Preliminary report on the seasonal abundance and distribution of cetaceans in the southern Salish Sea in response to TMX recommendations 5 and 6 (Year 1)

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PRELIMINARY REPORT ON THE SEASONAL ABUNDANCE AND DISTRIBUTION OF CETACEANS IN THE SOUTHERN SALISH SEA IN RESPONSE TO TMX RECOMMENDATIONS 5 AND 6 (YEAR 1)

by

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ABSTRACT

McMillan, C.J., Keppel, E.A., Spaven, L.D. and Doniol-Valcroze, T. 2022. Preliminary report on the seasonal abundance and distribution of cetaceans in the southern Salish Sea in response to TMX Recommendations 5 and 6 (Year 1). Can. Tech. Rep. Fish. Aquat. Sci. 3474: vi + 33 p.

In response to the need for spatial and temporal management measures to offset risks posed from marine shipping associated with the Trans Mountain Expansion Project, surveys are being undertaken to assess seasonal abundance and distribution of cetaceans in the southern Salish Sea and Swiftsure Bank. Fourteen systematic line-transect surveys between September 2020 and February 2022 resulted in 3,802 km of survey effort and 964 sightings of five cetacean species. Distance sampling methods were used to produce preliminary abundance estimates for the three cetacean species most frequently encountered: humpback whales, harbour porpoises, and Dall's porpoises. These species were sighted in the area year-round, although seasonal differences in the abundance and distribution of each species were evident. Estimated abundance ranged from 18 (95% CI: 9 - 36) in winter to 274 (95% CI: 160 - 468) in fall for humpback whales; from 584 (95% CI: 274 – 1,242) in winter to 1,430 (95% CI: 986– 2,073) in fall for harbour porpoises; and from 89 (95% CI: 36 - 218) in summer to 362 (95% CI: 203 - 643) in winter for Dall's porpoises. Continued data collection is required to: 1) refine seasonal abundance estimates and assess seasonal and interannual variability; and 2) acquire sufficient data to produce maps of spatially-explicit seasonal predicted density for humpback whales, harbour porpoises, Dall's porpoises, and potentially killer whale ecotypes throughout the study area to support future management measures.

RÉSUMÉ

McMillan, C.J., Keppel, E.A., Spaven, L.D. and Doniol-Valcroze, T. 2022. Preliminary report on the seasonal abundance and distribution of cetaceans in the southern Salish Sea in response to TMX Recommendations 5 and 6 (Year 1). Can. Tech. Rep. Fish. Aquat. Sci. 3474: vi + 33 p.

Il est nécessaire de connaître l'abondance et la distribution saisonnières des cétacés dans le sud de la mer des Salish et sur le banc Swiftsure pour élaborer des mesures de gestion spatiales et temporelles afin de compenser les risques posés par la navigation maritime associée au projet d'agrandissement du réseau de Trans Mountain (TMX). Quatorze relevés mensuels systématiques le long de transects linéaires ont été menés dans la zone du projet TMX entre septembre 2020 et février 2022. Cet effort de 3 802 km a produit 964 observations de cinq espèces de cétacés. Des méthodes d'échantillonnage des distance ont été utilisées pour produire des estimations saisonnières d'abondance et de densité pour les trois espèces les plus fréquemment rencontrées : les rorquals à bosse, les marsouins communs et les marsouins de Dall. Ces trois espèces ont été observées dans la zone toute l'année, avec cependant des différences saisonnières évidentes d'abondance et de distribution. L'abondance estimée variait d'un minimum de 18 (Intervalle de Confiance à 95 % : 9 - 36) en hiver à un maximum de 274 (IC à 95 % : 160 - 468) en automne pour les rorquals à bosse; de 584 (IC à 95 % : 274 – 1 242) en hiver à 1 430 (IC à 95 % : 986 – 2 073) en automne pour les marsouins communs ; et de 89 (IC 95 % : 36 - 218) en été à 362 (IC 95 % : 203 - 643) en hiver pour les marsouins de Dall. Il est nécessaire de continuer la collecte de données pour : 1) affiner les estimations saisonnières de l'abondance de ces cétacés et évaluer la variabilité saisonnière et interannuelle ; et 2) acquérir suffisamment de données pour produire des cartes de la densité saisonnière prévue pour les rorquals à bosse, les marsouins communs, les marsouins de Dall et potentiellement les écotypes d'épaulards dans toute la zone d'étude afin d'informer les futures mesures de gestion.

1 INTRODUCTION

Developing effective mitigation measures to reduce the impact of threats from human activities on cetacean species requires an understanding of their seasonal abundance, distribution, and habitat use. Vessel strikes and chronic acoustic disturbance from vessel noise are recognized as threats to the recovery or conservation of all cetacean species at risk in Canadian Pacific waters (Fisheries and Oceans Canada, 2007; 2009; 2011a; 2011b; 2013; 2018a; 2018b; Gregr et al., 2006). In February 2019, the National Energy Board submitted its Reconsideration Report on the Trans Mountain Expansion (TMX) Project (hereafter referred to as the Project), which would twin an existing pipeline from Edmonton, Alberta to the Westridge Marine Terminal in Burnaby, B.C. (Figure 1), and increase tanker traffic in the southern Salish Sea (National Energy Board, 2019). The report recommended approval of the Project, subject to 156 conditions and 16 recommendations. Recommendations 5 and 6 outlined the need for spatial and temporal measures to offset the underwater noise and vessel strike risk posed to marine mammals by Project-related marine shipping. Much of the focus of mitigation measures to date has been related to impacts on the Endangered southern resident killer whale population. The need for additional data on other at-risk cetaceans was identified to inform potential mitigation measures and their effectiveness.

Marine mammal species frequently sighted in the southern Salish Sea include humpback whales (*Megaptera novaeangliae*), harbour porpoises (*Phocoena phocoena*), Dall's porpoises (*Phocoenoides dalli*), harbour seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), southern resident killer whales, and Bigg's (transient) killer whales (*Orcinus orca*). There is significant and ongoing work underway to assess the abundance and distribution of several of these species, including Steller sea lions, harbour seals, and southern resident and Bigg's killer whales (e.g. DFO, 2021 ; Ford et al., 2013; Ford et al., 2017; Olesiuk, 2010; Olesiuk, 2018; Towers et al., 2019). There are, however, significant data gaps in knowledge of the seasonal abundance and habitat use of humpback whales, harbour porpoises, and Dall's porpoises in the area. Humpbacks and harbour porpoises are listed as Special Concern under the *Species at Risk Act* (SARA). Other less frequently observed cetacean species in the area include fin whales (*Balaenoptera physalus*, Threatened under SARA), grey whales (*Eschrichtius robustus*, Special Concern), and minke whales (*Balaenoptera acutorostrata*, Not At Risk).

Although there have been previous systematic aerial (Jefferson et al., 2016; Nichol et al., 2017) and boat-based (Best et al., 2015; Doniol-Valcroze et al., in press; Williams and Thomas, 2007; Wright et al., 2021) cetacean surveys that have included waters of the southern Salish Sea, many of these surveys were either conducted during a single season (Doniol-Valcroze et al., in press; Jefferson et al., 2016; Williams and Thomas, 2007; Wright et al., 2021), or have limited sample sizes which led to data from multiple seasons being pooled for analyses (Nichol et al., 2017). These surveys do not provide the information about seasonal or annual trends in abundance, distribution, or habitat use required to inform spatial and temporal mitigation measures in the TMX Project area.

Specific year-round systematic cetacean surveys in Canadian portions of the southern Salish Sea are limited to two studies, each of which were limited in spatial scope and comprised a single year of effort. These surveys were both undertaken at the turn of the century and are thus too outdated to inform current management. One of these studies focused exclusively on harbour porpoises in Haro and eastern Juan de Fuca Straits and used weekly line-transect surveys conducted over a one-year period to obtain abundance and density estimates for harbour porpoises in summer (April – October) and winter (November – March; Hall, 2004). The other study used BC Ferries as platforms of opportunity to conduct multi-species line-transect surveys for marine mammals between Vancouver and Nanaimo (Keple, 2002).

Here, preliminary results from 14 months of line-transect surveys in the southern Salish Sea are reported. The data collected during these surveys will not only inform measures under TMX Recommendations 5 and 6, but can also inform assessments of vessel impacts from other proposed projects in this area (e.g. Roberts Bank Terminal 2) and mitigation options for these impacts. These data can also provide insight about the seasonal and spatial risk of other threats to cetaceans (e.g. entanglement).

2 METHODS

2.1 STUDY AREA

The study area was designed to correspond with the area impacted by TMX Project-related marine shipping, including relevant sections of the marine shipping route between the Westridge Marine Terminal and Swiftsure Bank (i.e., the Strait of Georgia, Boundary Pass, Haro Strait, Juan de Fuca Strait, and out to the 12-nautical-mile territorial sea limit off southwestern Vancouver Island; National Energy Board, 2019).

The study area is comprised of the inbound and outbound shipping lanes (traffic separation scheme, TSS) with a 6 km buffer on either side (Figure 1). The TSS spans Canadian and U.S. waters, and understanding cetacean density and habitat use in adjacent U.S. portions of the marine shipping route is critical for informing impacts of vessel traffic and potential mitigation measures in the TMX Project area. However, restrictions associated with the COVID-19 pandemic required survey transects to be clipped to cover Canadian waters only for the period between September 2020 and February 2022. The 6 km buffer was designed to provide good coverage of each of the sections of the marine shipping route, while also allowing for a survey that could be completed in 5-6 days for the Canadian portions of the study area.

2.2 SURVEY DESIGN

Systematic, boat-based cetacean surveys were designed to be conducted monthly throughout the study area. For the purposes of survey design, the area was divided into seven sections and transect lines were generated for each section. This enabled the angles of the transect lines to vary among sections, which minimized off-effort transit time between transects and allowed the majority of transect lines to run perpendicular to depth gradients. A similar approach was used by Thomas et al. (2007) and Doniol-Valcroze et al. (in press). Effort was allocated equally across the seven sections, which were combined and analyzed as a single stratum.

The Distance Sampling Survey Design (dssd) R package (Marshall and Rexstad, 2021) was used to generate transect lines with an equal-spaced complementary zig-zag design. The survey design met the standard distance sampling assumption that all portions of the study area have an equal probability of being included in the sampled transect lines by using random start points generated in dssd for each iteration of the survey design. Several options for line spacing between 13 and 20 km were explored by conducting 1,000 simulations of potential survey designs to compare the mean estimated coverage based on a truncation distance of 2 km, and the mean total survey time for each design. A distance of 18 km between lines was selected to achieve a balance between minimizing the time required to conduct each monthly survey and maintaining good coverage throughout the study area. The survey design was used to generate different iterations of transect lines for each monthly survey.

2.3 DATA COLLECTION

Surveys were conducted on a monthly basis when possible, given weather, vessel, and crew availability. The 12.8 m research vessel R/V Manyberries traveled along pre-determined transects at approximately 10 knots (18.5 km hr^{-1}) when “on-effort” (i.e. actively surveying along transect lines). Data collected when vessel speed was less than 5 knots (9.2 km hr^{-1}) or greater than 13 knots (24.1 km hr^{-1}) were excluded from analyses. Observational effort was also halted when required for species confirmation or opportunistic photo-identification purposes. The order and direction that each line was surveyed varied between surveys, depending primarily on weather conditions throughout the study area.

