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Distribution of North Atlantic Right Whales, *Eubalaena glacialis*, in Eastern Canada from Line-Transect Surveys from 2017 to 2022

Anne P. St-Pierre[1], Talia Koll-Egyed[1], Valérie Harvey[1], Jack W. Lawson[2], Caroline Sauvé[1], Angélique Ollier[1], Pierre J. Goulet[2], Mike O. Hammill[1], Jean-François Gosselin[1]

[1] Maurice Lamontagne Institute
Fisheries and Oceans Canada
850 route de la Mer
Mont-Joli, Québec, G5H 3Z4

[2] Northwest Atlantic Fisheries Centre
Fisheries and Oceans Canada
80 East White Hills Road
St. John's, NL, A1C 5X1

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

In response to the unusually high number of North Atlantic Right Whales (NARW) carcasses (N=12) reported in the Gulf of St. Lawrence (GSL) in 2017, an unprecedented aerial survey effort was deployed for the monitoring of NARW presence in Canadian waters starting in late August 2017. Between 2017 and 2022, a total of 561,187 km of systematic transect lines have been surveyed over periods of up to 7.5 months in some years, involving up to three aircraft simultaneously. Survey effort was deployed in potential NARW foraging areas across eastern Canadian waters, by covering the entire GSL each summer, and the Scotian Shelf and the continental shelf around Newfoundland and southern Labrador every second summer. A total of 185 NARW groups (246 whales) were observed by primary observers during the systematic surveys, with 6 groups in 2017, 25 groups in 2018, 23 groups in 2019, 43 groups in 2020, 31 groups in 2021, and 57 groups in 2022. The vast majority of NARW sightings (93%) occurred in the two survey stratum in the southern GSL (i.e., separated into southeastern and southwestern stratum), however this area accounted for ~58% of the total survey effort. Abundance estimates in this study were calculated based on a distance sampling approach, and reported for each survey pass of each stratum in order to compare abundances among strata and over time (i.e., within a survey season in the case of repeated surveys, and also across years). Two correction factors specific to NARW and to the region surveyed were computed to correct inherent biases of aerial surveys, i.e., availability bias, for animals underwater when the aircraft passed overhead, and perception bias, for animals at the surface of the water that are missed by observers. These two corrections increased abundance estimates by a factor of ~3. While NARW were consistently detected at the beginning (May to mid-June) and at the end (September to November) of the survey season in the southeastern GSL stratum, they also occur in this area in July and August. Indeed, the highest abundance estimate in this stratum across survey years was recorded for the survey conducted in mid-August 2022 (97 animals, CI: 31-308). In the southwestern GSL stratum, peak abundances were observed consistently observed each year between early June and early August. The highest fully corrected abundance for the study period came from a pass of the southwestern GSL stratum in mid-June 2018, with 281 animals (CI: 100-790). All surveys of the southwestern GSL stratum conducted between June and end of August reported observations of NARW. Systematic aerial surveys are one of the set of tools available to monitor NARW which, combined with other approaches such as acoustic monitoring, provide useful information required for the conservation of the species.

INTRODUCTION

North Atlantic Right Whales (NARW), *Eubalaena glacialis*, have been designated as “Endangered” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2013), and “Critically Endangered” on the International Union for Conversation of Nature (IUCN) Red List (Cooke 2020), due to their current small population and decline caused by commercial whaling and mortality from ship strikes and entanglement in fishing gear, as well as declines in productivity (Aguilar 1986, Pace III et al. 2017, Reeves et al. 1999, Meyer-Gutbrod and Greene 2018). NARW occur regularly along the east coast of North America from Florida to the Gulf of St. Lawrence (GSL), with occasional sightings in Bermuda and the Caribbean to the south and the Davis Strait and Iceland to the north, as well as off Norway and the Azores (Davis et al. 2017, Hayes et al. 2018a, Jacobsen et al. 2004, Silva et al. 2012, Hayes et al. 2018b).

Due to their recurring seasonal use of some specific areas throughout their range, critical habitat for NARW have been identified in both Canada and the United States (Brown et al. 2009, NMSF 2016). Prior to 1995, most NARW sightings in Canadian waters were reported in summer in the Bay of Fundy and the nearby waters of the western Scotian Shelf (SS), with occasional sightings reported along the east and south coasts of Newfoundland and in the GSL (Daoust et al. 2017, Lien et al. 1989, Reeves 2001). Yet, NARW were not detected in the GSL during large-scale surveys of the area flown by the Department of Fisheries and Oceans Canada (DFO) in 1995, 1996, 2007, and 2016, although the latter did detect NARW on the SS and in the Bay of Fundy (Kingsley 1998, Lawson and Gosselin 2009, Lawson and Gosselin unpubl. data). Since 2015, there has been an increase in observations of NARW in the Gaspé-Magdalen Islands-Miscou area, which has been attributed to both a change in the distribution of NARW and increased survey effort in this area (Daoust et al. 2017, Cole et al. 2016, Meyer-Gutbrod et al. 2023). In addition, acoustic monitoring from 2011 to 2018 showed an increase in NARW vocalizations in the southern GSL since 2015 (Simard et al. 2019, DFO 2018). At the same time, anomalously low occurrences of NARW were reported in the traditional summering areas of Grand Manan and Roseway Basins between 2010 and 2016, also suggesting a shift of distribution (Davies et al. 2019, Meyer-Gutbrod et al. 2023). Hence, there was a call for increased monitoring efforts in several regions of Atlantic Canada including the GSL, the SS, and the Newfoundland and Labrador Shelf, to identify areas used by NARW, determine where NARW aggregations occur, and better understand the timing of NARW arrivals and departure from these areas (DFO 2018).

In 2017, 12 carcasses of NARW were found in the GSL between early June and late July (Daoust et al. 2017). The cause of death for six of the whales was attributed to either ship strikes or entanglement in fishing gear, which are known to be major sources of mortality for this species (Daoust et al. 2017, Kraus et al. 2005, Moore et al. 2004). Monitoring efforts established in the summer of 2017 gathered information on the distribution and abundance of NARW in the GSL and other areas of Canadian waters representing potentially suitable foraging habitats for NARW. In the following months, the government of Canada, in collaboration with industry, developed management measures intended to reduce NARW mortalities that have evolved over time to include a combination of speed reductions, and temporary or seasonal area closures of fisheries.

Information on the distribution and abundance of NARW in Canadian Atlantic waters was limited prior to the onset of targeted surveys in 2017 and broad-scale, repeated surveys in 2018. Given the apparent shift in summer distribution of NARW in Canadian waters, it was recognized that several regions in Canada could benefit from increased search efforts to determine their use by NARW, such as the GSL, most SS waters, and north of Newfoundland (Brillant et al. 2015, Knowlton et al. 2012, Pace III et al. 2017). The DFO NARW aerial surveillance program was develop to palliate this lack of data, with the specific objectives of 1) conducting scientific surveys in various areas to better understand NARW distribution and abundance, 2) monitoring whale presence around active fisheries, and 3) monitoring fishery closure areas to ensure compliance with the law.

This study presents results from the DFO Science NARW aerial surveillance program conducted from August 2017 to November 2022 across Atlantic Canada and focuses solely on NARW abundance and distribution. In particular, it presents the variability in abundance estimates among years and within the survey season each year. These results will contribute to providing advice on the spatial and temporal distribution of NARW in Canadian waters and to identifying potential areas where NARW occur across Atlantic Canadian waters, especially outside of the traditional areas in the Bay of Fundy and nearby SS waters.

METHODS

SURVEY COVERAGE AND DESIGN

In 2017, to assist with the development of a surveillance program, we examined the distribution of important NARW prey (*Calanus* spp.) and NARW energy requirements to identify potential foraging areas in the GSL and on the SS, where NARW presence was assumed to be more likely (Plourde et al. 2019). Fifteen strata were identified as potential foraging areas and were covered with a systematic parallel line design with random start and line spacing of 9.26 km (5 nautical miles) using the DFO Twin Otter from 29 August to 15 November 2017 (Figures 1 and 2). From late June to September 2017, the National Oceanic and Atmospheric Administration (NOAA) Twin Otter and Transport Canada's National Aerial Surveillance Program (NASP) Dash-8 surveyed the area of the southern GSL where an aggregation of NARWs was observed; however, these platforms did not apply the systematic survey protocol described below and used by the DFO Science platforms and, thus, observations from these platforms are not included in abundance analyses presented in this study. The DFO Twin Otter coverage was meant to complement the NOAA and NASP efforts to detect the presence of additional aggregations of NARW in other potential foraging areas of Canadian waters. The DFO Twin Otter was also sent to check areas where possible or definite NARW sightings were reported. This led to a fragmented and incomplete coverage of the planned design by the DFO Twin Otter in 2017 (Figures 2 and 3).

Starting in 2018, systematic surveys were implemented for DFO-Science aircrafts based on potential foraging areas and observations from the previous year. The area surveyed in 2018 covered the GSL, south coast of Newfoundland, SS, and Bay of Fundy (Figure 2). The southern GSL has been consistently surveyed several times per year since 2018. In the following years, for areas outside of the GSL, we alternated between the waters off the coast of Newfoundland and Labrador and the SS as a compromise between maintaining seasonal coverage of areas where NARW have been observed (mainly in the southern GSL) and increasing geographical coverage. In 2019 and 2021, the continental shelf off southern Labrador, the Grand Banks, and the south coast of Newfoundland were surveyed (Figure 2), in addition to the Bay of Fundy, the southwestern SS, and the entire GSL. In 2020 and 2022, surveys covered the SS, Bay of Fundy, the southwestern Scotian Shelf, as well as southern and western portions of the GSL (Figure 2). The survey area in the southern GSL was separated into two strata (southeastern and southwestern) to better capture differences in NARW abundance and spatial distribution between the Shediac and the Bradelle Valleys throughout the repeated surveys.

From 2018 to 2022, survey lines with a line spacing of 9.26 km (5 nautical miles) were placed over the Bay of Fundy, southern GSL, and northwestern GSL for an increased coverage of areas with higher likelihood of NARW sightings. In 2018, a line spacing of 9.26 km (5 nautical miles) was also used over the Cabot Strait. A wider line spacing of 18.52 km (10 nautical miles) was used in other areas in all years except 2017 (see above; Figure 2). The survey lines were generally oriented perpendicular to major isobaths. The lines were oriented east-west in the southern GSL starting in 2018 to be approximately perpendicular to the longer axis of the distribution of reported 2017 NARW sightings. The parallel survey designs were systematic with a different random start for each set of lines when a stratum was surveyed more than once, except for the southern GSL strata in 2020-2022 where the lines were at pre-defined latitudes to improve coordination and efficiency of platforms between systematic survey efforts and fisheries dynamic management requirements. The strata off Newfoundland and Labrador followed a zigzag design. The design of the South Newfoundland stratum provided a coverage similar to the parallel design with 18.52 km (10 nm) spacing, and the design for the three strata covering the southeast, east, and northeast of Newfoundland and southern Labrador provided half that coverage. Additional lines with spacing of 9.26 km (5 nautical miles) were completed over temporarily closed fishing areas as part of DFO's dynamic fishery management measures in the southern GSL and the Bay of Fundy, but are not considered part of the systematic survey effort. The aerial survey was flown at an altitude of 305 m (1,000 feet) in 2017 and 244 m (800 feet) in 2018-2022, and at a target speed of 185 km/h (100 knots). The length of the transect lines (used to estimate density) and the area of each stratum (used to estimate abundance) were measured in either a geographic information system (ArcView 3.2, ESRI) or in R 4.3.0 (R Development Core Team 2018) with the package "sf" (Bivand et al. 2013), in both cases using the Lambert Azimuthal Equal Area (Canada) projection, with -61.6°W as the central meridian and reference latitude of 48.03°N.

