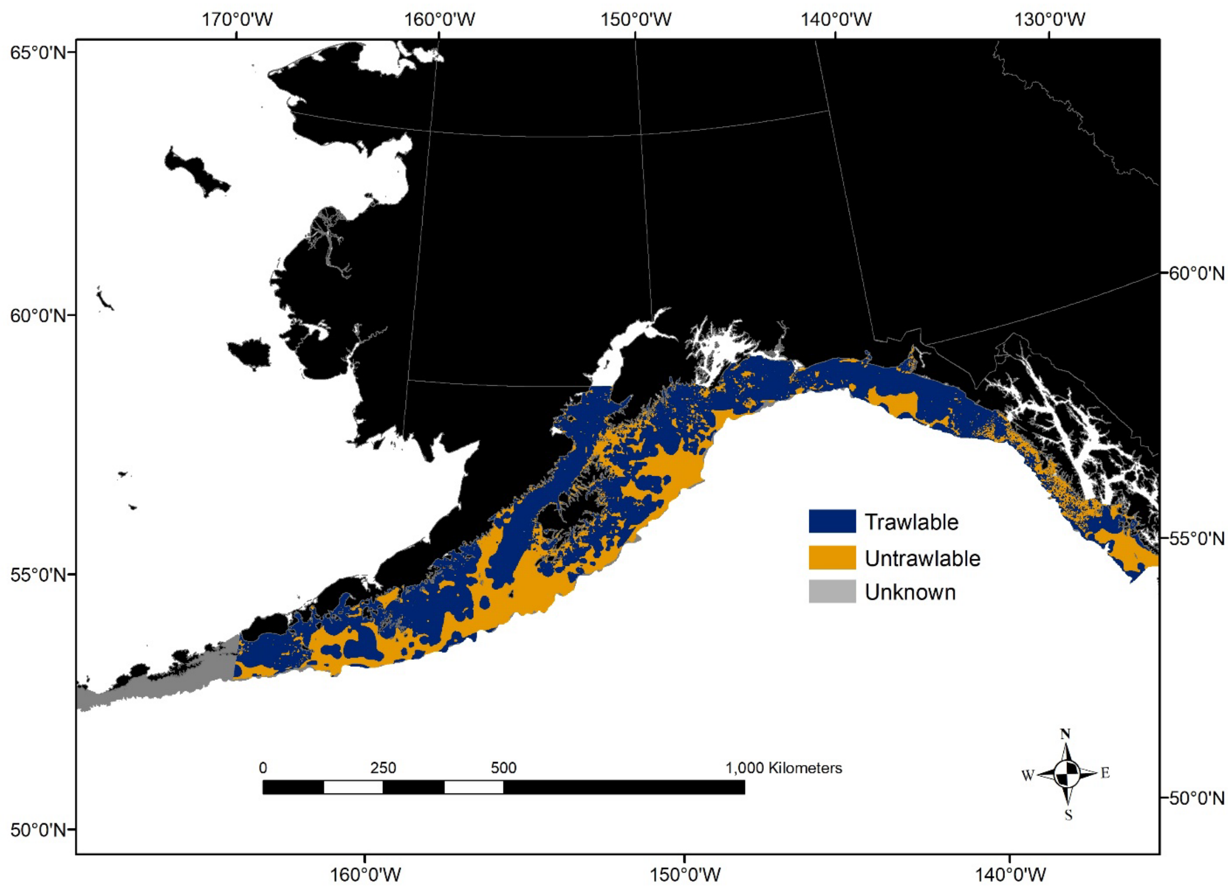
APPENDIX



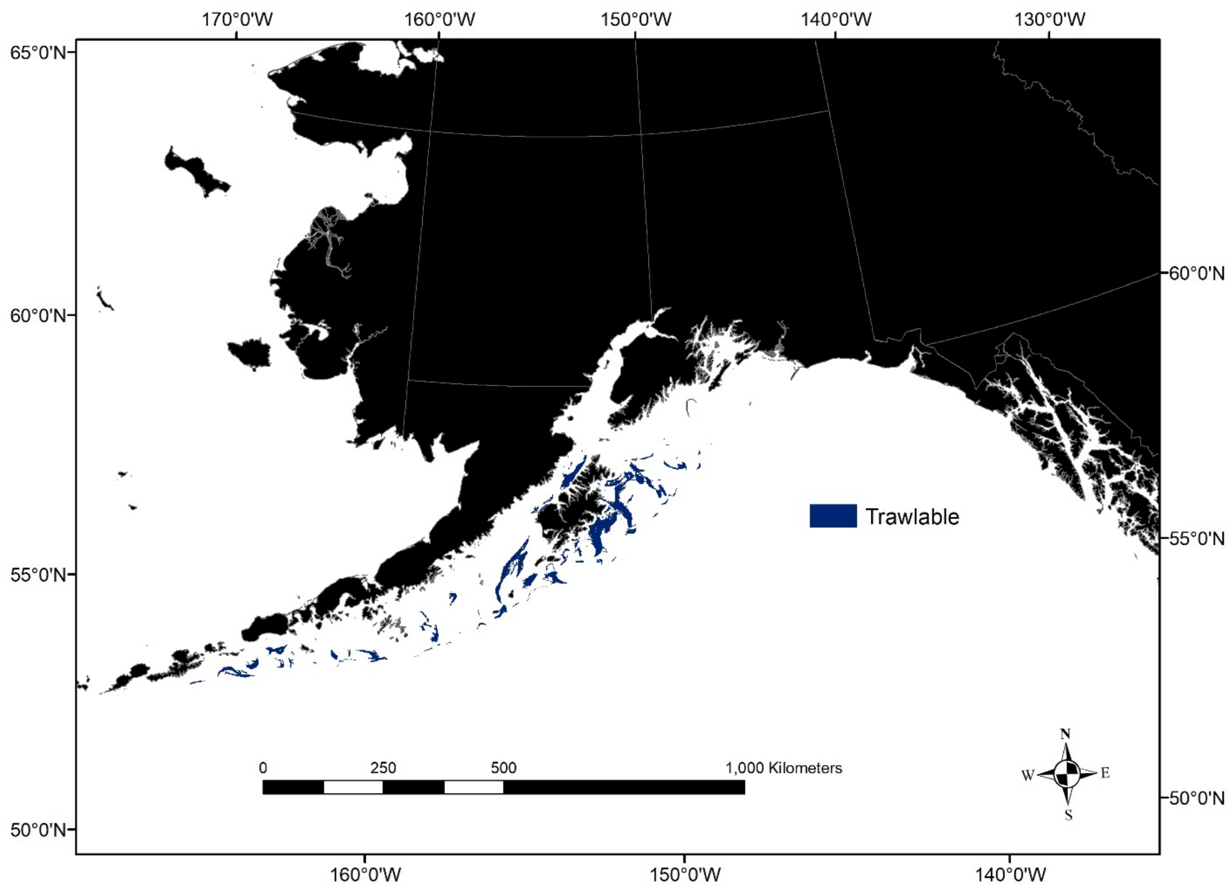
A1. 1 km^2 grid cells produced from the ME70 data layer (Pirtle et al. 2015). Blue indicates trawlable grids and orange untrawlable.