Two observers were positioned on each side of the vessel’s bow (285 cm average height of eye from sea level) and used 7x50 Fujinon binoculars to conduct observational effort from 0-90 degrees on each side of the transect line, plus a 10 degree overlap at the centre. The data recorder was positioned inside the wheelhouse and recorded data from the observers using Mysticetus software (Steckler and Donlan, 2018). The observers and the data recorder rotated positions after every transect line, or after 45 minutes depending on transect length, to avoid eye strain and fatigue. Each observer worked independently to communicate sightings to the data collection station with in-ear Ultra High Frequency (UHF) radio headsets. All sightings included in the analyses were made by the same three observers.

Mysticetus, connected to GPS, automatically collected vessel position and speed every 10 seconds, and also recorded the positional coordinates and timestamp upon effort or sightings data entry. Effort conditions were reported by observers at the start of each transect line and as conditions changed. These included visibility, Beaufort sea state, glare intensity, and swell height (Table 1). Sightings data included the bearing and reticle reading (or visually estimated radial distance if the sighting was very close to the vessel) to the animal(s), species, and group size (i.e. the number of animals spotted in a single detection). The reticle measurements built into the binoculars were used to determine the distance to each sighting by counting down from the horizon or nearest land mass to the location of the sighting. Digital or manual protractors were used to measure the radial angles to the sighting and the glare extent.

2.4 DATA PROCESSING

Data were examined for accuracy and consistency using a custom-made R script adapted from Wright et al. (2021). Incomplete sighting records were corrected if possible or excluded from the analyses.

Radial sighting distances were calculated based on the reticle readings, distance to the horizon, and the observational height of eye (Buckland et al., 2001). In some cases, reticles were measured from the nearest land mass at the time of observation, rather than from the horizon. In such cases, distance to the land mass was calculated using a custom R script and this was used in place of distance to the true horizon. The perpendicular distance of each sighting from the transect line was calculated from the radial sighting distance and the bearing to the sighting.

2.5 DETECTION FUNCTIONS

Detection functions (DFs) were fit to perpendicular sighting distances of each species using the ds() function in the R “Distance” package (Miller, 2017). Because the survey platform, protocols, and the team of observers remained consistent throughout the study period, DFs were informed by data from all seasons. Species abundance was estimated separately for each season.

Models were fit beginning with key-only models (half-normal, hazard-rate, and uniform keys), considered with and without adjustment terms. Environmental data (visibility, Beaufort sea state, swell, and glare), individual observer, and group size were considered as candidate covariates in the DFs. Covariates were added to the key-only models in a stepwise forward selection process. Comparisons were made between the key-only and each of the covariate models based on Akaike information criterion (AIC) values and goodness of fit using Cramer-von Mises tests and visual inspection of quantile-quantile (Q-Q) plots.

To determine an appropriate right-truncation distance, the selected DF was examined for the perpendicular distance at which the probability of detection was approximately 0.15, as recommended in Buckland et al. (2001).

Some covariate levels were pooled to ensure sufficient numbers of sightings in each covariate category. Beaufort sea state was pooled into three categories: 0-1, 2, and 3+; and visibility was pooled into two categories: good/excellent or moderate/poor. Group sizes of four and above were pooled together; and swell and glare were each pooled into categories of present or absent. The selected categories were consistent among all species.

2.6 SEASONAL ABUNDANCE ESTIMATES

Months were grouped into seasons as: winter (January to March), spring (April to June), summer (July to September), and fall (October to December). Abundance ($\hat{N}$) was estimated seasonally, using a Horvitz-Thomson-like estimator:

$$\hat{N} = \frac{A}{2L} \sum_{i=1}^{n} f(0|z_i) * s_i \tag{1}$$

where A is the total study area (in the current report, only the Canadian portion of the full study area), L is the total length of transects surveyed for that season, n is the number of sightings for the species in that season, $f(0|z_i)$ is the probability density function of detected distances at zero perpendicular distance for observation i with covariates z_i, and s_i are the group sizes.

Given abundance, density ($\hat{D}$) was estimated per season as:

$$\hat{D} = \hat{N}/A \quad (2)$$

95% log-normal confidence intervals were calculated for abundance and density estimates following methods described in Buckland et al. (2001).

3 RESULTS

3.1 LINE-TRANSECT SURVEYS

Fourteen surveys were conducted between September 2020 and February 2022, resulting in a total of 3,802 km of effort along pre-determined transect lines in Canadian portions of the study area (Figure 2). Surveys were conducted at least once during all months with the exception of December. On-effort distance covered varied among seasons, from a low of 730 km in summer, to a high of 1,275 km in winter. Coverage of the western-most and northern-most transect lines in some months of each season was limited by weather conditions.

3.2 SPECIES SIGHTINGS AND GENERAL DISTRIBUTION PATTERNS

A total of 964 sightings of five cetacean species (1,698 individuals), comprised of humpback whales, harbour porpoises, Dall's porpoises, fin whales and killer whales, were observed while surveying along pre-determined transect lines (Table 2). In addition, grey whales and minke whales were sighted in the survey area while "off-effort" (transiting between transect lines).

Humpback whales were sighted during all seasons (192 sightings comprised of 296 individuals); however, no individuals were observed while on-effort in February or March 2021 (Figure 3). Peak detections occurred in early fall, and secondarily in summer. Winter humpback sightings primarily occurred in Juan de Fuca Strait while spring sightings were concentrated on Swiftsure Bank. The highest number and broadest distribution of humpback sightings occurred in October in both years.

Harbour porpoises were the most frequently sighted species of cetacean (636 sightings, 1,053 individuals) and were detected during all surveys (all months January through November; Figure 4). There were fewer sightings in late fall/ early winter, while the greatest number of sightings were in late summer/fall, with a second peak in spring. Most detections involved groups of 1-2 porpoises, but some larger group sizes were encountered including a sighting of approximately 45 individuals in April 2021 in southern Haro Strait. Harbour porpoise sightings were distributed throughout the study area, with greatest concentrations around Haro Strait, and were detected most months year-round throughout the southern Strait of Georgia, Boundary

Pass and eastern Juan de Fuca Strait. Sightings of harbour porpoises decreased in western Juan de Fuca Strait and were rare on Swiftsure Bank.

Dall's porpoises were encountered during all surveys though less frequently than harbour porpoises (102 sightings, 254 individuals; Figure 5). The highest numbers of Dall's porpoise sightings were in the Strait of Georgia in fall and winter surveys.

Groups of southern resident and Bigg's (transient) killer whales were encountered eight and seven times, respectively, while on-effort. Six groups of killer whales were sighted for which ecotype could not be determined, either because weather conditions prohibited the potential for photo-identification, or because breaking transect to collect identification photographs would have detracted from the primary objective of the survey (i.e. to cover the maximum extent of the survey area possible during each month).

Two single fin whales were sighted in summer in Juan de Fuca Strait (Figure 6). Single minke whales were sighted on two occasions in southern Haro Strait. Grey whales were sighted on three occasions, two in western Juan de Fuca Strait and one in southern Haro Strait.

3.3 DETECTION FUNCTIONS

Three species (humpback whales, harbour porpoises, and Dall's porpoises) had sufficient sightings to fit detection functions. For each species, two or more models performed similarly in terms of AIC and goodness of fit. Comparisons of the top-performing models with delta AICs of less than five are presented in Tables 3, 4, and 5.

The top performing detection functions for humpback whales included hazard-rate and half-normal key functions with visibility as a covariate, as well as a uniform key function with cosine adjustment terms of order 1, 2, and a hazard-rate key model with no covariates or series adjustments (Table 3). Two models had equal support: the hazard-rate model with visibility as a covariate and the uniform model, having nearly identical AIC scores and similar fit. Average detectability was slightly lower in the uniform model than in the hazard-rate model (0.44, compared to 0.49). The uniform model was selected because the added complexity of including the visibility covariate in the hazard-rate model did not improve model performance. Humpback whale sightings were right-truncated at a distance of 2 km. The resulting effective strip half-width (esw) for the selected model was 0.88 km (Figure 7a). Goodness of fit was visually assessed with Q-Q plots (Figure 7b).

The best-fitting detection functions for harbour porpoises were half-normal key functions with covariates of Beaufort sea state plus individual observer, or Beaufort alone (Table 4). Radial distances estimated by eye rather than calculated using binocular reticles were removed ($n = 15$) while fitting detection functions, as several of these sightings were estimated as falling directly on the trackline, contributing to some heaping of sightings at zero perpendicular distance. These sightings were returned to the dataset prior to abundance and density estimation. Harbour porpoise sightings were right-truncated at 0.7 km. The half-normal model with covariates of Beaufort and observer was selected, and had an esw of 0.41 km (Figure 8a). The distribution of perpendicular detection distances for each category of these covariates are presented in Figure 9 and Figure 10. Goodness of fit did not vary significantly among the top models (Table 4).

Average detectability was equivalent among the models with delta AIC less than five.

The detection functions with the lowest AICs for Dall's porpoises were half-normal key functions with the covariates glare, swell, glare plus swell, or no covariates (Table 5). Model averaging was considered but, with the exception of the hazard-rate models that included group size as a covariate, average detectability was very similar among models with delta AICs of less than five. The model with the lowest AIC was therefore selected, the half-normal key model with covariates of swell and glare (Figure 11). The relationship between covariates and perpendicular sighting distances are presented in Figure 12 and Figure 13. Sightings were right-truncated at a distance of 0.9 km and the esw was 0.44 km (Table 5, Figure 11).

3.4 SEASONAL ABUNDANCE ESTIMATES

Abundance and density were estimated seasonally for humpback whales, harbour porpoises, and Dall's porpoises (Tables 6, 7, and 8). Abundance is presented for the Canadian portion of the study area only (Figure 1; 2,938 km^2). Density is presented per 25 km^2 which was deemed an appropriate scale considering the size of the study area and the detection distances, and facilitates comparison with similar work (e.g. Wright et al., 2021).

Humpback whale estimated abundance was lowest in winter at 18 (CV: 0.36; 95% CI: 9 – 36) animals, significantly increasing through spring and summer to 84 (CV: 0.38; 95% CI: 40 – 174) and 96 (CV: 0.31; 95% CI: 52– 176) animals, respectively, to a peak in fall of 274 (CV: 0.28; 95% CI: 160 – 468; Table 6, Figure 14).

Harbour porpoise estimated abundance was also lowest during winter at 584 (CV: 0.40; 95% CI: 274 – 1,242) animals, increasing through spring and summer to 915 (CV: 0.21; 95% CI: 603 – 1,387) and 1,089 (CV: 0.22; 95% CI: 709 – 1,674) animals, respectively, to its peak in fall of 1,430 (CV: 0.19; 95% CI: 986 – 2,073; Table 7, Figure 14).

Dall's porpoise seasonal abundance trends differed from those of the other two species (Table 8, Figure 14). Dall's porpoise abundance peaked in winter, the season with lowest harbour porpoise abundance, with an estimated 362 (CV: 0.30; 95% CI: 203 – 643) animals. Estimated Dall's porpoise abundance then dropped to 131 (CV: 0.39; 95% CI: 62 – 278) animals in spring while harbour porpoise abundance was increasing, and decreased further to 89 (CV: 0.48; 95% CI: 36 – 218) animals in summer. In fall, when harbour porpoise reached their peak abundance, Dall's porpoise estimated abundance increased to 182 (CV: 0.36; 95% CI: 80 – 413) animals.