Platforms

Three different platform types were used during surveys, all being high wing, twin engine aircraft: 1) a DeHavilland DH-6 Twin Otter 300, 2) a Cessna 337 Skymaster, and 3) a Partenavia P68 Observer. The Twin Otter was the only platform used for systematic surveys in 2017. In subsequent years when multiple aircraft were used, they were generally assigned to different survey strata. The period during which one, two, or three aircraft were conducting surveys simultaneously varied among years.

The Twin Otter had two (left and right) forward bubble side windows immediately behind the cockpit bulkhead, plus a bubble window in the right rear door. The Cessna 337 Skymasters had bubble windows at all three observer positions, i.e., at the co-pilot seat, and both left and right rear seats. The Partenavia P68 Observer had bubble windows at both left and right rear seats, and a large window at the co-pilot seat. Surveys were flown either in single platform configuration, i.e., with one observer on each side of the aircraft, or in double platform configuration, i.e., with two observers on the right side of the plane surveying the same area, in addition to the left (single) observer. In all platform types, observers within an aircraft were isolated from each other visually and aurally.

In the Twin Otter, in addition to the observers, an additional team member seated in an intermediate position acted as a navigator and data recorder using a custom survey program (2017-2018: Voice Operated Recorder [VOR]; 2019-2022 Visual Surveyor). Weather conditions and observations were reported by the observers to the data recorder via a dedicated intercom system, which also acoustically isolated the observers. At all times the aircraft position on the track line was recorded every 1 or 2 s via the survey software. Observers rotated positions at the end of each transect line or at irregular intervals during longer transects, except from 2020 to 2022 when COVID-19 protocols were in place and observers maintained the same position for the whole day.

In the Cessna and Partenavia, single platform surveys were conducted with one observer on each side of the aircraft, seated in the left rear and copilot seats (Cessna) or in the two rear seats (Partenavia). The position and altitude of the aircraft were recorded every two seconds on a GPS (Garmin GPSMap 78s, Garmin GPSMap 64s, and/or BadElf Pro+). Weather and observation data (see below) were recorded by each observer separately on digital audio recorders and later transcribed to a standardized template. Observers rotated positions at the end of each flight or at the end of each day while COVID-19 protocols were in place.

Survey method

All observers received line-transect sampling training prior to the surveys. Observers were instructed to record observations of all marine megafauna species encountered including large and small cetaceans, seals, sea turtles, sunfish, large sharks, tuna, and other species. The sightings were recorded as groups of whales, along with number of whales in the group (*i.e.,* cluster size). Groups were defined as animals swimming within a few body lengths of each other. Observers recorded the time when animals passed abeam of the aircraft and measured the inclination angle to the center of each group using clinometers (Suunto) or digital geometers (Pi Technologies; Hansen et al. 2019) in the case of the Twin Otter from 2019-2022. The relative bearing was recorded using an angle meter when inclination was measured for distant animals that were not abeam. The perpendicular distance of the animals from the plane was obtained from the inclination angle and the altitude using the formula by Lerczak and Hobbs (1998). Observers were instructed to give priority to the time of observation, species, and estimation of group size, followed by inclination angle and then other variables such as animal behaviour and any changes in behaviour assumed to be a reaction to the approaching plane, if time permitted.

Weather and observation conditions were recorded at the beginning of each transect line, at regular intervals along the lines, and whenever changes in sighting conditions occurred. The conditions noted included sea state (Beaufort scale), subjective visibility (5 levels: excellent, good, medium, low, null), cloud cover (percent), angle of searching area affected by sun reflection (i.e., glare), and sun reflection intensity (4 levels: 1- intense when animals were certainly missed in the center of reflection angle; 2- medium when animals were likely missed in the center of reflection angle, 3- low when animals were likely detected in center of reflection angle and 4- none when there was no reflection). Surveys were only initiated when sea conditions were Beaufort 3 or less, and when cloud cover was above the target altitude. Time when observers began and ended to actively search for animals (i.e., “on-effort”) was also recorded. The time recorded by each observer for sightings and conditions was synchronized with the GPS (either within the recording system for the Twin Otter, or post-hoc). The position of each observation was then estimated using time and interpolation from consecutive GPS outputs.

Closing procedure

When a NARW or possible NARW was detected on the trackline (i.e., while the observers were in “passing mode”, actively observing), the observer teams were instructed to break the transect line after recording the sighting-related data (see above) and to circle over the detection area for at least 20 minutes to confirm species identification and get an estimate of the number of NARW present in the area. The number of unique whales was recorded during these closing mode procedures and animals were photographed when possible for further individual identification. After the closing mode procedure was completed, survey on the track line was resumed at the original break off point. Additional NARW observed during closing mode were not included in the abundance analysis, as closing mode sightings are considered off-effort and therefore do not contribute to the total survey effort.

ABUNDANCE ESTIMATIONS

Data preparation and analyses

Analysis of the visual survey can be separated into five steps, described in more detail below: 1) data preparation, including identification of outliers and truncation distances; 2) selection of the key function and covariates of the detection function; 3) bootstrapping to include observations with missing perpendicular distances into the abundance estimates; and application of the 4) availability bias and 5) perception bias correction factors. To ensure a sufficiently large sample size, these five steps were applied to the combined data from all survey years. In addition, NARW sightings obtained from flights over temporarily closed fishing areas as part of the dynamic management measures of fisheries, which used the same observation protocol, were used to increase the sample size of observations for estimating the detection function. However, these observations were not used to calculate abundances as they were not part of the systematic survey effort.

Analyses were completed using the ungrouped perpendicular distances of observed NARW groups. The minimal statistical unit was an "observation" or "sighting", which refers to a group of animals detected by an observer where group size is one whale or more. Abundance for each survey stratum was estimated using a distance sampling approach and the package "mrds" (Laake et al. 2013) in R 4.3.0 (R Development Core Team 2018).

The overall distribution of perpendicular distances was examined to determine if right truncation was necessary to discard outliers far from the track line. Five potential right truncation distances were tested: 1) no truncation; 2) removal of the observations with distances greater than that of an obvious gap in the distribution of observed perpendicular distances; 3) removal of 10% of the observations furthest from the track line; 4) removal of outliers based on a boxplot analysis (i.e., values greater than 75% quartile); and 5) removal of observations with distances greater than the perpendicular distance at which the detection function from a hazard rate model reached a probability of detection of 0.15 (Buckland et al. 2001). The right truncation distance providing the best fit of the detection function near the track line while maintaining good overall fit, was applied (Buckland et al. 2001).

Generally, line transect surveys assume maximum probability of detection on the track line but, because there may be a blind area underneath the plane depending on the type of aircraft and size of bubble windows used, this assumption is not always met. This can be corrected for by applying a left truncation to the data (Thomas et al. 2009) to discard observations with perpendicular distances shorter than that at which the maximum probability of detection is estimated. In the present analysis, no left truncations were applied and, instead, a gamma key function was tested during detection function selection to fit the reduced number of detections near the track line (Laake et al. 2013; see below). This approach is more objective than applying a left truncation to the data and allows the complete use of the observation data.

Choice of detection function

Model selection and inclusion of covariates followed the stepwise procedure detailed in Marques and Buckland (2003). In short, half-normal, hazard-rate, and gamma key function models, with and without adjustment terms, were fitted to the right truncated distribution of the ungrouped perpendicular sighting distances (i.e., each sighting was recorded with a perpendicular distance, sightings were not grouped into bins), and the model with the lowest

Akaike Information Criterion (AIC) was selected as the key function. Using the selected key function, we examined if AIC could be reduced further (ΔAIC >2) by the addition of one of the following covariates: group size, sea state (Beaufort: 0 to 6, also tested as 3 binned categories of 0-1, 2, and 3+), glare intensity (4 levels: Intense, medium, low, none), cloud cover (%), visibility (5 levels: excellent, good, medium, low, null), platform type ("Twin Otter" vs "Small plane", where the latter includes both Cessna and Partenavia), and altitude (305 m in 2017 vs 244 m in all other survey years). Due to their inherent relationship, the covariates for sea state, glare intensity, cloud percentage, and visibility were never combined in the same model. If AIC was significantly reduced by the addition of a covariate (ΔAIC >2; Arnold 2010), the model with the covariate was retained if it also satisfied the following additional conditions: 1) if the addition of the covariate only affected the scale and not the form of the detection function (e.g., covariate was not included if its addition created a new spike compared to the key function or previous step's model); and 2) if < 5% of the estimated probabilities of detection of sightings were < 0.2 and none were < 0.1 (Buckland et al. 2001, Laake et al. 2013). The addition of a second covariate into the model was tested and retained only if it reduced the AIC by > 2 while still respecting the above conditions.

Calculation of abundance indices

In distance sampling analyses, the estimated indices of density ($\widehat{D}_i$) and abundance ($\widehat{N}_i$) of NARW at the surface during each systematic survey of each stratum, *i*, are estimated using the following equations (equation 3.67 in Buckland et al. 2001).

$$\widehat{D_i} = \frac{n_i \cdot \hat{E}_i(s)}{2L_i \cdot \widehat{ESHW}} \qquad \text{[Eq. 1]}$$

$$\widehat{N}_i = \widehat{D}_i \cdot A_i \qquad \text{[Eq. 2]}$$

where n_i is the number of groups detected, $\hat{E}_i(s)$ is the expected cluster size, L_i is the sum of lengths of all transects, and A_i is the area of the stratum *i*. The estimated effective strip half-width ($\widehat{ESHW}$) is estimated from the selected detection function (see above, "Choice of detection function"). In theory, the associated variance of density and abundance of animals at the surface during the systematic survey is estimated by the following formula:

$$\widehat{var}\left(\widehat{D}_i\right) = \widehat{D}_i^2 \cdot \left[\frac{\widehat{var}[(n/L)_i]}{(n/L)_i^2} + \frac{\widehat{var}(\widehat{ESHW})}{(\widehat{ESHW})^2} + \frac{\widehat{var}[\hat{E}_i(s)]}{[\hat{E}_i(s)]^2}\right] \qquad \text{[Eq. 3]}$$

$$\widehat{var}\left(\widehat{N}_i\right) = A_i^2 \cdot \widehat{var}(\widehat{D}_i) \qquad \text{[Eq. 4]}$$

In some cases, observations lacked a perpendicular distance measurement. This usually occurred when high animal densities were encountered over a short period of time, during which observers did not have sufficient time to record detailed information about all groups and were instructed to prioritize the recording of group size. These observations were not used for the selection of the detection function. However, observations without a recorded perpendicular distance measurement were assumed to be within truncation distances, as the effective searching width was expected to be narrower at higher densities. To include these observations without distances in the estimates of density and abundance, we assigned a randomly-selected perpendicular distance from the distribution of perpendicular distances observed within the same survey year to each observation. To that effect, a bootstrap procedure was used to calculate abundance estimates for each stratum in each survey year. In each of the 5,000 bootstrap iterations, each observation recorded without a perpendicular distance was assigned a perpendicular distance randomly selected from the distribution of observed distances within the same survey year. Then, the detection function previously selected (key function and associated covariates) was applied to the newly created dataset of observations. Estimates of abundance, density, encounter rate, expected group size, probability of detection ($\hat{P}$), and *ESWH* were obtained per stratum from the detection function applied to the newly created dataset for each iteration, with associated variances for each estimate.