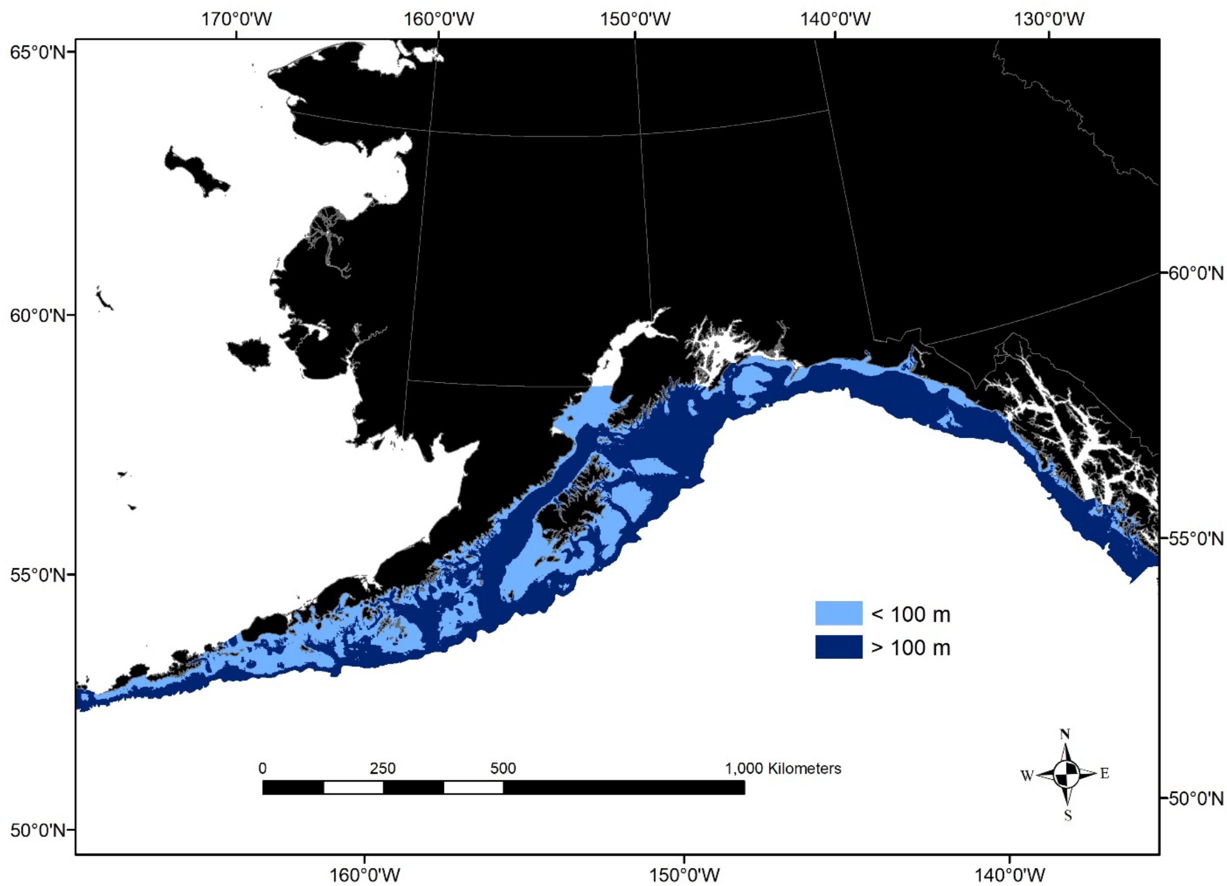
A2. 1 km^2 grid cells produced from the BOV data layer (Baker et al. 2019). Blue indicates trawlable grids and orange untrawlable.



A3. 1 km^2 grid cells produced from the RNR data layer (Pirtle et al. (2019). Blue indicates trawlable grids and orange untrawlable.



A4. 1 km^2 grid cells produced from the VMS data layer. Blue indicates trawlable grids.



A5. Map indicating 1 km^2 grid cells that have a mean bottom of less than or greater than 100 m.