4 DISCUSSION

As the first year-round, multi-species systematic cetacean survey effort to cover the Canadian portions of the southern Salish Sea and Swiftsure Bank, this study provides preliminary estimates of seasonal abundance and density for the three most frequently encountered species of cetacean in the TMX Project area. The results confirm that all three species are present in this area year-round.

4.1 HUMPBACK WHALES

The survey results provide evidence of the year-round use of the study area by humpback whales. Generally, humpbacks that feed in the waters off southern B.C. between spring and fall are known to migrate to Hawaii, Mexico, or Central America for the winter (Calambokidis et al., 2008; Barlow et al., 2011). However, humpback whales were observed in the study area during all seasons. The presence of humpbacks in the study area year-round is an important consideration for any measures to address the threats of vessel strikes and noise to this population.

Humpback whales were detected on Swiftsure Bank during all seasons, with high densities of sightings in this area in spring, summer, and fall (Figure 3). The results of the systematic cetacean line-transect surveys conducted coast-wide in 2018 did not highlight Swiftsure Bank as an area of predicted high humpback whale density (Wright et al., 2021). However, earlier systematic aerial surveys predicted high humpback density in this area (Nichol et al., 2017), and Swiftsure Bank was previously identified as critical habitat for humpback whales (Fisheries and Oceans Canada, 2013), prior to their legal listing changing from Threatened to Special Concern in 2017. Nichol et al. (2017) also predicted high densities of humpback whales to the north and west of the study area boundaries, indicating that the impacts of vessel traffic on this population extend beyond the area surveyed.

The selected model for humpback whales was a uniform key function that included a cosine series adjustment. Half-normal and hazard-rate models including visibility as a covariate had almost identical support to the selected model based on AIC. Average detectability was slightly lower for the uniform model, leading to higher seasonal humpback whale abundance estimates than those generated by the models that included covariates. This sensitivity to the choice of different models with identical support creates additional uncertainty in the abundance estimates not represented in the confidence intervals. Increasing the sample size and using model-averaging can potentially resolve this uncertainty in future analyses.

The results of these surveys corroborate observations from previous systematic and opportunistic effort indicating the rapid increase in humpback whale use of the southern Salish Sea in recent years following decades of absence as a result of commercial whaling. During the systematic cetacean surveys conducted in 2004, no humpback whales were sighted in the southern Salish Sea (Williams and Thomas, 2007). Since that time, humpback whale numbers have increased significantly in the study area as the species reoccupied historical habitat (Merilees, 1985). In the current study, humpback whale abundance was estimated at 274 individuals, and density at over 2.3 whales per 25 km^2 during fall for the entire study area.

During the coast-wide survey in summer 2018, Wright et al. (2021) predicted density of humpback whales within the Salish Sea to be highest in parts of Juan de Fuca Strait, with over three animals per 25 km^2. Predicted density in the southern Strait of Georgia, however, where a large number of humpback whales were detected in October 2020 and 2021, was less than one animal per 25 km^2 (Wright et al., 2021). In the future, spatially-explicit seasonal density estimates based on ongoing survey efforts can further inform seasonal trends in humpback whale habitat use.

4.2 HARBOUR PORPOISE

Harbour porpoises were sighted year-round, with the highest number of detections in fall and the lowest in winter. However, the number of harbour porpoise sightings was high year-round, especially in Haro and eastern Juan de Fuca Straits. Hall (2004) estimated a significantly higher abundance of porpoises in Haro and eastern Juan de Fuca Straits from April – October, compared to November – March. Based on encounter rates, Hall (2004) identified August to October as months with the highest numbers of porpoise sightings. Similar patterns of high numbers of detections in September and October were observed during the 2020-22 surveys, but these surveys identified another, previously unreported period of increased harbour porpoise sightings in March, April, and May (Figure 4).

This study identified Haro and eastern Juan de Fuca Straits as the areas with the highest numbers of harbour porpoise sightings. These corresponded with areas of predicted high harbour porpoise density from surface density models based on 2004 and 2018 cetacean surveys (Best et al., 2015; Wright et al., 2021). However, neither of these models highlighted the areas in the southern Strait of Georgia close to Vancouver where a large number of harbour porpoises were detected in some months, especially January, February, and April (Figure 4). This difference may be explained by the multi-season nature of the current study; both former studies were conducted during summer only. Seasonal shifts in distribution and the potential for interannual variability in abundance and distribution are primary reasons why additional survey effort is required to better understand cetacean habitat use of the study area.

The harbour porpoise data showed a spike near zero perpendicular distance, which can be a sign of responsive movement toward the vessel. However, harbour porpoises are not known to approach vessels to bow-ride. Best et al. (2015) and Doniol-Valcroze et al. (in press) also found spikes close to zero perpendicular distance for harbour porpoises and concluded that the steep declines in detection probabilities likely accurately reflected observers' abilities to detect harbour porpoises. If, however, responsive movement toward the vessel did occur, this could result in over-estimation of harbour porpoise abundance in the study area.

The selected detection function for harbour porpoises included Beaufort and individual observer as covariates. Perpendicular sighting distance plots illustrate that at Beaufort 3 or higher, there were very few detections at larger distances (Figure 9). Given the small size, low profile, and often cryptic behaviour of harbour porpoises, it is not surprising that sea state impacted detection distances for this species. The lack of sightings of harbour porpoises at high Beaufort levels makes it difficult to accurately model the impact of these higher sea states on detection probability. The unsheltered waters of the western-most portions of the study area (Swiftsure Bank and the mouth of Juan de Fuca Strait) tended to have higher sea states and swell heights during survey effort and this likely impacted the ability to detect harbour porpoises in these areas. Acoustic data collection is underway to address this challenge. Acoustic detections of harbour porpoise based on their vocalizations will provide further insight into harbour porpoise use of the exposed portions of the study area.

4.3 DALL'S PORPOISE

Dall's porpoises were detected during all monthly surveys but at a lower estimated abundance than harbour porpoises in all seasons. Estimated abundance of Dall's porpoises was highest in winter, when the estimated seasonal abundance for harbour porpoises was lowest (Figure14). Analysis of stomach contents has indicated that harbour and Dall's porpoises have significant overlap in prey species in the Salish Sea (Nichol et al., 2013), so their respective seasonal trends in abundance may indicate that there is some temporal partitioning of habitat between these two species.

As with harbour porpoises, the Dall's porpoise data showed a moderate spike near zero perpendicular distance. Unlike harbour porpoises, however, Dall's porpoises are known to show responsive movement toward vessels to bow-ride, and this behaviour was observed several times during survey efforts. Responsive movement toward the vessel could result in an over-estimate of Dall's porpoise abundance. In the surveys reported on in Best et al. (2015), the behaviour of approximately 5% of the Dall's porpoises detected was noted as "approaching." Consequently, Best et al. (2015) and Williams and Thomas (2007) selected half-normal models with slightly higher AICs for their Dall's porpoise detection functions, rather than hazard-rate models that tracked these spikes in the data, to correct for responsive movement in their detection function. In this study, the model with the lowest AIC was already a half-normal model that did not exhibit a sharp decline close to zero perpendicular distance. Behaviours associated with responsive movement (e.g. approaching or bow-riding behaviour) will be recorded in future surveys, to inform the extent that responsive movement may be impacting detection functions.

4.4 OTHER SPECIES

Systematic survey efforts to date have resulted in a total of 21 killer whale sightings, a sample size that is too small to reliably fit detection functions either by ecotype or grouped by species. However, With continued survey effort it is plausible that enough data could be collected (usually 60-80 sightings; Buckland et al., 2001) to provide seasonal and spatially explicit density estimates for killer whales. The populations of both southern resident and Bigg's killer whales are monitored through photo-identification (Center for Whale Research, 2022; Towers et al., 2019) and there is extensive recent research focused on the occurrence and habitat use of southern resident killer whales in the study area (e.g. Ford et al., 2017; DFO, 2021). As Bigg's killer whales, a Threatened population under SARA, have increased their use of the Strait of Georgia in recent decades (Ford et al., 2013), further insight into their seasonal habitat use could help to inform measures under TMX Recommendations 5 and 6, and contribute to refining the identification of habitats required for the survival and recovery of this population.

Fin whales were encountered twice in the study area, both times in Juan de Fuca Strait during summer 2021. Although no fin whales were detected in this area during systematic cetacean surveys conducted in 2004 or 2018 (Williams and Thomas, 2007; Doniol-Valcroze et al., in press), fin whales in the waters between Vancouver Island and the mainland have been documented several times since 2005 (Towers et al., 2018). The highest impact threats to fin whales (listed as Threatened under SARA) are collisions with and noise from ships (COSEWIC, 2019). Twelve dead fin whales, all with evidence of vessel strikes, were documented in the southern Salish Sea between 1986 and 2017 (Towers et al., 2018). Despite their relatively infrequent presence in the area, fin whales are highly susceptible to vessel strikes and should be considered in measures to address vessel impacts from Project-related shipping.

Grey and minke whales were not detected while surveying along pre-determined transect lines, but were sighted three and two times, respectively, during periods of off-effort transiting. Eastern North Pacific grey whales are currently listed as special concern under SARA, and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has recommended splitting grey whales into three populations, including two assessed as Endangered (COSEWIC, 2017). Vessel strikes are considered one of two principal threats to the survival and recovery of grey whales (Gavrilchuk and Doniol-Valcroze, 2021) and vessel traffic in the study area has the potential to impact members of these populations. Minke whales are known to feed in parts of the study area, including southern Haro and eastern Juan de Fuca Straits (Towers et al., 2013). Their erratic surfacing patterns and lack of a visible blow make them difficult to detect visually, especially when weather conditions are not ideal. Accurate assessments of abundance and habitat use are therefore challenging for this species.

4.5 ASSUMPTIONS AND UNCERTAINTY

All distribution and abundance information from this technical report should be interpreted with caution, as more data are required to sufficiently capture seasonal and interannual variability. Additionally, the distributions of each species described in this report are based on detections alone; factors including environmental conditions and diel differences in habitat use have not yet been accounted for.

Caution is also needed when interpreting results for months and for areas that have had less coverage. At least one survey was conducted from the R/V Manyberries in every month except December, because required vessel repairs in December 2020 and 2021 precluded its use as a survey platform. Transect lines in the western-most portion of the study area (Swiftsure Bank, Figure 2) as well as the northern-most transect lines (near Vancouver) have been completed during a limited number of surveys thus far due to weather conditions. Additional surveys will provide for more consistent effort throughout the study area, resulting in more precise abundance and density estimates and informing seasonal and interannual variability.

To date, survey effort has been conducted in Canadian portions of the study area only. The survey design includes the U.S. portions of the southern Salish Sea and Swiftsure Bank, and with travel restrictions associated with the COVID-19 pandemic lifting, there are plans to include U.S. waters in future surveys. Understanding cetacean density and habitat use in adjacent U.S. waters is critical for informing impacts of vessel traffic and potential mitigation measures in the TMX Project area.