Abundance indices per survey year and stratum were calculated (separately for each survey pass for years when a given stratum was surveyed multiple times) as the mean of the abundances obtained via the bootstrap procedure. The variance associated to the mean bootstrap estimate (σ_B^2) was calculated by the following formula :

$$\sigma_B^2 = var(V) + mean(\sigma_V^2) \qquad \text{[Eq. 5]}$$

where *V* is a vector of the 5,000 abundance indices estimated by the bootstrap procedure, each of which has an associated variance estimate (σ_V^2) calculated by the software using equation 3. For density, encounter rate, expected group size, probability of detection ($\hat{P}$), and *ESWH,* the mean of the bootstrap estimate per survey and stratum is presented, with associated bootstrap 95% confidence intervals derived using the percentile method.

CORRECTION FACTORS

Availability bias correction

An availability bias occurs when observers cannot detect whales because the animals are diving below depths at which they can be seen while the survey aircraft passes overhead (Laake et al. 1997, McLaren 1961). Hence, the number of animals recorded by the observers is an underestimate. In the absence of readily-available diving data from telemetry tags deployed on NARW in the GSL, NARW presence data recorded during closing procedures was used to estimate a correction factor. As a proxy for the proportion of animals available to be detected, each NARW sighting recorded on the track line was assigned an availability value (ai) calculated as the number of animals detected from the survey transect line for this specific sighting (i) divided by the total number of animals observed during the closing procedures (described above) triggered by that sighting. Sighting events for which no NARW were seen during the closing procedure cannot provide a proportion (i.e., the animal was never found again after breaking from the transect line, hence would mean dividing by zero whales seen in closing) and thus were ignored. Availability bias correction factors (â) were then calculated by averaging the availability values based on the timing of surveys and/or geographical locations. Several availability bias correction factors were considered and are described in Appendix 1. Given that most of the NARW sightings and aggregations were recorded in the Shediac valley (see Results), it was decided that an availability correction factor that separated the southwestern GSL stratum (which includes the Shediac Valley) from the rest of the survey strata would be used. In addition, surveys were divided into three periods to account for times where most whales are assumed to be travelling (i.e., from the start of the surveys in April until end of May, and from September to the end of surveys in November) and times where most whales are observed forming aggregations mainly in the Shediac Valley (June to August). Hence, a total of six availability bias correction factors were calculated which combined the zones and periods described above (see Appendix 1 for further details).

Perception bias correction

A perception bias occurs when observers fail to detect animals that are at or near the surface within the observers' field of view (Fleming and Tracey 2008, Laake et al. 1997, Marsh and Sinclair 1989, Melville et al. 2008). Once again, this means that the number of animals recorded by the observers is an underestimate. Data recorded with a double-platform configuration (see "Survey coverage – Platforms" section above) in all years surveyed was used to estimate perception bias correction factors via mark-recapture distance sampling (MRDS) analyses (Laake and Borchers 2004). All observations made by observers on the right side of the plane while both observers were actively searching for animals (i.e., “on effort”) were used for this analysis, and both observers were considered as independent platforms. All MRDS analyses were performed in R 4.3.0 (R Development Core Team 2018) with the package “mrds” (Laake et al. 2013).

Prior to conducting MRDS analyses, duplicate sightings, i.e., groups of animals detected by both the primary and secondary observers, were identified through coincidence in location based on: 1) the difference in time of recording, and 2) the difference in clinometer measurement. Species identity was also used as a criterion in duplicate identification in this analysis, meaning that both sightings needed to have the same species recorded to be considered duplicates. In the primary literature, time thresholds used in surveys of cetacean species generally vary from 3 to 10 s, while clinometer thresholds generally range from 5 to 15° (e.g., Pike and Doniol-Valcroze 2015, Pike et al. 2008, Panigada et al. 2017, Lambert et al. 2019). Based on previous surveys using the same protocol and aircraft (St-Pierre et al. 2024) and expert opinion, thresholds of 10 s and 10° were selected for identifying duplicates in this study. It was considered that these thresholds were the most likely to capture true duplicate sightings while minimizing the number of false duplicates. For observations with missing clinometer values, only the time threshold was considered.

Because MRDS analyses require that perpendicular distance and covariate values be identical for a given duplicate pair, we attributed an average value (for numeric covariates, i.e., perpendicular distance, cluster size, cloud cover, and Beaufort, although the latter was converted as a categorical factor after averaging) to these variables for the observations identified as duplicates if the two observers had recorded different values. The average perpendicular distance was used for distance analyses. For categorical covariates (i.e., glare intensity and visibility), duplicates for which the two observers had recorded different values were assigned the value with the greatest negative effect on one’s ability to observe animals (e.g., if one observer recorded visibility as good and the other recorded visibility as low, the latter value was assigned for this duplicate sighting).

MRDS analyses consist of two functions: 1) a multiple covariate distance sampling (MCDS) detection function for detections pooled across the two right-side observers, and 2) a MRDS detection function to estimate the probability of detection on the track line (Buckland et al. 2001, Buckland et al. 2009). Both functions used the same right truncation distances as that identified during the analysis of the single-platform dataset (see “Choice of the detection function” section). For the MCDS function, AIC was used to select between half-normal, hazard-rate, and gamma key functions, and to examine if the addition of covariates (group size, Beaufort state, glare intensity, cloud cover, and visibility) yielded a better fit following the procedure outlined in Marques and Buckland (2003). The key function and covariates yielding the lowest AIC in the MCDS detection function were used in the MRDS models. The latter were built with and without covariates and compared using AIC. A point independence configuration was applied in the MRDS models because detection probabilities may be correlated between observers even though the primary and secondary observers acted independently and were isolated from each other. For example, detection probabilities could be correlated to factors like group size if both observers are more likely to detect larger groups than smaller groups as distance increases. This configuration assumes that platforms are symmetrical and that sightings are independent only on the track line, which is more robust than a configuration assuming independent detection at all perpendicular distances (Buckland et al. 2009, Burt et al. 2014). By definition, perpendicular distance is included as a covariate in all point-independence MRDS models (Buckland et al. 2009). The best fitting MRDS model was selected and used to estimate the perception bias *p(0)* for each observer position. Perception bias was calculated using all double-platform survey data combined into a single MRDS analysis to yield a global value of *p(0)*. Estimates of *p(0)* for the primary observer were then used to correct the abundance estimates calculated using data from the primary observers. The following formula was used to correct abundance indices for availability bias (*â*) and perception bias (*p(0)*) for each survey and strata, assuming that *p(0)* was the same for primary observers on the right and left side of the aircraft:

$$fully\ corrected\ abundance = abundance_i \cdot \frac{1}{\hat{a}_i} \cdot \frac{1}{p(0)} \qquad \text{[Eq. 6]}$$

where *i* represents each unique survey and stratum. The variance of the fully corrected abundance estimates was obtained by combining the variances of the abundance index, of the availability bias correction factor, and of the perception bias correction factor via the delta method (Powell 2007).

RESULTS

SURVEY EFFORT

From 29 August 2017 to 22 November 2022, a total of 558,187 km of systematic transect lines were surveyed by DFO-Science crews as part of the NARW surveillance efforts, with up to three aircraft flying simultaneously (Table 1).

The survey effort by DFO in 2017 was limited to late August (29-31) and 15 September to 15 November. The DFO Twin Otter was directed towards potential foraging areas that were not covered by the NASP Dash-8, which focussed on detecting NARW in the Shediac Valley, in the southern GSL, and in shipping lanes north and south of Anticosti in August 2017. The Twin Otter only flew in the southern GSL from 20-30 September and in November 2017. Hence, the survey covered eight of the 15 planned strata, each of which being surveyed one to six times (Table 1; Figure 3) for a total of 18,746 km of transect flown that year.

From 2018 to 2022, the surveys started between 10 April (2018) and 29 April (2019) and ended between 4 November (2019) and 25 November (2018, Table 1). The surveys were completed by two aircraft flying simultaneously for most of the survey seasons in 2018 and 2019, and by three aircraft from 2020 to 2022. The survey effort was divided into 10 (2020) to 18 (2021) strata with some surveyed several times per year. Most of the effort occurred in the East and West strata of the southern GSL, which were surveyed five (2018, 2019) to eleven (2020, 2022) times per year (Table 1).

A total of 36,210 groups or 134,096 individuals from 32 species of marine mammals, fishes, sharks, and sea turtles were detected by primary observers during systematic surveys across the six survey years (Figure 4). From these, some were identified to species including 185 NARW groups (detailed below), 4,130 other baleen whales (4,826 individuals), 9,284 odontocetes (25,301 individuals), and 2,510 seals (24,667 individuals). Other animal groups were also identified to species, including 1,202 groups of basking sharks (1,449 individuals), 38 groups of blue sharks (77 individuals), 356 individual leatherback turtles, 15 loggerhead turtles, 95 groups of tunas (360 individuals) and 2,860 groups of sunfish (3,785 individuals).

NARW SIGHTINGS

The sightings for the six survey years come from different survey coverage and different periods of the year, which needs to be considered when comparing distributions of sightings between years. A total of 1294 sightings, or 1697 NARW were detected by DFO-Science aircraft from

2017 to 2022, considering all flights (i.e., systematic surveys, closing procedures, and flights over temporarily closed fishing areas as part of the dynamic management measures of fisheries).

A total of 246 NARW, separated into 185 groups, were observed by primary observers in passing mode during the systematic line-transect surveys (Table 1; Figure 5), with 6 groups in 2017, 25 groups in 2018, 23 groups in 2019, 43 groups in 2020, 31 groups in 2021, and 57 groups in 2022. Overall, 93% of the NARW sightings were made within the southern GSL strata (East and West). During the systematic surveys of 2019, 2021, and 2022, no NARW groups were observed outside of these two strata.

Except for surveys in 2017 which started late in the summer season, the first NARW sightings of each year by primary observers during the systematic survey occurred between 8 May (2020) and 30 May (2018 and 2021). The last NARW sighting of each year made by primary observers during the systematic survey occurred between 26 October (2021) and 9 November (2017). The highest number of sightings on a single day by primary observers on-effort during systematic survey occurred on 12 June 2022, with 10 NARW groups recorded (12 whales, in the southwestern GSL strata; this does not include the number seen during closing procedures).

DETECTION CURVE

In addition to the 185 sightings of NARW recorded by primary observers during the systematic survey, 63 NARW sightings (73 whales) obtained from fisheries surveillance flights conducted by the DFO-Science survey aircraft and following the same observation protocol were used to compute the detection curve for a total of 248 NARW sightings. This total included 26 NARW sightings (33 whales) for which perpendicular distance was not recorded – these were excluded from the detection curve but taken into account during the bootstrap procedure. Based on the distribution of perpendicular distances recorded across surveys and strata, the following distances were tested as right truncation distances and compared to the absence of right truncation: 1) distances of 2,100 m and 2,800 m, corresponding to obvious gaps in the distribution of observed distances (see Figures 6 and 7); 2) 1,683 m, corresponding to the removal of the furthest 10% of observed distances; 3) 2,450 m, corresponding to the outlier identified from a boxplot analysis; and 4) 1,800 m, corresponding to the perpendicular distance at which the detection function from a hazard rate model reached a probability of detection of 0.15. The right truncation distance which improved the fit of the detection function near the track line the most was 1,800 m. Hence, after discarding sightings without perpendicular distance and sightings with a perpendicular distance greater than the truncation distance of 1,800 m, a total of 205 sightings were retained for analysis.