Visual surveys are limited to daylight hours only and thus do not capture diel changes in humpback whale and porpoise behaviour. These changes can affect detection patterns and could lead to some habitats being undervalued if based on daytime data alone (Calambokidis et al., 2019; Williamson et al., 2017). Additionally, harbour porpoises are very difficult to detect visually in sea states greater than Beaufort 2, likely impacting the number of detections in the more exposed portions of the study area.

Key assumptions for distance sampling include that animals are sighted at their initial locations (i.e. no directed movement prior to detection), that all animals are available at the surface to be counted, and that all available animals on the transect line are detected. Violation of the latter two assumptions can lead to availability bias or perception bias, respectively. The relatively low height of eye on the R/V Manyberries restricts the time and distance over which animals can be detected, which may impact when animals are sighted and the number of sightings on the trackline that are missed. For example, it is possible that the low height of eye of the platform influenced whether porpoises were detected prior to any directed movement.

The space available for observation on R/V Manyberries does not allow for a double-platform set-up to test if all animals on the trackline are detected and to estimate a perception bias correction. However, data collection are underway to correct for availability bias (the bias resulting from animals that are not detected due to being underwater). Time-depth recording tags deployed on humpback whales in the study area will provide data to inform correction factors for the abundance estimates.

Violation of these assumptions could result in biased abundance and density estimates for cetaceans in the study area, as well as underestimation of the uncertainty associated with these estimates. However, the consistency in protocols and observers throughout these surveys means that these biases are unlikely to vary significantly in space or time, so they should not affect comparisons of relative density across seasons and areas.

4.6 CONCLUSIONS AND NEXT STEPS

The preliminary results from data collected to date provide new insight into the seasonal presence and abundance of humpback whales, harbour porpoises, and Dall's porpoises in the southern Salish Sea and Swiftsure Bank. These three species are present in the area year-round but there are strong seasonal differences in their abundance and distribution.

Additional survey effort is needed to better understand seasonal and annual variability and to refine seasonal estimates of abundance. Best et al. (2015) found that incorporation of additional years of cetacean survey data following the 2004-05 surveys from Williams and Thomas (2007) altered abundance estimates and tightened confidence intervals for all cetacean species. It is therefore critical to continue survey efforts for several years for accurate abundance estimation. Additional years of survey effort will also provide sufficient data to use a density surface modeling approach for production of spatially-explicit predicted seasonal distribution maps.

Additional data collection is underway to address some of the limitations associated with diel behaviour patterns and weather. Time-depth recording tags are being deployed on humpback whales in the study area to investigate diel differences in fine-scale habitat use and dive behaviour, and how this may impact their vulnerability to vessel strikes. Because harbour porpoise detections are strongly affected by Beaufort sea state, deployments of autonomous acoustic recorders are underway to detect porpoise presence from their characteristic high frequency vocalizations. Future analysis of the acoustic data will show whether porpoise abundance has been underestimated by visual surveys in the more exposed parts of the study area and will provide a more complete picture of harbour porpoise distribution and habitat use.

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7 TABLES & FIGURES

Table 1. Candidate covariates recorded during line-transect surveys and definitions for each covariate level.

Covariate	Level	Definition
Visibility	Excellent/Good	The horizon is unobstructed in your entire field of view from 0° to +/- 45°
Visibility	Moderate	The horizon is partially obstructed from 0° to +/- 45°, and < 3 Nm visibility
Visibility	Poor	There is <2 Nm visibility from 0° to +/- 45°
Beaufort sea state	0	Glassy (calm, flat, no wave height, <1 kt wind)
Beaufort sea state	1	Ripples (light air, no wave crests, < ½ m swell height, 1 - 3 kts wind)
Beaufort sea state	2	Small wavelets (light breeze, glassy unbreaking crests, < ½ m swell, 4 - 6 kts wind)
Beaufort sea state	3	Scattered whitecaps (gentle breeze, large wavelets, < 1 m swell, 7 - 10 kts wind)
Beaufort sea state	4	Frequent whitecaps (moderate breeze, small waves, 1 - 2 m swell, 11-16 kts wind)
Beaufort sea state	5	Many whitecaps/little spray (fresh breeze, 2-3m swell, 17 - 21 kts wind)
Beaufort sea state	6	Foam/airborne spray (strong breeze, long waves, 3 - 4 m swell, 22 - 27 kts wind)
Beaufort sea state	7	Foam streaks (high gale wind, sea heaps up, 4 - 5.5 m swell, 28-33 kts wind)
Swell height	None	No swell
Swell height	Low	< 1 m swell
Swell height	Moderate	1 - 2 m swell
Swell height	Big	> 2 m swell
Glare	None	No glare at all
Glare	Mild	There is glare, but you can see through it without sunglasses
Glare	Severe	There is glare, and you cannot see into it without sunglasses

Table 2. Survey sightings summary. Number of sightings, number of individuals sighted and average group size (+/- standard deviation). All data presented are on-effort survey sightings unless otherwise noted.

Species	Number of sightings	Number of individuals	Mean group size (+/- SD)
Humpback whale	192	296	1.5 (+/- 1)
Harbour porpoise	636	1053	1.7 (+/- 2.1)
Dall's porpoise	102	254	2.5 (+/- 1.4)
Unknown porpoise	12	15	1.2 (+/- 0.5)
Killer whale - southern resident	8	28	3.5 (+/- 2.1)
Killer whale - Bigg's	7	26	3.7 (+/- 1)
Killer whale - unknown ecotype	6	25	4.2 (+/- 3.1)
Fin whale	1	1	1 (+/- NA)

Table 3. Humpback whale detection function models; truncation distance=2 km. Comparison among models with strong support (i.e. delta AIC less than five). Key function, Formula=covariates in model, CvM p-value=Cramer-von-Mises test p-value, Average detect.=average detectability, SE(Average detect.)=standard error of the average detectability. Delta AIC= difference in AIC from the top performing model.

Key function	Formula	CvM p-value	Average detect.	SE (Average detect.)	Delta AIC
Hazard-rate	Visibility	0.95	0.49	0.04	0.00
Uniform with cosine adjustment terms of order 1,2	NA	0.96	0.44	0.03	0.10
Half-normal	Visibility	0.64	0.48	0.03	1.02
Hazard-rate	1	0.95	0.49	0.04	1.37
Hazard-rate	Beaufort + Visibility	0.84	0.48	0.04	1.43
Hazard-rate	Beaufort	0.89	0.48	0.04	1.44
Hazard-rate	Visibility + Observer	0.99	0.47	0.04	1.52
Hazard-rate	Observer	0.98	0.46	0.04	2.07
Hazard-rate	Beaufort + Observer	0.89	0.47	0.04	3.05
Half-normal	Glare	0.81	0.49	0.03	3.13
Hazard-rate	Glare	0.95	0.49	0.04	3.36
Half-normal	Beaufort + Visibility	0.57	0.48	0.03	3.60
Half-normal with cosine adjustment terms of order 2,3	1	0.98	0.48	0.06	3.74

Table 4. Harbour porpoise detection function models; truncation distance=0.7 km. Comparison among models with strong support (i.e. delta AIC less than five). Key function, Formula=covariates in model, CvM p-value=Cramer-von-Mises test p-value, Average detect.=average detectability, SE(Average detect.)=standard error of the average detectability. Delta AIC= difference in AIC from the top performing model.

Key function	Formula	CvM p-value	Average detect.	SE (Average detect.)	Delta AIC
Half-normal	Beaufort + Observer	0.17	0.54	0.02	0.00
Half-normal	Beaufort	0.13	0.54	0.02	0.69
Half-normal	Beaufort + Group Size	0.14	0.54	0.02	5.19

Table 5. Dall's porpoise detection function models; truncation distance=0.9 km. Comparison among models with strong support (i.e. delta AIC less than five). Key function, Formula=covariates in model, CvM p-value=Cramer-von-Mises test p-value, Average detect.=average detectability, SE(Average detect.)=standard error of the average detectability. Delta AIC= difference in AIC from the top performing model.

Key function	Formula	CvM p-value	Average detect.	SE (Average detect.)	Delta AIC
Half-normal	Swell + Glare	0.61	0.51	0.04	0.00
Half-normal	Swell	0.59	0.52	0.04	0.80
Half-normal	1	0.58	0.53	0.04	1.37
Half-normal	Glare	0.58	0.52	0.04	1.93
Uniform with cosine adjustment term of order 1	NA	0.49	0.54	0.03	2.07
Hazard-rate	Group Size	0.62	0.19	0.08	3.06
Half-normal	Visibility	0.57	0.52	0.05	3.27
Half-normal	Beaufort	0.53	0.52	0.04	4.00
Hazard-rate	Swell + Group Size	0.58	0.20	0.10	4.02

Table 6. Humpback whale abundance estimates. n=number of groups sighted, ER=encounter rate (per km), cv.ER=coefficient of variation of the encounter rate, GS=estimated group size, N=estimated abundance, cv.N=coefficient of variation of the abundance estimates, D=estimated density (per 25 km^2), cv.D = coefficient of variation of the density estimates, L95 and U95=lower and upper bounds of a log-normal 95% confidence interval.

Season	n	ER	cv.ER	GS	N	cv.N	L95.N	U95.N	D	cv.D	L95.D	U95.D
Winter	14	0.01	0.35	1.17	18	0.36	9	36	0.16	0.36	0.08	0.31
Spring	46	0.05	0.38	1.28	84	0.38	40	174	0.71	0.38	0.34	1.48
Summer	42	0.06	0.31	1.17	96	0.31	52	176	0.81	0.31	0.44	1.50
Fall	145	0.16	0.27	1.77	274	0.28	160	468	2.33	0.28	1.36	3.98

Table 7. Harbour porpoise abundance estimates. n=number of groups sighted, ER=encounter rate (per km), cv.ER=coefficient of variation of the encounter rate, GS=estimated group size, N=estimated abundance, cv.N=coefficient of variation of the abundance estimates, D=estimated density (per 25 km^2), cv.D = coefficient of variation of the density estimates, L95 and U95=lower and upper bounds of a log-normal 95% confidence interval.

Season	n	ER	cv.ER	GS	N	cv.N	L95.N	U95.N	D	cv.D	L95.D	U95.D
Winter	188	0.15	0.40	1.79	584	0.40	274	1242	4.97	0.40	2.33	10.56
Spring	218	0.24	0.21	1.43	915	0.21	603	1387	7.78	0.21	5.13	11.80
Summer	207	0.28	0.23	1.35	1089	0.22	709	1674	9.27	0.22	6.03	14.25
Fall	330	0.37	0.19	1.73	1430	0.19	986	2073	12.17	0.19	8.39	17.64

Table 8. Dall's porpoise abundance estimates. n=number of groups sighted, ER=encounter rate (per km), cv.ER=coefficient of variation of the encounter rate, GS=estimated group size, N=estimated abundance, cv.N=coefficient of variation of the abundance estimates, D=estimated density (per 25 km^2), cv.D = coefficient of variation of the density estimates, L95 and U95=lower and upper bounds of a log-normal 95% confidence interval.

Season	n	ER	cv.ER	GS	N	cv.N	L95.N	U95.N	D	cv.D	L95.D	U95.D
Winter	134	0.11	0.28	2.73	362	0.30	203	643	3.08	0.30	1.73	5.47
Spring	34	0.04	0.35	2.12	131	0.39	62	278	1.12	0.39	0.53	2.37
Summer	18	0.02	0.44	2.25	89	0.48	36	218	0.76	0.48	0.31	1.86
Fall	60	0.07	0.42	2.22	182	0.43	80	413	1.55	0.43	0.68	3.52

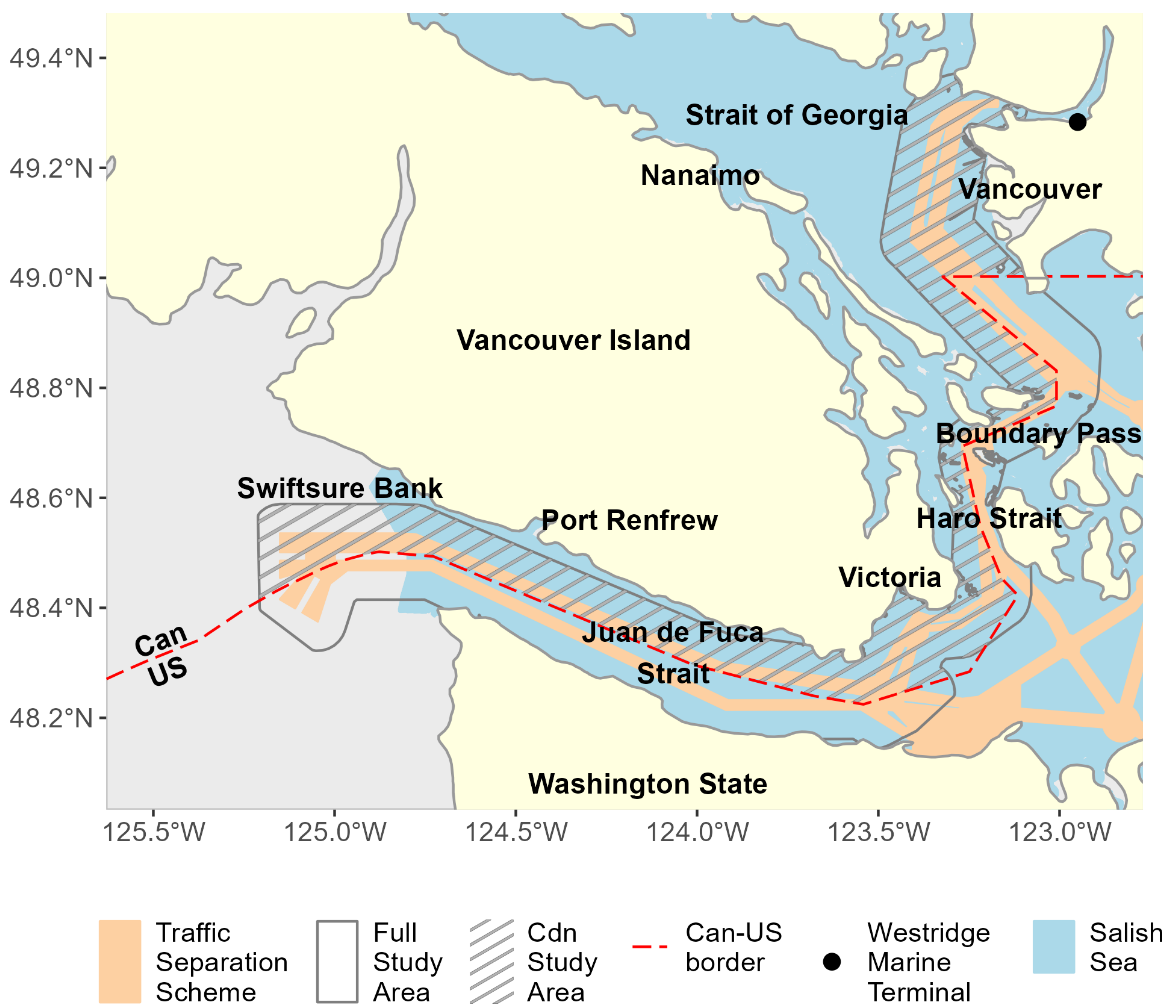

Figure 1. Study area, highlighting the inbound and outbound shipping lanes (traffic separation scheme, TSS), the full study area, and the Canadian portions of the study area surveyed to date.

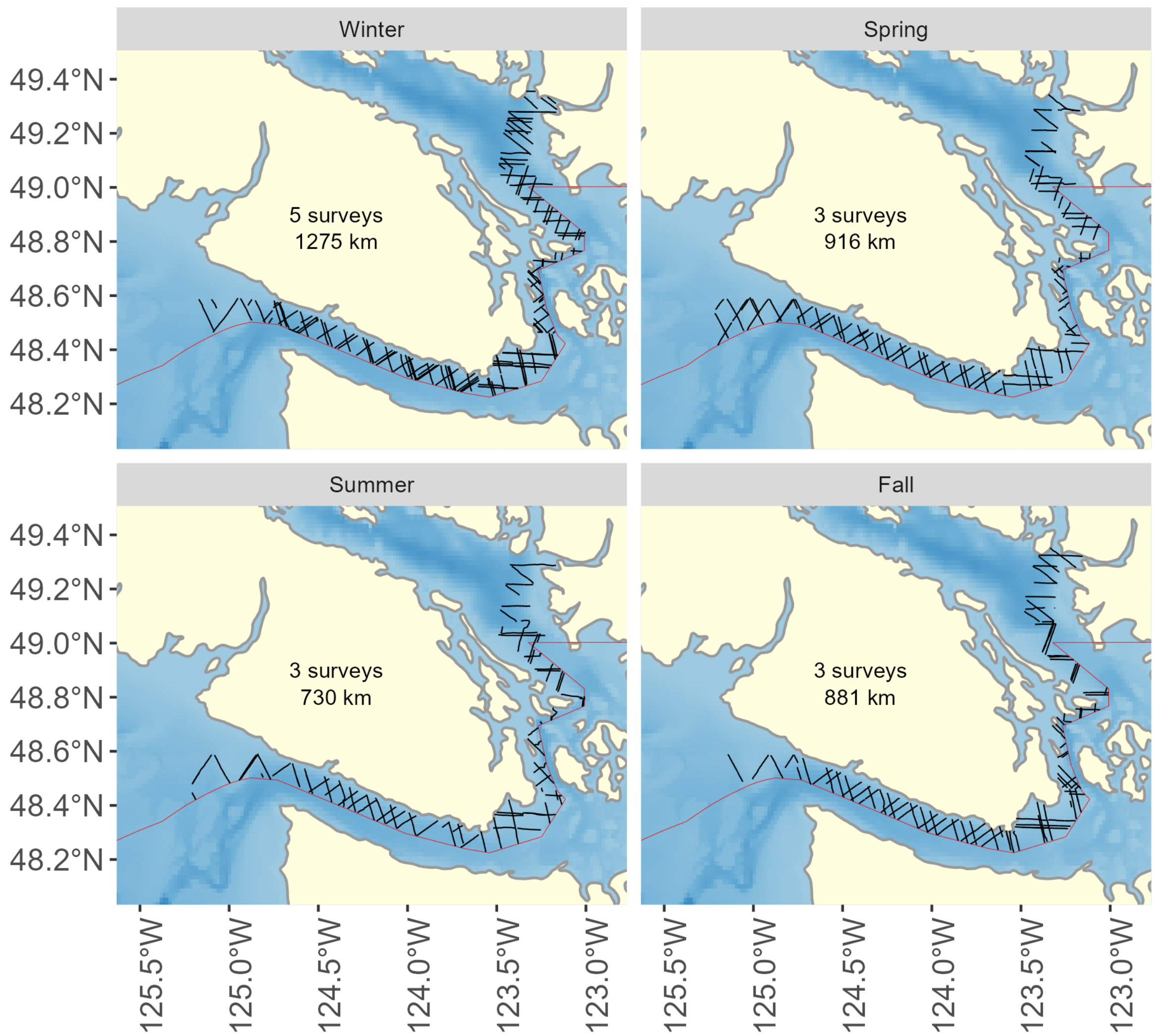

Figure 2. Realized seasonal survey effort from September 2020 to February 2022. Number of monthly surveys conducted and total realized effort in km displayed by season. Winter = January through March, spring = April through June, summer = July through September, fall = October through December.

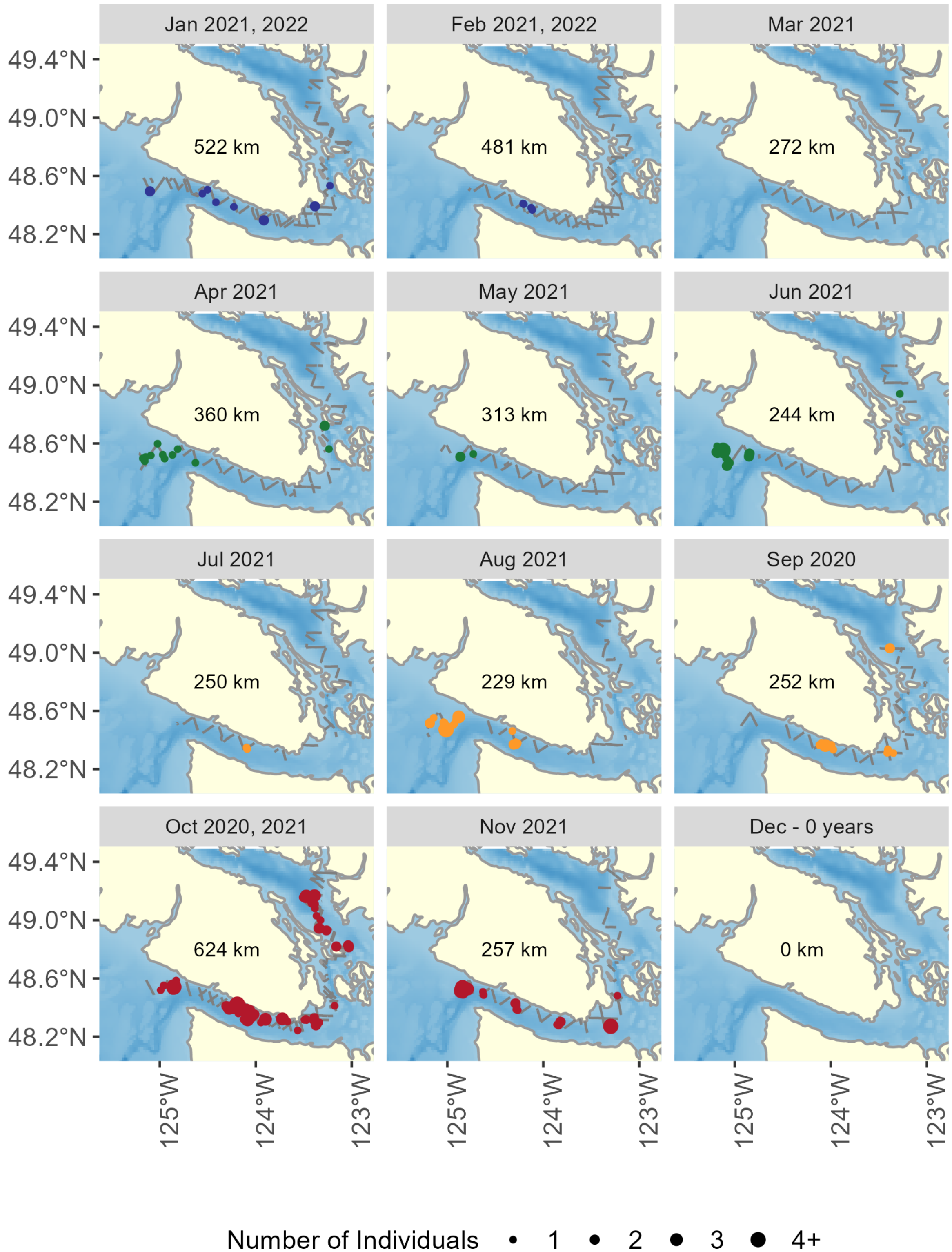

Figure 3. Humpback whale on-effort sightings and realized survey effort by month from September 2020 to February 2022. No surveys have yet been conducted in December. Monthly data are pooled over years. Relative point size indicates group size for each sighting. Total realized effort in km displayed by month. Months are grouped into seasons across rows. Blue = winter, green = spring, orange = summer, and red = fall.