The hazard-rate key function (Figure 7) was selected over the half normal and gamma key functions as the former had the lowest AIC value (200.32, vs 205.75 and 269.35 for the half normal and gamma, respectively). None of the covariates tested reduced the model's AIC, and therefore they were not included in the final model (see Appendix 2 for model output). Including observations with missing perpendicular distance via bootstrapping (see "Calculation of abundance estimates" section) yielded an overall effective strip half-width of 916 m (95% CI: 856-973 m) and a probability of detection of 0.509 (95% CI: 0.476-0.540).

Raw group size was tested as a covariate in the detection function but was not selected as an informative covariate (i.e., it did not improve model fit). During the systematic surveys, 67% of the 185 NARW sightings made from the track line were single animals, while 23% were observed in pairs, and 10% were observed in groups of more than two whales. The largest group recorded among all surveys by primary observers while on-effort (i.e., on the transect line) was one of 6 NARW, observed in 2018 in the southwestern GSL stratum (see Table 1).

Based on bootstrap results, the average expected group size varied from 1 to 4.5 across surveys and strata where NARW were observed (Table 2).

AVAILABILITY AND PERCEPTION BIAS CORRECTIONS

The availability bias correction factor was calculated based on the ratio of NARW seen from the track line and during the closing procedure, for each NARW sighting event Overall, 27% of closing procedures lasted more than 30 minutes (including the time required to return to the trackline and restart the systematic survey). For 16% of closings, the NARW sighted from the track line that triggered the closing procedure could not be found during closing mode. In approximately 65% of cases where the whale that triggered the closing was found, the number of whales detected during the closing procedure was higher than the counts from the track line. For 32% of closing procedures during which the whale that triggered the closing was found, the number of animals observed during the closing mode was equal to the number of NARW seen from the track line. Across all survey years and strata, the availability bias averaged 0.548 (CV: 66%). The total number of NARW seen during a closing procedure varied greatly, with a maximum of 32 NARW observed during a closing in the southeastern GSL stratum on 8 July 2021 during a flight conducted for fisheries management monitoring (i.e., not during the systematic survey). The highest number of NARW observed during a single closing procedure triggered by an observation made during systematic survey efforts was 16 NARW (Figure 8), observed in the southwestern GSL stratum on 14 July 2022. Because NARW display different behaviours (ex; feeding, travelling) at different times of the year and in different areas, it was decided to calculate separate availability biases to explore these differences (Appendix 1). Six availability biases correction factors were calculated to take into account potential differences in availability across time periods (i.e., for April-May, June-August, and September-November) and between the southwestern GSL stratum and other areas (Table 3). The lowest availability was observed in the western half of the southern GSL strata in the June-to-August period (0.451, CV: 76%), while the highest availability was observed in the western half of the southern GSL strata in the April-May period (0.810, CV: 42%).

The perception bias was calculated using 103 unique NARW sightings recorded by the observers on the right side of the planes over the six survey years (Figure 9). Of these, 29 sightings were identified as duplicates between the primary and secondary observers. Using the same right truncation distances as the detection function (see above), the MRDS analysis identified the best-fitting model as one with a hazard-rate key function (without adjustment) and glare intensity as covariate. This model yielded a perception bias estimate, or primary *p(0)* of 0.583 (CV = 17.8%), which accounted for the fact that only one observer was seated on the left side of the plane and thus the abundance estimates are calculated using only the primary observers. This primary *p(0)* was used to correct NARW abundance indices across all survey years.

CORRECTED ABUNDANCE ESTIMATES

Abundance estimates corrected for both availability and perception biases were calculated for all strata where NARW were observed during the systematic survey (Table 2). Although the abundance estimates from the 2017 surveys are presented in Table 2, they are difficult to compare to other survey years given the partial coverage of the 2017 surveys. Most of the NARW sightings occurred in the southern GSL strata (East and West), and abundance estimates from this area can be compared over time (Figure 10). In the southeastern GSL strata, NARW are consistently detected at the beginning of the survey season (May to mid-June) and at the end (September to November), although animals can also occur at lower abundances in this stratum in July and August (Appendix 3). In 2022 however, NARW were seen in record numbers in this stratum in mid-August 2022 (97 animals, CI: 31-308; Table 2 Figure 10). NARW observed during the June to August period were generally centered around the Shediac Valley, in the southwestern GSL stratum, although exhibiting some variations among years (Appendix 3). NARW sightings made later in the season, during the September to November period, were more dispersed across the two southern GSL strata (East and West; Appendix 3).

In the southwestern GSL stratum, peak abundances each year were observed between early June and early August. The highest fully corrected abundance was observed in the third survey of the stratum in 2018, with 281 animals (CI: 100-790; Figure 10).

Fully corrected abundances in strata other than those in the southern GSL were relatively low given the infrequent observations of NARW, with abundance of 15 (CI: 3-83) in the Bay of Fundy and Roseway Basin stratum in late May 2018 (Table 2) and 27 (CI: 5-146) in the northwestern GSL strata in late July of the same year (Table 2). Observations of NARW in the northwestern GSL strata in 2020 (Table 2), led to fully corrected abundance estimates of 28 (CI: 8-101), 14 (CI: 3-72), 35 (CI: 9-134), and 13 (CI: 4-49), in the four consecutive surveys of this stratum (Table 2), flown between late-July and November.

GEOGRAPHIC LOCATION OF NARW SIGHTINGS

No NARW were detected within areas with water depths less than 37 m (20 fathoms) while observers were on-effort during all years of the systematic survey, despite ~13 to 19% of the area surveyed each year being comprised of water depths less than 37 m. However, two unidentified whales were seen during the systematic survey in depths less than 37 m near the Magdalen Islands in 2021, which were confirmed as NARW afterwards during closing procedures.

The systematic surveys conducted after 2017 flew over the static mandatory restricted area in the Shediac Valley, which was implemented in 2018 and modified in its shape in 2019, 2020, and 2021 to better match with the distribution of NARW sightings. The Shediac Valley restricted area (SVRA) outlined in this document represents the area identified in 2021 and has remained unchanged since that year (Figure 5). From 2018 to 2021, between 39 and 48% of all NARW observations made while flying over the systematic transect lines occurred within the 2021 SVRA (Figure 5). In 2018, 48% of the 25 NARW observations made during the systematic survey occurred within the 2021 SVRA. Observations made outside of this zone were generally situated more to the east, between the Shediac Valley and the Magdalen Islands. Similarly in 2019, 39% of the 23 NARW observations occurred within the 2021 SVRA, and observations outside of this area occurred to the east, between the Bradelle Valley and the Magdalen Islands, with a few sightings just north of Prince Edward Island (PEI) and south of the Magdalen Islands. NARW sightings in 2020 were distributed more widely, with more sightings in the northwestern GSL stratum than in all other years. Still, roughly 42% of the 43 NARW observations made during the systematic survey that year occurred within the 2021 SVRA. Additionally, some observations were made around the Magdalen Islands, with a few to the west and one to the east, as well as one observation to the west of Cape Breton. In 2021, 42% of observations occurred within the SVRA out of 31 observations in total that year. Observations of NARW outside of this area occurred to the southeast of the restricted area, as well as around the Magdalen Islands (north, east, and south). In 2022, the distribution of the observations appeared to shift, with only 19% of NARW observations occurring within the 2021 SVRA (11 out of 57). The bulk of NARW observations occurred to the southeast of the restricted area, as well as west of the Magdalen Islands and north of the eastern tip of PEI.

DISCUSSION

Given their wide distribution range across the Atlantic Ocean and their small and decreasing population size, assessing the abundance and distribution of NARW over its range is challenging. Repeated aerial surveys of specific regions, as presented in this study, have the advantage of generating abundance estimates that remain comparable over time, provided that the area surveyed is consistent. In addition to providing abundance and location data which can be used to inform habitat models (Roberts et al. 2016, Roberts et al. 2024, Mosnier et al. in preparation[1]), these surveys also allow the collection of ancillary data such as behavioural observations and photographs that can be used for photographic identification (Crowe et al. 2021). Together with passive acoustic monitoring which can track the presence of vocalizing NARWs across vast expanses and for extended periods (Simard et al. 2019, Simard et al. in press, Moors-Murphy et al. in preparation[2]) and mark-recapture models that provide another approach to abundance estimates, systematic aerial survey efforts continue to provide information on NARW distribution and habitat occupancy patterns in Canadian waters

From 2017 to 2022, an unprecedented survey effort has been undertaken for the monitoring of NARW presence in Canadian waters. During this period, a total of 561,187 km of transect lines have been surveyed over a period of up to 7.5 months per year, involving up to three aircraft simultaneously, and using a consistent protocol since 2018 to enable comparisons of abundance estimates across years. Survey effort was deployed in potential NARW foraging areas across eastern Canadian waters, by endeavouring to cover most of the GSL each summer, and either the SS or the continental shelf around Newfoundland and southern Labrador every second summer. Aggregations of NARW have been detected every year in the southern GSL during this survey effort. The current study presents abundance estimates from these surveys which incorporate new availability bias correction factors and perception bias correction factors for NARW, both calculated from the survey data and specific to the survey region.

Abundance estimates in the present study varied greatly among the different strata surveyed and throughout the survey season. The vast majority of NARW sightings (93%) occurred in the southeastern and southwestern strata of the GSL, but this area represented roughly 58% of survey efforts across surveys. NARW sightings in other strata were rare and amounted to maximum abundances of 35 animals in the northwestern GSL surveyed in mid-September 2020 (Tables 1 and 2). Variations in the distribution of NARW within the southern GSL area were also observed, especially in 2022 where a shift of the major NARW aggregation area to the southeast of the SVRA was observed, which was illustrated by the decrease in the proportion of NARW sighted within vs outside of the SVRA (i.e., 19% in 2022 vs 39-48% in 2018 to 2021). Still, the Shediac Valley remained a major area of aggregation for NARW in Canadian waters throughout the six survey years (2017-2022). Despite considerable surveillance effort, no aggregation comparable to that observed in the Shediac Valley was detected elsewhere in Canadian waters between 2017 and 2022 (Figure 5). Still, it is important to note that while each

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[1] Mosnier, A., Harvey, V., Plourde, S., Gosselin, J.-F. and Lehoux, C. In preparation. A Species Distribution Modeling Approach Based on Aerial Survey Observations from 2017 to 2022 to Understand and Predict North Atlantic Right Whale Habitats in the Estuary and Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc.