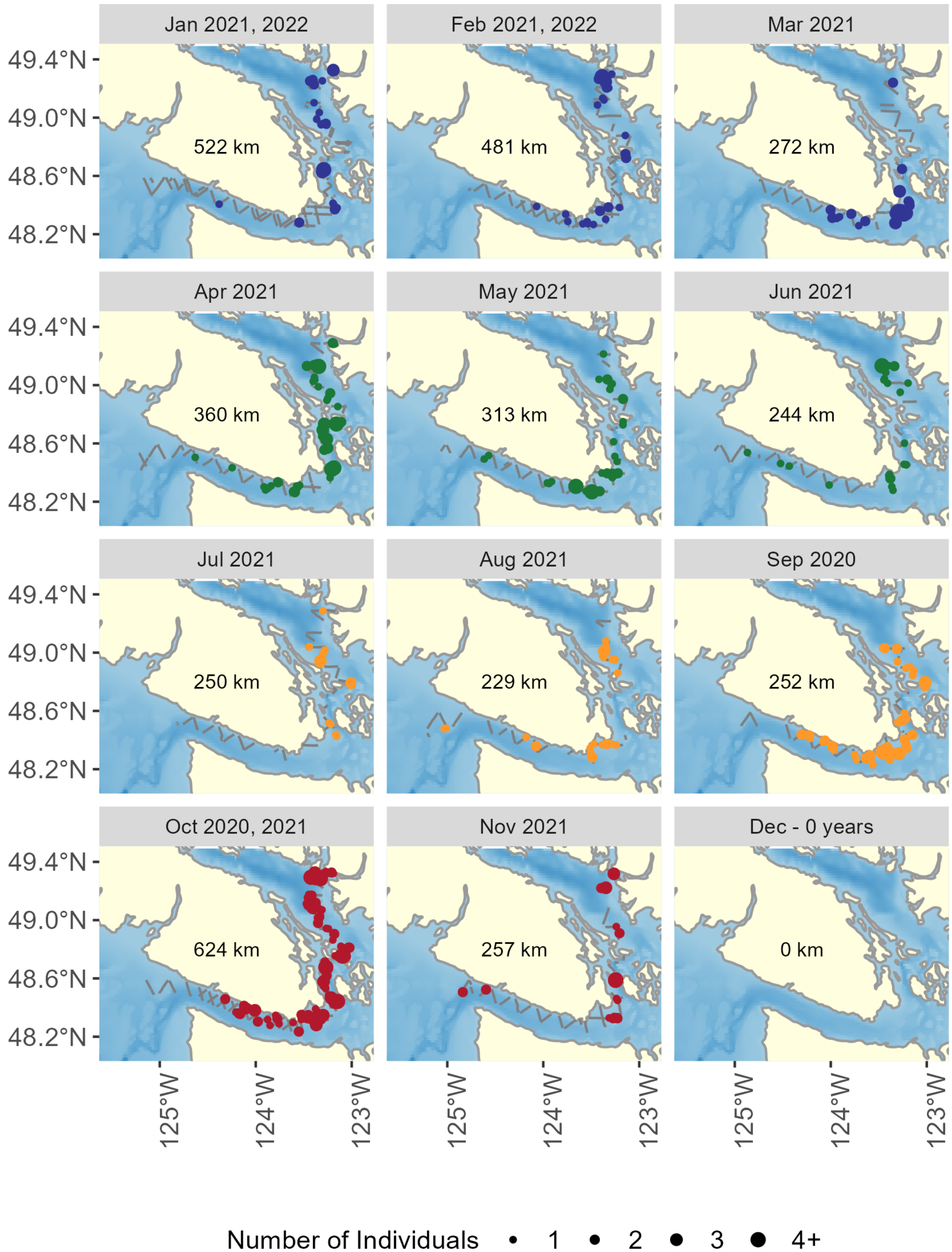

Figure 4. Harbour porpoise on-effort sightings and realized survey effort by month from September 2020 to February 2022. No surveys have yet been conducted in December. Monthly data are pooled over years. Relative point size indicates group size for each sighting. Total realized effort in km displayed by month. Months are grouped into seasons across rows. Blue = winter, green = spring, orange = summer, and red = fall.

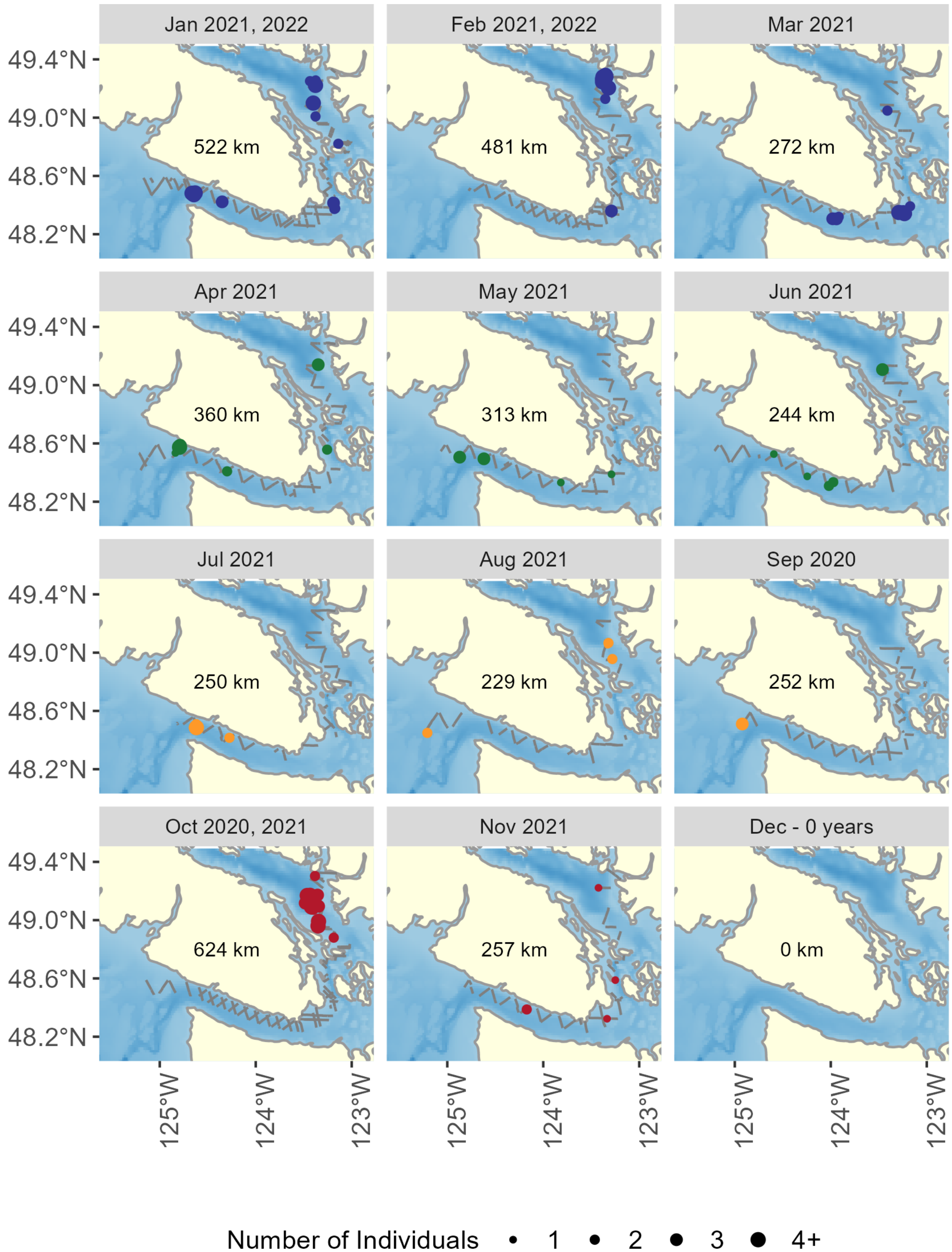

Figure 5. Dall's porpoise on-effort sightings and realized survey effort by month from September 2020 to February 2022. No surveys have yet been conducted in December. Monthly data are pooled over years. Relative point size indicates group size for each sighting. Total realized effort in km displayed by month. Months are grouped into seasons across rows. Blue = winter, green = spring, orange = summer, and red = fall.

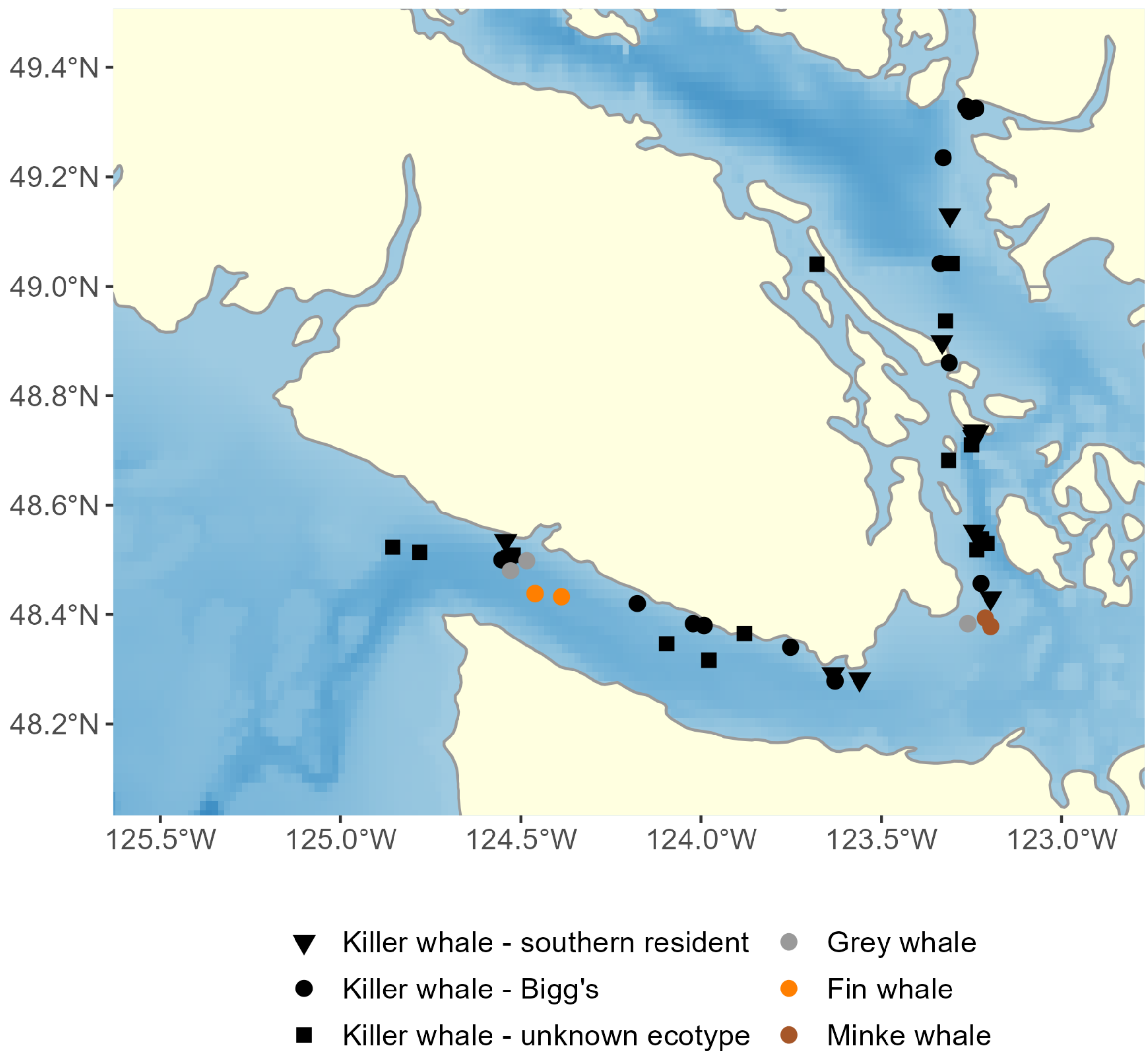

Figure 6. Detections of species (killer whales, fin whales, grey whales, and minke whales) with insufficient sightings to fit detection functions. Includes detections during on-effort surveying and off-effort transiting.

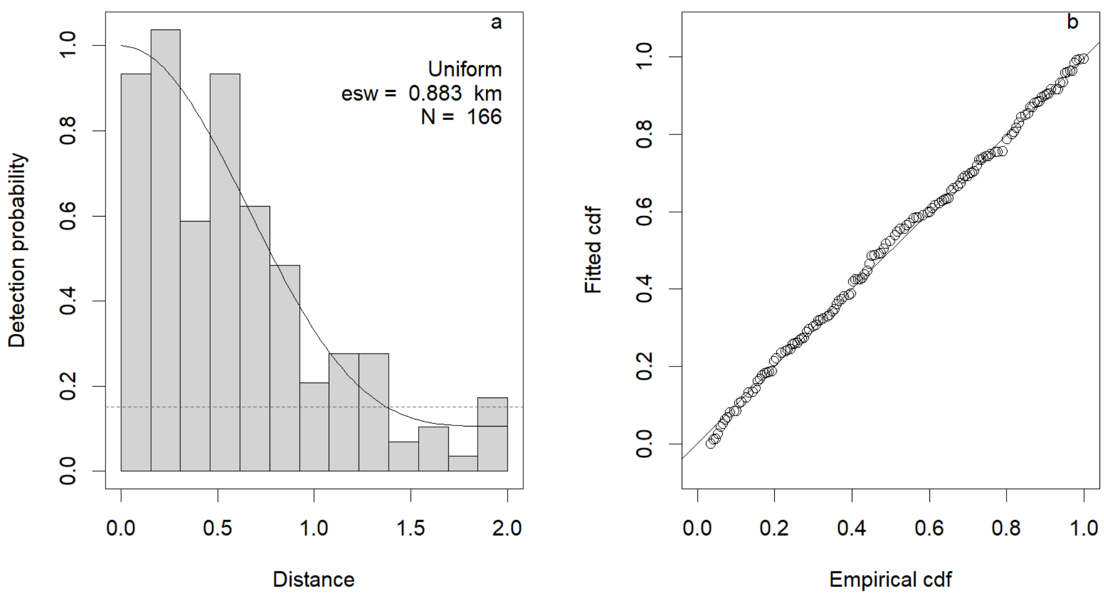

Figure 7. a) Histogram of perpendicular sighting distances of humpback whales with the selected detection function model (uniform key function with cosine adjustment of order 1, 2). The key function of the model, effective strip half-width (esw) and number of individual humpback whales sighted (N, within truncation of 2.0 km) are included. The dotted line indicates where estimated detection probability is 0.15. b) Q-Q plot (fitted cumulative distribution (cdf) against empirical cdf) for the selected detection function model for assessment of goodness of fit.

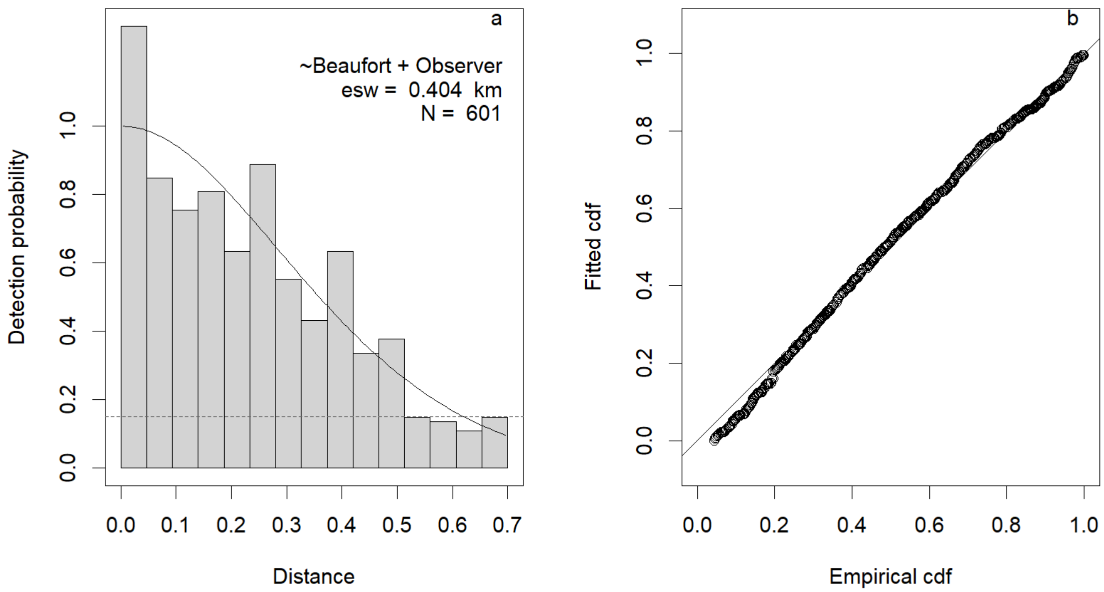

Figure 8. a) Histogram of perpendicular sighting distances of harbour porpoises with the selected detection function model (half-normal key function with Beaufort and observer as covariates). The key function of the model, effective strip half-width (esw) and number of individual harbour porpoises sighted (N, within truncation of 0.7 km) are included. The dotted line indicates where estimated detection probability is 0.15. b) Q-Q plot (fitted cumulative distribution (cdf) against empirical cdf) for the selected detection function model for assessment of goodness of fit.

Figure 9. Distribution of perpendicular distances of harbour porpoise detections at Beaufort sea state categories of 0-1, 2, and 3+. Porpoise sightings are truncated at a perpendicular distance of 0.7 km. The shape of the violin plots indicate the distribution of the data; i.e. wider sections indicate areas of higher probability that the perpendicular distances will fall in these ranges. Boxplots within the violin plots indicate the median and interquartile ranges of perpendicular distances. The number of harbour porpoise detections at each Beaufort category are included at the top of each plot.

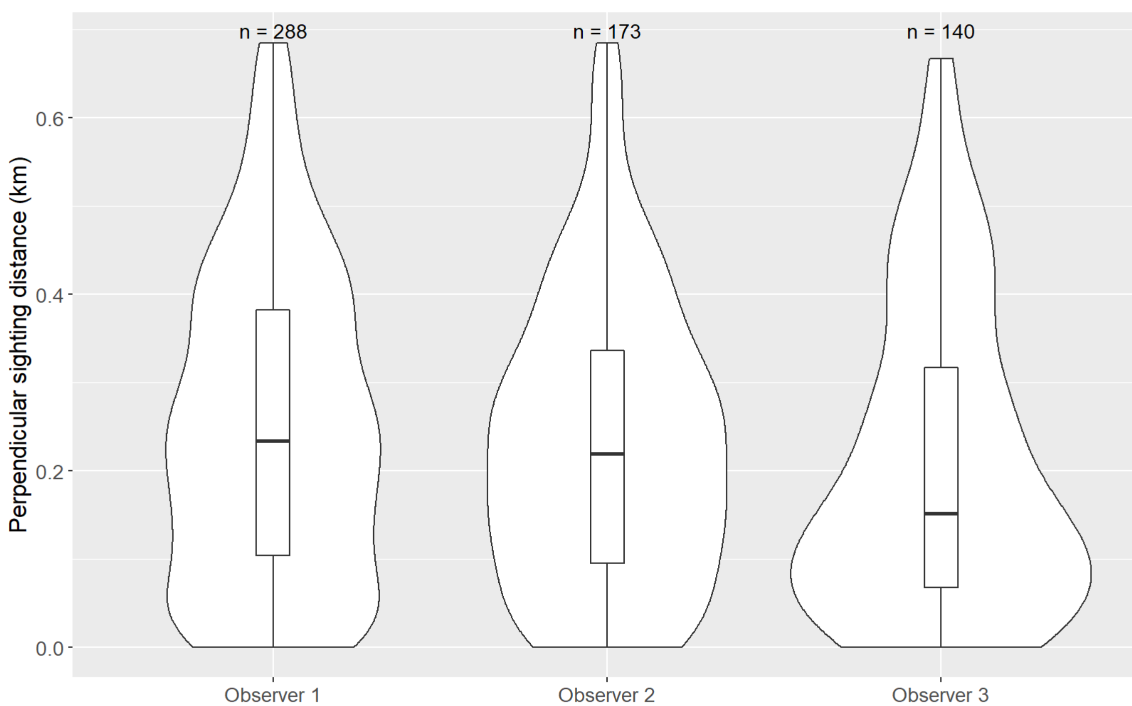

Figure 10. Distribution of perpendicular distances of harbour porpoise detections by unique observer. Porpoise sightings are truncated at a perpendicular distance of 0.7 km. The shape of the violin plots indicate the distribution of the data; i.e. wider sections indicate areas of higher probability that the perpendicular distances will fall in these ranges. Boxplots within the violin plots indicate the median and interquartile ranges of perpendicular distances. The number of harbour porpoise detections by each observer are included at the top of each plot.