[2] Moors-Murphy, H. B., Macklin, G., Evers, C., Stanistreet, J., Colbourne, N., Wingfield, J., Xu, J. and Vanderlaan, A. In preparation. Acoustic Occurrence of North Atlantic Right Whales (*Eubalaena glacialis*) from 2017-2022 off Nova Scotia, Canada. DFO Can. Sci. Advis. Sec. Res. Doc.

systematic survey of the southeastern and southwestern GSL strata is conducted over a period of approximately a week (or longer when conditions are inclement), it represents a snapshot of the distribution of NARW that could be very dynamic due to whale movement. This movement of whale should not, in principle, have had a major impact on the reliability of the abundance estimates calculated since the layout and execution of the transects were independent of animal movement, thus the assumption of independence among transects was respected (Buckland et al. 2001). Although Crowe et al. (2021) showed that most individuals do not travel far within a day (75% of daily distances traveled in their study of NARW in the GSL based on photo ID were less than 9.1 $km \cdot d^{-1}$), some NARW also displayed movements of up to approximately 80 $km \cdot d^{-1}$ (0.92 $m \cdot s^{-1}$), and others have been reported travelling at an average speed of 79 km per day based on satellite tag estimates when moving out of the Bay of Fundy (Baumgartner and Mate 2005). In addition, migrating right whales are more challenging to detect visually (Firestone et al. 2008, Whitt et al. 2013), which may impact the abundance estimates presented here during the shoulder seasons, a period during which the geographic position and behavioural observations from observers in the planes suggest whales are travelling. However, using period-specific availability biases helps address this potential difference in detectability.

Within the two southern GSL strata (southeastern and southwestern), abundances varied through time as the animals moved through the region. NARW were generally observed in the southeastern GSL stratum towards the shoulders of the summer season – in May and June, and then in September to November – suggesting that the whales are observed in that stratum while travelling towards feeding grounds such as the Shediac Valley. Yet, some sightings were also made in the southeastern GSL stratum around early August in 2018 and 2022, but with the majority in valleys west of the Magdalen Islands. In contrast, peak abundances in the southwestern GSL stratum (which includes the Shediac Valley) tend to occur between early June and early August each year. Although the specific location of large NARW aggregations varies among years, the general vicinity of the Shediac Valley remains an important area throughout summer.

The aerial survey findings generally support the passive acoustic monitoring data, with the majority of sightings and detections occurring in the southern GSL. Based on the aerial survey data, sightings of NARW in the GSL begin in May and continue through November whereas the acoustic data shows that NARW presence begins slightly earlier in April on the Southwestern shelf and slope of the Laurentian Channel (Simard et al. in press). There is an overlap between the rise in acoustic detections and the peak abundance estimates from aerial surveys in the southern GSL, as NARW acoustic detections increase from May to July predominantly in the Shediac Valley and persist until mid-October at which point a decrease in occurrence is recorded (Simard et al. in press). By December, the occurrence of NARW calls in acoustic recordings is practically null in the GSL, although some detections have occurred in the past until mid-January (Simard et al. 2019). These similarities underscore the importance of having multiple sources of data to help provide information needed for the conservation of NARW.

The abundance estimates presented here used only the sightings of NARW recorded by primary observers on the systematic transect lines while on effort and were subsequently corrected for availability bias, *i.e.*, for animals underwater when the aircraft passed overhead, and for perception bias, *i.e.,* for animals at the surface of the water that are missed by observers (McLaren 1961, Marsh and Sinclair 1989, Laake and Borchers 2004). While these fully-corrected estimates allow the investigation of abundance trends within and among years in the GSL, comparisons to abundance estimates obtained through other methods should be made with caution due to the wide CVs on the systematic aerial survey estimates. Using mark-recapture approaches, the total abundance of NARW was estimated at 469 animals in 2015 and was 451 in 2016 (Linden 2023). These numbers have been revised yearly using the model developed by Pace III et al. (2017) and suggest a decline in recent years, with an estimate for 2022 of 356 whales (95% CI: 346-363)(Linden 2023). Mark-recapture studies conducted by NOAA in the GSL between 4 June and August 12, 2018, using a similar approach to Pace III et al (2017), provided an abundance estimate of 131 whales (95% CI: 130-143; Cole et al. 2020, Crowe et al. 2021). In contrast, the unique aerial survey estimate available for the same timeframe for the southwestern GSL (i.e., where most of the mark-recapture study took place) was more than double this mark-recapture estimate, at 281 animals after correction for availability and perception biases but with a wide 95% CI (100 – 790) that includes the mark-recapture value (Table 2). However, despite the wide confidence intervals of individual systematic aerial survey estimates, the average of the southern GSL estimates from June to August over 2018 to 2022 is at 121 whales (95%CI: 25-579) and remains close to the 2018 mark-recapture estimated by Cole et al. (2020).

At its peak each year, NARW abundances in the southwestern GSL stratum estimated from aerial surveys could represent as much as 37 to 79% of the total estimated 2022 NARW population (Linden 2023). But again, the average of the southern GSL estimate from June to August over 2018 to 2022 was 121 (95%CI: 25 to 579), which would represent only 34% of the 2022 population estimate from (Linden 2023). In comparison, a recent study by Crowe et al. (2021) based on mark-recapture analysis of NARW photographic identification obtained between 2015 and 2019 suggests that approximately 40% of the NARW population uses the GSL as habitat between early May and December, with individuals showing a high rate of inter-annual return that is not typical in other regions. Hence, the systematic aerial survey results suggest that this trend in the use of GSL by NARW has been continuing since the start of dedicated surveys in 2017. The systematic survey data also has the advantage of providing abundances per stratum surveyed, which cannot be obtained from photographic identification work.

The availability bias correction applied in the present study represents a novel approach. Typically, estimations of surface and dive times from independent visual observations or telemetry studies are used in conjunction with the time an animal remains in view of the observers to calculate availability bias correction factors (Laake and Borchers 2004, Forcada et al. 2004, Gómez de Segura et al. 2006). However, since there is no published diving data from NARW telemetry in the GSL, we used data collected during closing procedures to compute an approximate availability bias correction factor. Data from the closing procedures were used to evaluate the proportion of animals that were present near the surface while the plane flew overhead in comparison to the number of animals present in the area each time NARW were detected from the systematic transect line. The closing mode approach used here differs from circle-back procedures, i.e., when conventional single-plane line-transect techniques are adjusted by having the plane circle back and re-survey a segment of the original track line to obtain a better estimate of group size in large aggregations of marine mammals (Palka 2005, Hiby 2021, Bradford et al. 2014). The duration of the closing procedure used in this study (at least 20 minutes of continuous circling) was chosen to ensure sufficient time for most NARW in an area to surface, given that dive durations (excluding short dives during surface bouts) for NARW tracked using time-depth recorders in the Bay of Fundy and Roseway Basin in July and August 2000 and 2001 averaged 12.17 min with a range of 7.83 to 16.32 min (Baumgartner and Mate 2003). Similarly, NARW diving activity off Cape Cod in May 1980-1981 recorded mean dive durations of 7.09 min and a maximum of 15.8 min (CeTAP 1982) while NARW diving activity off the Florida coast and Georgia in January and February 1992, 1993, and 1995 for an adult female in a mother/calf pair to average 10.1 min (Hain et al. 2021). The availability estimates obtained through our approach yielded availability bias estimates ranging from 0.451 (CV 41.9%) to 0.810 (CV 76.2%) depending on the zone and timing of surveys. Although these values are within the range of NARW availability biases reported in the literature (see below), it is important to note that estimates of availability bias calculated for NARW in other regions, using information on the average surface and dive time, show important temporal and seasonal variations. Ganley et al. (2019) calculated that the availability of NARW to be sighted from a small aircraft (Cessna 182) in Cape Cod increased monthly from 0.27 in January to 0.91 in April. In the southern breeding ground, estimated NARW availability varied according to group size and composition from 0.32 for a single long-diving juvenile, 0.57 for single juveniles, 0.59 for mothers and 0.93 for surface active-groups (Hain et al. 2021). Roberts et al. (2016) applied equation three from Carretta et al. (2000) to NARW diving data from the literature to obtain availability estimates of 0.334 for northern feeding grounds (Carretta et al. 2000, CeTAP 1982 dive data) and as low as 0.216 based on diving data from Bay of Fundy and Roseway Basin (Baumgartner and Mate 2003 dive data). Based on the same dataset, Palka et al. (2017) calculated a correction factor of 0.265. The availability bias calculated here from the closing procedures should be compared with the more traditional time-in-view method (Laake and Borchers 2004, Forcada et al. 2004, Gómez de Segura et al. 2006) based on dive duration until telemetry data becomes available from NARW tagged in Canadian waters to better understand differences and to be fully comparable with other regions. Further information on dive patterns and behavioural differences among NARW groups (ex., based on group composition) observed within the southern GSL will be particularly useful to develop more specific telemetry-based availability corrections in the future.

A perception bias correction was developed using data from all NARW survey efforts conducted between 2017 and 2022. In these surveys, the double-platform configuration was possible only on the right side of the plane given the aircraft used and crew availability. Therefore, the perception bias calculated (primary *p(0)*) in this study is only applicable to abundance estimates obtained using the observations recorded from the primary observers only, and not the abundance estimates calculated from the combined observations of both primary and secondary observers as could be done in other studies (where the combined *p(0)* would be applied rather than the primary *p(0)*). The perception bias obtained in the present study (0.583, CV = 17.8%) is higher than values for other large whale species such as humpback (0.28) and fin (0.16 to 0.53) whales in eastern Canada (DFO, unpublished data), meaning that the corrected abundances for NARW are closer to the uncorrected values. This may be due in part to the distinctive blow of the NARW and its behaviour in surface active groups which, when the whale is present at the surface and available to the observer, makes it easier to identify to the species level. In comparison, the primary *p(0)* obtained here for NARW are similar to those of other cetaceans from surveys in Canadian waters such as beluga in the St. Lawrence Estuary (ranging from 0.514 to 0.748; St-Pierre et al. 2024), and to the *p(0)* of 0.67 calculated for an assemblage of large whales (including humpback, blue, right, and Northern beaked whales) along the Northeast U.S. shelf and adjacent offshore waters year-round (Palka et al. 2021). Given these comparisons, both the availability and perception correction factors applied in this study appear to fall within the expected range for this species.

Before the start of the NARW-targeted systematic surveys in 2017, no NARW had been detected in the southern GSL during previous DFO visual survey efforts which used similar protocols and designs (Kingsley and Reeves 1998, Lawson and Gosselin 2009, Lawson and Gosselin, unpubl. data). During a systematic survey of the GSL (1995) and northern GSL (1996), no NARW were reported and although eleven sightings (16 whales) of unidentified large whales were reported, the authors specifically mentioned that these were not NARW (Kingsley and Reeves 1998). Again, no NARW were detected in the southern GSL during two large-scale surveys of the Canadian east coasts in July and August of 2007 and 2016, although four NARW were detected in the Bay of Fundy in 2016 (Lawson and Gosselin 2009; Lawson and Gosselin unpubl. data). Yet, at the time of the 2016 survey, NARW were detected in both the Shediac Valley and Percé areas by passive acoustic monitoring, although with a lower number of hours with NARW calls per day in the basin off Gaspé than during the same month (August) in 2015, 2017, and 2018 (Simard et al. 2019). In addition, opportunistic sightings of NARW in the southern GSL were rarely reported before 2015 (Daoust et al. 2017, Lien et al. 1989, Reeves 2001), but NARW were observed by NOAA during a dedicated survey in the GSL from July 22 to August 22, 2015, for a total of 40 individual whales (Cole et al. 2016). Although the substantial increase in monitoring efforts must be in part responsible for the increased observations of NARW since 2015, there is clear evidence that NARW distribution and occupancy patterns have shifted throughout their range in recent years, including outside of previously established protection zones and designated critical habitat areas. First, given the size of NARW aggregations and the abundance estimates presented here, it is unlikely that numbers comparable to those of the 2018 to 2022 surveys were present in the GSL during previous surveys and missed entirely. Yet, the fact that the survey design was less extensive during the 2007 and 2016 surveys compared to the 2018-2022 survey design may have reduced the likelihood of sighting NARW. Second, the mean daily occurrence of NARWs estimated by passive acoustic monitoring in the feeding grounds off Gaspé quadrupled after 2015 compared to 2011−2014 (Simard et al. 2019), suggesting an increase in NARW presence. Third, there appeared to be a decline in rate of detection of animals during the NARW sighting surveys conducted in northeastern U.S. to Roseway Basin by NOAA after 2013 (Khan et al. 2018), and an increase of sightings in the GSL, suggesting a shift in distribution (Meyer-Gutbrod et al. 2023, Davies et al. 2019). Lastly, the proportion of the NARW population which now visits the GSL (40%, as per Crowe et al. 2021) based on photographic identification from aerial survey platforms and opportunistic sightings highlights the new importance of this area, in contrast with previous assessment which had not identified it as a critical area for the species based on the available sighting and historical distribution data at the time (DFO 2007).