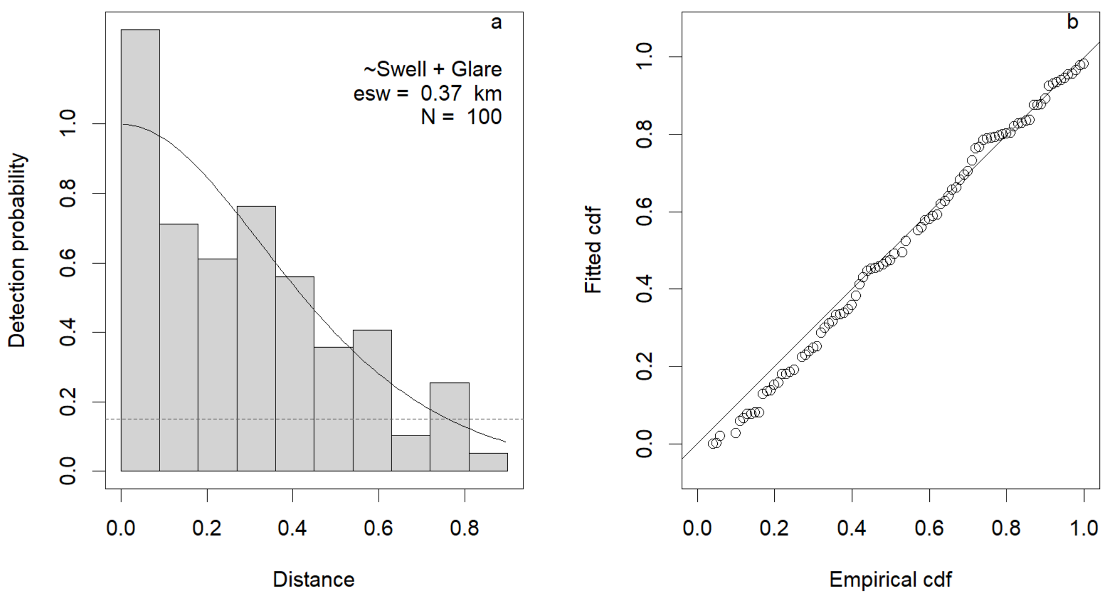

Figure 11. a) Histogram of perpendicular sighting distances of Dall's porpoises with the selected detection function model (half-normal key function with swell and glare as covariates). The key function of the model, effective strip half-width (esw) and number of individual Dall's porpoises sighted (N, within truncation of 0.9 km) are included. The dotted line indicates where estimated detection probability is 0.15. b) Q-Q plot (fitted cumulative distribution (cdf) against empirical cdf) for the selected detection function model for assessment of goodness of fit.

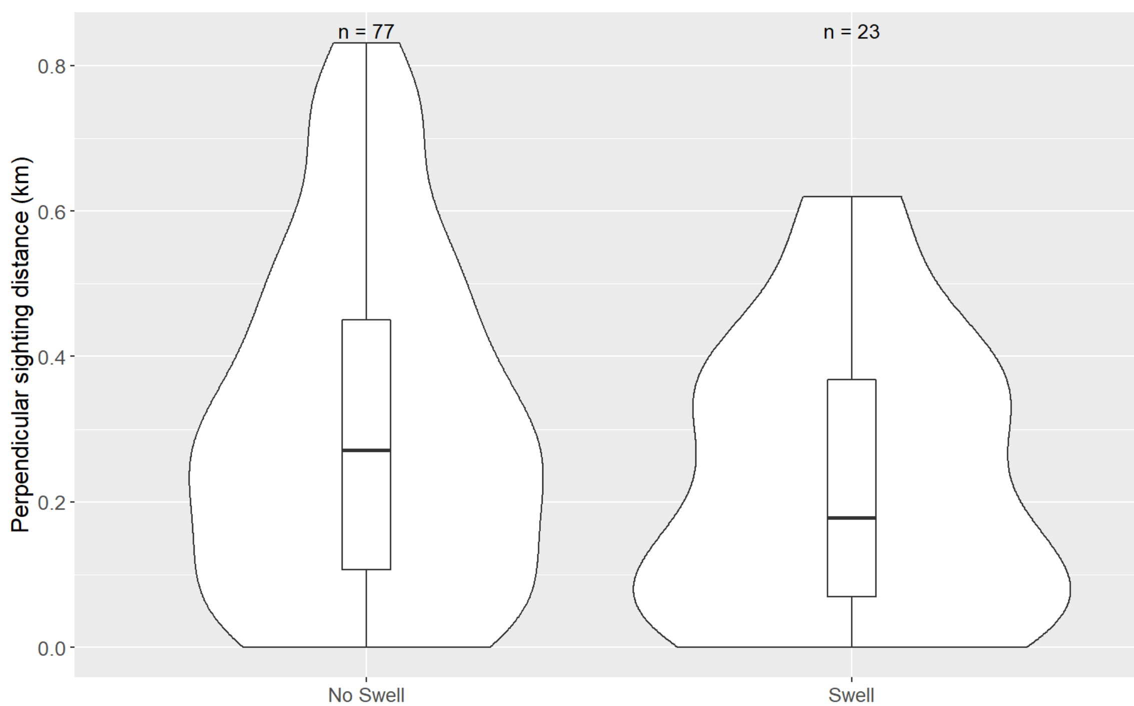

Figure 12. Distribution of perpendicular distances of Dall's porpoise detections with swell presence/absence. Sightings are truncated at a perpendicular distance of 0.9 km. The shape of the violin plots indicate the distribution of the data; i.e. wider sections indicate areas of higher probability that the perpendicular distances will fall in these ranges. Boxplots within the violin plots indicate the median and interquartile ranges of perpendicular distances. The number of Dall's porpoise detections in each swell category are included at the top of each plot.

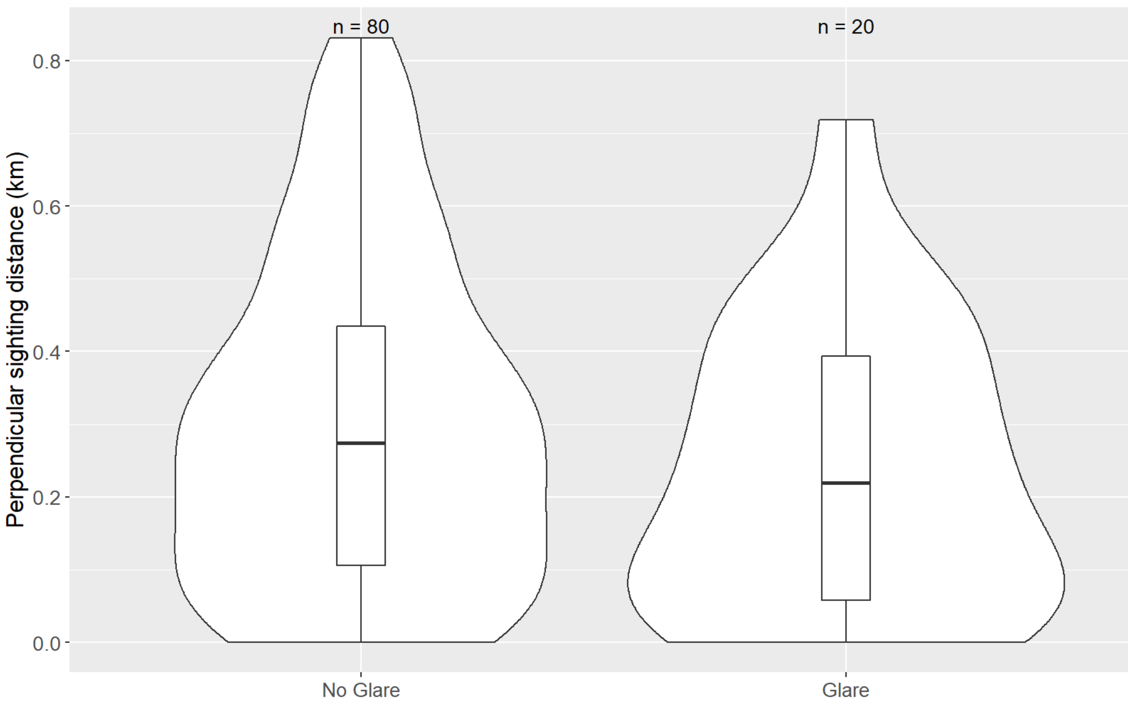

Figure 13. Distribution of perpendicular distances of Dall's porpoise detections with glare presence/absence. Sightings are truncated at a perpendicular distance of 0.9 km. The shape of the violin plots indicate the distribution of the data; i.e. wider sections indicate areas of higher probability that the perpendicular distances will fall in these ranges. Boxplots within the violin plots indicate the median and interquartile ranges of perpendicular distances. The number of Dall's porpoise detections in each glare category are included at the top of each plot.

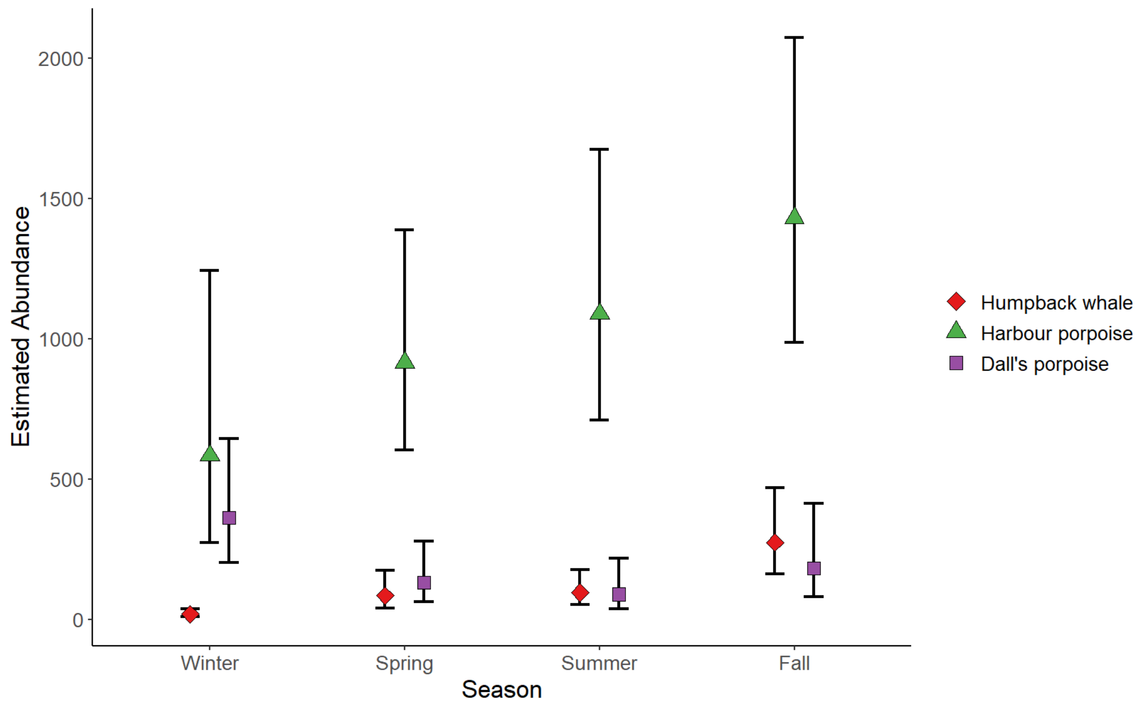

Figure 14. Estimated species abundance by season with the lower and upper bounds of a log-normal 95% confidence interval.