Canadian designated critical habitat for NARW, which includes the Grand Manan and Roseway Basins (Figure 1), were surveyed each year from 2018 to 2022 when covering the stratum with the same name. The timing of survey in these areas varied among years (Table 1), with six surveys being repeated in 2018 between April and October, two in 2019 in April and October only, and one survey in late-July and August of 2020. In 2021 and 2022, the survey strata covering the critical habitat was separated into two halves (north and south) for logistical reasons, which were surveyed two to three times in May and June 2021, and between May and September 2022. Despite this effort, only a single NARW was observed in these strata on 30 May 2018 in the Roseway Basin. However, systematic survey effort over the Grand Manan/Roseway Basin critical habitats and the larger areas of the Bay of Fundy and western SS was concentrated in spring and fall to complement the effort by other organizations in summer, and may not have covered the main period of utilization of these areas by NARWs. In contrast, acoustic monitoring around Nova Scotia has identified that NARW are present in this region throughout the year, with higher occurrence of NARW calls in the September to November period (Moors-Murphy et al. in preparation[2]). More specifically, relatively high acoustic presence and persistence in Grand Manan Basin and Roseway Basin support that these areas remain Critical Habitat for NARW, despite the scarcity of sightings recorded during aerial surveys (Moors-Murphy et al. in preparation[2]). The differences between the aerial survey sightings and the acoustic detections highlight the importance of combining approaches for a comprehensive understanding of whale distribution, and suggest that the presence of NARW in the Grand Manan Basin and Roseway Basin during summer was likely significantly lower than in the southern GSL during the same period.

Systematic aerial surveys are an important tool for the monitoring of NARW. When overlapped with concurrent passive acoustic monitoring, systematic surveys can provide information on the number of animals present in specific areas at a given time while the continuous presence and number of vocalisations are documented by passive acoustic recorders. Aerial surveys provide precise locations of whales and, with sufficiently wide coverage, can provide the data required for habitat modelling. Habitat modelling may be useful for identifying geographic areas with environmental conditions similar to those where NARW were detected and, thus, to predict additional potentially important habitats for NARW. This can help to direct future passive acoustic monitoring deployments and aerial survey efforts to enhance our chances of detecting whales in new areas. Predicting the habitats that are or may become important for NARW will be useful for developing efficient conservation management measures.

The closing protocol included in the systematic surveys provides photo-identification images that are shared with the NARW consortium for the estimation of population abundance. Although photo-identification efforts directed towards known aggregations or groups more rapidly increase the number of identified individuals in a year, the systematic survey facilitates the detection of new groups in different areas and provides opportunities to identify additional individuals. The systematic survey aircraft also represent the major platforms for the implementation of the dynamic fishery measures to reduce the risk of entanglement in Canadian waters.

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TABLES

Table 1. Survey effort and number of North Atlantic right whale (NARW), Eubalaena glacialis, groups and whales detected during systematic surveys of eastern Canadian waters from 29 August 2017 to 6 November 2022. Dates are presented as MM-DD. Stratum names combine survey year (YY), stratum number (st##) and repetition number (se##). For strata that were separated into halves, an additional letter (N, S, E, W) indicating the cardinal direction was added to the stratum number. GSL, Gulf of St. Lawrence.

Year and Stratum	Start date	End date	Stratum area (km²)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
2017	**08-29**	**11-15**	**-**	**-**	**18,746**	**6 (8)**
Southern GSL					**6,666**	**4 (6)**
17st02se01	09-20	09-30	26,867	29	2,844	2 (2)
17st02se02	11-02	11-02	4,189	6	435	0
17st02se03	11-05	11-08	15,487	20	1,564	0
17st02se04	11-09	11-09	9,304	13	948	2 (4)
17st02se05	11-13	11-13	5,943	8	570	0
17st02se06	11-15	11-15	3,659	4	305	0
Northwestern GSL					**3,573**	**1 (1)**
17st03se01	10-09	10-09	9,645	10	996	0
17st03se02	10-09	10-13	5,214	12	445	0
17st03se03	10-13	10-22	5,647	15	649	1 (1)
17st03se04	10-23	10-23	1,274	14	1,062	0
17st03se05	11-14	11-14	9,596	12	421	0
Cabot Strait					**917**	**0**
17st04se01	09-16	09-17	8,850	12	917	0
Scotian Shelf					**1,729**	**0**
17st05se01	09-17	09-22	15,609	22	1,729	0
Northeastern GSL					**3,531**	**0**
17st07se01	08-29	08-29	6,438	14	591	0
17st07se02	08-30	08-31	16,240	30	1,626	0
17st07se03	10-27	10-27	5,576	13	365	0
17st07se04	10-28	10-28	9,298	16	949	0
Eastern GSL					**913**	**0**
17st08se01	10-29	10-29	8,771	16	913	0
North Anticosti					**1,006**	**1 (1)**
17st09se01	10-22	10-24	10,589	20	1,006	1 (1)
South Coast of Newfoundland					**411**	**0**
17st11se01	08-29	08-29	6,377	3	411	0

Year and Stratum	Start date	End date	Stratum area (km^2)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
2018	**04-10**	**11-25**	**-**	**-**	**97,703**	**25 (58)**
Bay of Fundy and Roseway Basin					**20,610**	**1 (1)**
18st01se01	04-10	04-12	30,908	25	3,083	0
18st01se02	04-25	04-25	5,492	6	557	0
18st01se03	05-18	05-30	56,939	29	5,990	1 (1)
18st01se04	06-30	07-12	56,939	29	6,546	0
18st01se05	09-10	09-10	6,895	10	750	0
18st01se06	10-23	10-31	56,939	22	3,684	0
Southeastern GSL					**17,932**	**2 (4)**
18st02Ese01	04-16	04-23	35,045	29	3,622	0
18st02Ese06	05-27	06-06	35,218	29	3,660	0
18st02Ese07	06-20	06-22	35,218	28	3,462	0
18st02Ese08	08-03	08-11	35,218	29	3,733	1 (2)
18st02Ese09	09-05	10-07	30,319	30	3,455	1 (2)
Southwestern GSL					**19,571**	**21 (51)**
18st02Wse01	04-18	04-23	25,485	29	3,101	0
18st02Wse06	05-27	06-04	26,540	29	3,024	0
18st02Wse07	06-15	06-26	26,540	29	3,522	4 (18)
18st02Wse08	08-06	08-12	26,540	28	2,959	4 (6)
18st02Wse09	09-05	09-30	29,860	37	5,970	12 (25)
18st02Wse10	11-05	11-25	9,338	11	995	1 (2)
Northwestern GSL					**9,284**	**1 (2)**
18st03se01	04-21	04-21	8,572	10	914	0
18st03se04	06-23	06-28	38,680	36	4,153	0
18st03se05	07-20	08-04	38,680	36	4,217	1 (2)
Cabot Strait					**6,746**	**0**
18st04se01	05-02	05-02	14,057	10	1,385	0
18st04se02	06-12	06-14	16,855	16	2,653	0
18st04se03	08-13	08-24	16,855	16	2,708	0
Scotian Shelf					**15,605**	**0**
18st05se01	05-21	06-11	113,833	35	7,307	0
18st05se02	07-07	07-07	3,138	4	289	0
18st05se03	08-25	09-09	109,124	28	5,966	0
18st05se04	10-15	10-29	30,292	10	1,648	0
18st05se0eb	04-25	04-25	3,801	6	395	0

Year and Stratum	Start date	End date	Stratum area (km^2)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
Northeastern GSL					**2,217**	**0**
18st07se01	07-13	07-19	42,042	26	2,217	0
Eastern GSL					**1,646**	**0**
18st08se01	07-19	07-19	29,441	10	1,646	0
North Anticosti					**1,297**	**0**
18st09se01	07-21	07-31	23,984	12	1,297	0
South Anticosti					**1,055**	**0**
18st10se01	06-26	06-26	10,925	5	530	0
18st10se02	07-20	07-20	10,925	5	525	0
South coast of Newfoundland					**1,740**	**0**
18st11se01	08-20	08-25	30,478	17	1,740	0
2019	**04-29**	**11-04**	-	-	**78,991**	**23 (35)**
Bay of Fundy and Roseway Basin					**10,181**	**0**
19st01se01	04-29	05-12	56,938	30	6,116	0
19st01se02	10-29	11-04	37,476	23	4,065	0
Southeastern GSL					**20,217**	**10 (16)**
19st02Ese01	05-19	05-28	32,857	28	3,520	3 (3)
19st02Ese02	06-07	06-18	32,857	28	3,606	2 (7)
19st02Ese03	07-03	07-21	40,381	32	4,360	0
19st02Ese04	08-12	08-23	40,381	32	4,346	0
19st02Ese05	10-11	10-28	40,381	32	4,385	5 (6)
Southwestern GSL					**15,759**	**13 (19)**
19st02Wse01	05-13	05-28	28,250	30	3,147	0
19st02Wse02	05-29	06-05	28,250	28	3,015	1 (1)
19st02Wse03	07-03	07-22	29,790	30	3,202	5 (8)
19st02Wse04	08-03	08-16	29,790	29	3,199	6 (9)
19st02Wse05	10-08	10-11	29,790	29	3,196	1 (1)
Northwestern GSL					**12,061**	**0**
19st03se01	06-18	07-03	38,680	36	4,163	0
19st03se02	08-24	09-03	36,423	36	3,970	0
19st03se03	09-30	10-08	36,423	35	3,928	0
Cabot Strait					**1,380**	**0**
19st04se01	05-28	05-29	19,242	7	1,061	0
19st04se02	10-11	10-11	6,375	3	319	0
Northeastern GSL					**2,279**	**0**

Year and Stratum	Start date	End date	Stratum area (km²)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
19st07se01	09-10	09-16	42,039	26	2,279	0
Eastern GSL					**1,558**	**0**
19st08se01	09-28	10-02	26,208	10	1,558	0
Northeastern Anticosti					**3,900**	**0**
19st09se01	09-07	09-12	23,984	12	1,290	0
19st09se02	09-17	09-21	23,984	23	2,610	0
Southeastern Anticosti					**821**	**0**
19st10se01	09-18	09-19	7,451	11	821	0
South Newfoundland					**4,932**	**0**
19st11se01	08-02	09-10	114,820	22	4,932	0
Southeastern Newfoundland					**888**	**0**
19st12se01	08-22	10-10	52,172	5	888	0
East of Newfoundland					**2,248**	**0**
19st13se01	08-18	09-15	106,702	7	2,248	0
Northeastern Newfoundland					**2,767**	**0**
19st14se01	08-26	10-12	172,388	8	2,767	0
2020	**04-26**	**11-13**	-	-	**115,222**	**43 (48**
Fundy-Roseway Basin					**5,623**	**0**
20st01se01	07-30	08-28	52,165	16	5,623	0
Southeastern GSL					**47,831**	**7 (8)**
20st02Ese01	05-03	05-17	45,286	33	4,926	1 (1)
20st02Ese02	05-21	06-04	38,817	30	4,196	0
20st02Ese03	06-10	06-19	45,286	33	4,954	1 (1)
20st02Ese04	06-23	07-07	45,286	30	4,175	0
20st02Ese05	07-16	07-22	45,286	33	4,930	0
20st02Ese06	07-24	08-09	45,286	33	4,930	0
20st02Ese07	08-13	08-17	45,286	33	4,930	1 (1)
20st02Ese08	09-01	09-13	45,286	33	4,930	0
20st02Ese09	09-20	10-13	45,286	33	4,930	1 (1)
20st02Ese10	10-23	11-08	45,286	33	4,930	3 (4)
Southwestern GSL					**37,370**	**27 (30)**
20st02Wse01	04-26	05-18	31,595	30	3,403	0
20st02Wse02	05-20	06-09	31,595	29	3,395	0
20st02Wse03	05-31	06-13	31,595	30	3,404	6 (6)
20st02Wse04	06-19	06-24	31,595	30	3,405	2 (2)

Year and Stratum	Start date	End date	Stratum area (km²)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
20st02Wse05	07-11	07-18	31,595	30	3,405	4 (4)
20st02Wse06	07-21	07-23	31,595	30	3,405	10 (13)
20st02Wse07	08-09	08-13	31,595	30	3,405	1 (1)
20st02Wse08	08-21	09-01	31,595	29	3,369	2 (2)
20st02Wse09	09-12	09-21	31,595	30	3,405	1 (1)
20st02Wse10	10-12	10-23	31,595	30	3,405	1 (1)
20st02Wse11	11-09	11-13	31,595	29	3,369	0
Northwestern GSL					**10,913**	**9 (10)**
20st03se01	07-24	08-06	25,045	24	2,719	2 (2)
20st03se02	08-22	08-24	25,045	24	2,744	1 (1)
20st03se03	09-11	09-22	25,045	23	2,668	4 (5)
20st03se04	09-26	11-08	25,045	24	2,782	2 (2)
Scotian Shelf east-center					**8,764**	**0**
20st05se01	08-29	09-26	204,902	29	8,764	0
Scotian Shelf west end					**1,719**	**0**
20st06se01	08-01	08-02	34,174	5	1,719	0
Upper Fundy					**349**	**0**
20st11se01	07-28	08-04	6,775	10	349	0
Baie des Chaleurs					**291**	**0**
20st12se01	07-01	07-01	2,723	6	142	0
20st12se02	09-12	09-12	2,723	5	149	0
Northumberland Strait					**1,258**	**0**
20st13se01	08-06	08-07	11,959	16	629	0
20st13se02	09-02	09-05	11,959	16	629	0
Northwestern GSL – West					**499**	**0**
20st14se01	07-23	07-24	10,183	5	499	0
St. Lawrence Estuary					**605**	**0**
20st15se01	07-21	07-23	12,016	17	605	0
2021	**04-14**	**11-12**	-	-	**125,555**	**31 (37)**
Fundy-Roseway Basin – North					**5,052**	**0**
21st01Nse01	05-05	05-07	15,289	16	1,695	0
21st01Nse02	06-07	06-13	15,289	16	1,664	0
21st01Nse03	05-24	06-06	15,289	16	1,693	0
Fundy-Roseway Basin – South					**8,087**	**0**
21st01Sse01	05-10	06-14	36,897	14	4,043	0

Year and Stratum	Start date	End date	Stratum area (km^2)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
21st01Sse02	06-14	06-24	36,897	15	4,044	0
Southeastern GSL					**42,137**	**6 (7)**
21st02Ese01	04-21	05-04	45,092	33	4,855	0
21st02Ese02	05-12	05-15	45,092	33	4,862	0
21st02Ese03	05-19	06-02	45,092	33	4,854	2 (2)
21st02Ese04	06-02	06-21	45,092	33	4,877	0
21st02Ese05	06-24	07-11	45,092	33	4,814	0
21st02Ese06	07-12	08-20	45,092	33	4,872	0
21st02Ese07	08-29	09-17	45,092	33	4,621	0
21st02Ese08	10-05	10-26	45,092	33	4,679	4 (5)
21st02Ese09	10-30	11-12	28,093	23	3,703	0
Southwestern GSL					**30,734**	**25 (30)**
21st02Wse01	04-14	05-04	31,725	30	3,398	0
21st02Wse02	05-05	05-13	31,725	30	3,400	0
21st02Wse03	05-15	05-29	31,725	30	3,323	0
21st02Wse04	05-31	06-03	31,725	30	3,384	10 (12)
21st02Wse05	06-20	06-24	31,725	30	3,383	4 (4)
21st02Wse06	07-03	07-12	31,725	30	3,653	6 (8)
21st02Wse07	08-19	08-29	31,725	30	3,391	4 (4)
21st02Wse08	09-16	10-05	31,725	30	3,394	1 (2)
21st02Wse09	10-14	10-25	31,725	30	3,408	0
Northwestern GSL					**11,638**	**0**
21st03se01	06-25	07-02	25,053	23	2,666	0
21st03se02	07-18	07-18	6,631	9	709	0
21st03se03	07-23	08-05	25,053	24	2,794	0
21st03se04	09-09	09-29	25,053	24	2,692	0
21st03se05	10-28	11-12	25,053	24	2,777	0
Cabot Strait					**2,411**	**0**
21st04se01	05-21	05-21	18,706	4	498	0
21st04se02	06-03	06-03	18,706	6	1,061	0
21st04se03	08-30	08-30	10,652	5	852	0
Scotian Shelf west end					**1,751**	**0**
21st06se01	05-03	05-13	34,312	5	1,751	0
Northeastern GSL					**3,280**	**0**
21st07se01	07-02	07-09	42,014	26	2,307	0

Year and Stratum	Start date	End date	Stratum area (km^2)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
21st07se02	08-29	09-15	18,817	15	973	0
Eastern GSL					**1,219**	**0**
21st08se02	07-10	07-11	23,714	8	1,219	0
Northeastern Anticosti					**1,238**	**0**
21st09se01	07-13	07-13	24,036	11	1,238	0
Southeastern Anticosti					**368**	**0**
21st10se01	07-17	07-17	6,995	6	368	0
Upper Fundy					**722**	**0**
21st11se01	05-04	05-05	6,778	10	385	0
21st11se03	05-20	05-24	6,778	9	337	0
Baie des Chaleurs					**289**	**0**
21st12se01	05-21	05-21	2,723	5	147	0
21st12se02	08-06	08-06	2,723	5	142	0
Northumberland Strait					**636**	**0**
21st13se01	09-17	09-23	11,957	16	636	0
South Newfoundland					**8,623**	**0**
21st17se01	07-14	09-12	157,567	32	8,623	0
Southeastern Newfoundland					**1,302**	**0**
21st18se01	07-30	09-09	52,284	7	1,302	0
East of Newfoundland					**3,366**	**0**
21st19se01	07-18	09-22	106,821	8	3,366	0
Northeastern Newfoundland					**2,702**	**0**
21st20se01	08-24	09-29	138,590	9	2,702	0
2022	**04-14**	**11-06**	-	-	**122,575**	**57 (61)**
Fundy-Roseway Basin - North					**5,003**	**0**
22st01Nse01	05-06	05-07	15,316	16	1,651	0
22st01Nse02	06-03	06-11	15,316	16	1,634	0
22st01Nse03	09-07	09-08	15,316	16	1,718	0
Fundy-Roseway Basin – South					**6,792**	**0**
22st01Sse01	06-07	06-22	36,950	14	4,011	0
22st01Sse02	06-25	06-30	20,974	8	2,274	0
22st01Sse03	09-12	09-12	36,950	2	507	0
Southeastern GSL					**48,614**	**15 (15)**
22st02Ese01	04-14	05-03	45,310	33	4,843	0
22st02Ese02	05-09	05-19	45,310	31	4,471	0

Year and Stratum	Start date	End date	Stratum area (km²)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
22st02Ese03	05-20	05-25	45,310	33	4,878	0
22st02Ese04	05-29	06-07	45,310	33	4,854	2 (2)
22st02Ese05	06-12	06-22	45,310	33	4,644	1 (1)
22st02Ese06	06-26	07-13	45,310	33	4,907	0
22st02Ese07	07-14	07-21	45,310	33	4,869	0
22st02Ese08	07-24	07-28	45,310	33	4,787	1 (1)
22st02Ese09	08-11	08-20	45,310	33	4,887	7 (7)
22st02Ese10	08-21	10-24	45,310	33	4,875	4 (4)
22st02Ese11	10-30	11-04	4,429	8	599	0
Southwestern GSL					**33,586**	**42 (46)**
22st02Wse01	05-04	05-09	31,814	30	3,402	1 (1)
22st02Wse02	05-14	05-20	31,814	27	2,982	1 (1)
22st02Wse03	05-26	05-29	31,814	30	3,392	4 (4)
22st02Wse04	06-07	06-12	31,814	30	3,395	10 (10)
22st02Wse05	06-18	06-26	31,814	30	3,405	3 (4)
22st02Wse06	07-07	07-15	31,814	30	3,385	4 (4)
22st02Wse07	07-22	07-24	31,814	30	3,376	5 (7)
22st02Wse08	07-28	08-10	31,814	30	3,406	9 (9)
22st02Wse09	08-17	08-23	31,814	30	3,406	1 (1)
22st02Wse10	09-10	10-05	31,814	30	3,388	4 (5)
22st02Wse11	10-30	10-30	377	1	49	0
Northwestern GSL					**2,778**	**0**
22st03se01	08-01	08-03	25,129	24	2,778	0
Cabot Strait					**3,857**	**0**
22st04se01	05-09	05-10	18,550	5	1,024	0
22st04se02	08-05	08-06	18,550	6	1,058	0
22st04se03	08-26	08-26	18,550	6	1,059	0
22st04se04	11-06	11-06	14,096	4	716	0
Scotian Shelf east-center					**11,022**	**0**
22st05se01	07-27	09-05	205,316	35	11,022	0
Scotian Shelf west end					**1,954**	**0**
22st06se01	05-30	06-06	34,233	5	1,954	0
Northeastern GSL					**3,409**	**0**
22st07se01	07-15	07-22	42,141	26	2,291	0
22st07se02	09-20	09-21	20,098	18	1,118	0

Year and Stratum	Start date	End date	Stratum area (km^2)	Number of transects	Total effort track length (km)	Number of NARW groups (whales) observed
Eastern GSL					**2,546**	**0**
22st08se02	07-04	07-15	23,906	17	2,546	0
Northeastern Anticosti					**1,314**	**0**
22st09se01	08-27	09-03	24,096	12	1,314	0
Southeastern Anticosti					**383**	**0**
22st10se01	08-24	09-03	6,984	6	383	0
Upper Fundy					**363**	**0**
22st11se01	05-08	05-08	6,790	11	363	0
Baie des Chaleurs					**293**	**0**
22st12se01	08-02	08-02	2,731	5	148	0
22st12se02	09-27	09-27	2,731	6	145	0
Northumberland Strait					**661**	**0**
22st13se01	09-30	10-22	11,989	16	661	0

Table 2. Abundance (uncorrected, corrected for availability bias only, and corrected for both availability and perception biases) of North Atlantic right whale (NARW), Eubalaena glacialis, observed in eastern Canada during surveys from 29 August 2017 to 6 November 2022. Only the strata where NARW were detected during systematic visual line-transect surveys are presented here (see Table 1 for further details). Note that some strata have an abundance of zero, as a result of the truncation of the observations prior to abundance analysis (see Methods). Values in parentheses represent the 95% confidence intervals. The three periods are April-May (AM), June-August (JA) and September-November (SN), and were used in conjunction with the Zone (either inside the southwestern Gulf of St. Lawrence (GSL) strata [SWGSL] or outside of that strata [Outside]) to determine the availability bias correction to apply for each survey of each strata (see Methods, Table 3, and Appendix 1 for details regarding availability bias corrections).

Year and strata	Period	Zone	Uncorrected abundance		Abundance corrected for availability bias only		Abundance corrected for both availability and perception				Density (whale/km^2)		Encounter rate (groups/km)		Expected group size	
			Value	Variance	Value	Variance	Value	(95%CI)	Variance	CV						
2017																
Southern GSL																
17st02se01	SN	SWGSL	10	108.6	18	335.2	31	(6-164)	1017.6	1.032	0.00038	(0.00036-0.00041)	0.0007	(0.0007-0.0007)	1	(1-1)
17st02se04	SN	SWGSL	21	466.9	37	1440.9	64	(12-340)	4374.8	1.030	0.00231	(0.00217-0.00246)	0.0042	(0.0042-0.0042)	2	(2-2)
Northwestern GSL																
17st03se03	SN	Outside	5	24.4	6	42.7	11	(2-59)	129.3	1.059	0.00084	(0.00079-0.0009)	0.0015	(0.0015-0.0015)	1	(1-1)
North Anticosti																
17st09se01	SN	Outside	6	33.9	8	59.3	13	(2-69)	179.9	1.033	0.00054	(0.00051-0.00058)	0.0010	(0.001-0.001)	1	(1-1)
2018																
Bay of Fundy and Roseway Basin																
18st01se03	AM	Outside	5	26.9	9	84.8	15	(3-83)	257.4	1.039	0.00009	(0.00009-0.0001)	0.0002	(0.0002-0.0002)	1	(1-1)
Southeastern GSL																
18st02Ese08	JA	Outside	10	105.6	16	274.0	28	(5-148)	832.3	1.023	0.00029	(0.00028-0.00031)	0.0005	(0.0005-0.0005)	2	(2-2)
18st02Ese09	SN	Outside	10	99.5	13	174.0	22	(4-119)	527.3	1.060	0.00032	(0.0003-0.00034)	0.0006	(0.0006-0.0006)	2	(2-2)
Southwestern GSL																
18st02Wse07	JA	SWGSL	74	1551.7	164	7749.6	281	(100-790)	25,324.6	0.566	0.00279	(0.00263-0.00298)	0.0051	(0.0051-0.0051)	4.50	(4.5-4.5)
18st02Wse08	JA	SWGSL	34	657.7	75	3255.8	129	(34-498)	10,118.7	0.778	0.00127	(0.00108-0.00138)	0.0023	(0.002-0.0024)	1.78	(1.75-2)
18st02Wse09	SN	SWGSL	38	306.5	66	983.2	114	(45-290)	3305.2	0.505	0.00122	(0.0008-0.00137)	0.0022	(0.0015-0.0023)	1.50	(1.13-1.56)
18st02Wse10	SN	SWGSL	10	103.0	18	318.1	31	(6-159)	966.9	1.013	0.00110	(0.00103-0.00117)	0.0020	(0.002-0.002)	2	(2-2)
Northwestern GSL																
18st03se05	JA	Outside	10	102.8	16	266.7	27	(5-146)	809.4	1.038	0.00026	(0.00024-0.00028)	0.0005	(0.0005-0.0005)	2	(2-2)
2019																
Southeastern GSL																
19st02Ese01	AM	Outside	15	140.9	26	457.9	45	(11-187)	1414.1	0.827	0.00047	(0.00044-0.0005)	0.0009	(0.0009-0.0009)	1	(1-1)
19st02Ese02	JA	Outside	0	0.0	0	0.0	0	(0-0)	-	0	0	(0-0)	0	(0-0)	0	(0-0)
19st02Ese05	SN	Outside	30	301.0	40	532.6	68	(23-205)	1715.7	0.607	0.00075	(0.0007-0.0008)	0.0014	(0.0014-0.0014)	1.20	(1.2-1.2)
Southwestern GSL																
19st02Wse02	AM	SWGSL	5	26.7	6	41.5	11	(2-58)	125.9	1.036	0.00018	(0.00017-0.00019)	0.0003	(0.0003-0.0003)	1	(1-1)
19st02Wse03	JA	SWGSL	35	469.2	77	2331.9	132	(41-424)	7415.8	0.655	0.00112	(0.00084-0.00127)	0.0020	(0.0016-0.0022)	1.45	(1.4-1.67)
19st02Wse04	JA	SWGSL	30	649.9	67	3211.8	115	(27-497)	9878.7	0.864	0.00100	(0.00083-0.00109)	0.0018	(0.0016-0.0019)	1.21	(1.2-1.25)
19st02Wse05	SN	SWGSL	5	26.6	9	82.2	15	(3-81)	249.5	1.036	0.00017	(0.00016-0.00018)	0.0003	(0.0003-0.0003)	1	(1-1)
2020																
Southeastern GSL																
20st02Ese03	JA	Outside	5	25.5	8	66.1	14	(3-73)	200.5	1.036	0.00011	(0.0001-0.00012)	0.0002	(0.0002-0.0002)	1	(1-1)

Year and strata	Period	Zone	Uncorrected abundance		Abundance corrected for availability bias only		Abundance corrected for both availability and perception				Density (whale/km^2)		Encounter rate (groups/km)		Expected group size	
			Value	Variance	Value	Variance	Value (95%CI)		Variance	CV						
20st02Ese07	JA	Outside	0	0.0	0	0.0	0	(0-0)	-	0	0	(0-0)	0	(0-0)	0	(0-0)
20st02Ese09	SN	Outside	5	25.2	7	44.1	11	(2-59)	133.9	1.021	0.00011	(0.0001-0.00012)	0.0002	(0.0002-0.0002)	1	(1-1)
20st02Ese10	SN	Outside	20	147.9	26	261.2	45	(14-142)	834.3	0.637	0.00044	(0.00042-0.00047)	0.0008	(0.0008-0.0008)	1.33	(1.33-1.33)
Southwestern GSL																
20st02Wse03	AM	SWGSL	26	189.0	32	308.6	55	(19-157)	1005.5	0.574	0.00082	(0.00068-0.00089)	0.0015	(0.0013-0.0015)	1	(1-1)
20st02Wse04	JA	SWGSL	10	52.2	22	258.6	38	(11-140)	808.6	0.739	0.00032	(0.0003-0.00034)	0.0006	(0.0006-0.0006)	1	(1-1)
20st02Wse05	JA	SWGSL	19	135.7	41	674.3	71	(22-228)	2146.6	0.651	0.00058	(0.00044-0.00064)	0.0011	(0.0008-0.0011)	1	(1-1)
20st02Wse06	JA	SWGSL	65	1068.6	145	5349.2	249	(93-665)	17,710.3	0.535	0.00207	(0.00188-0.00223)	0.0038	(0.0035-0.0038)	1.30	(1.3-1.33)
20st02Wse07	JA	SWGSL	5	26.2	11	129.3	19	(4-102)	392.4	1.030	0.00016	(0.00015-0.00017)	0.0003	(0.0003-0.0003)	1	(1-1)
20st02Wse08	JA	SWGSL	10	53.8	23	266.5	39	(11-142)	832.7	0.742	0.00032	(0.00031-0.00035)	0.0006	(0.0006-0.0006)	1	(1-1)
20st02Wse09	SN	SWGSL	5	26.1	9	80.4	15	(3-80)	244.2	1.030	0.00016	(0.00015-0.00017)	0.0003	(0.0003-0.0003)	1	(1-1)
20st02Wse10	SN	SWGSL	5	25.9	9	79.9	15	(3-80)	242.5	1.026	0.00016	(0.00015-0.00017)	0.0003	(0.0003-0.0003)	1	(1-1)
Northwestern GSL																
20st03se01	JA	Outside	10	50.5	16	133.1	28	(8-101)	416	0.741	0.00040	(0.00038-0.00043)	0.0007	(0.0007-0.0007)	1	(1-1)
20st03se02	JA	Outside	5	25.2	8	65.4	14	(3-72)	198.4	1.032	0.00020	(0.00019-0.00021)	0.0004	(0.0004-0.0004)	1	(1-1)
20st03se03	SN	Outside	15	133.9	20	235.2	35	(9-134)	730.6	0.782	0.00059	(0.0004-0.00065)	0.0011	(0.0007-0.0011)	1.55	(1.5-2)
20st03se04	SN	Outside	6	17.9	8	31.5	13	(4-49)	98.4	0.745	0.00024	(0.00022-0.00025)	0.0004	(0.0004-0.0004)	1	(1-1)
2021																
Southeastern GSL																
21st02Ese03	AM	Outside	10	105.3	18	331.9	30	(6-164)	1006.6	1.052	0.00023	(0.00021-0.00024)	0.0004	(0.0004-0.0004)	1	(1-1)
21st02Ese08	SN	Outside	26	181.3	35	322.2	59	(22-162)	1060.8	0.548	0.00058	(0.00055-0.00062)	0.0011	(0.0011-0.0011)	1.25	(1.25-1.25)
Southwestern GSL																
21st02Wse04	AM	SWGSL	61	968.2	76	1589.5	130	(47-359)	5216.3	0.555	0.00194	(0.00182-0.00207)	0.0035	(0.0035-0.0035)	1.20	(1.2-1.2)
21st02Wse05	JA	SWGSL	20	152.9	45	760.4	78	(25-243)	2430.4	0.635	0.00064	(0.00058-0.00069)	0.0012	(0.0012-0.0012)	1	(1-1)
21st02Wse06	JA	SWGSL	38	650.7	84	3228.4	144	(42-497)	10,163.8	0.701	0.00119	(0.0011-0.00128)	0.0022	(0.0022-0.0022)	1.33	(1.33-1.33)
21st02Wse07	JA	SWGSL	20	154.5	45	768.5	78	(25-244)	2453.6	0.639	0.00064	(0.00061-0.00069)	0.0012	(0.0012-0.0012)	1	(1-1)
21st02Wse08	SN	SWGSL	10	103.7	18	320.0	31	(6-160)	972.2	1.020	0.00032	(0.0003-0.00034)	0.0006	(0.0006-0.0006)	2	(2-2)
2022																
Southeastern GSL																
22st02Ese04	AM	Outside	10	52.3	18	172.3	30	(8-115)	536.7	0.764	0.00023	(0.00021-0.00024)	0.0004	(0.0004-0.0004)	1	(1-1)
22st02Ese05	JA	Outside	11	116.6	17	302.5	29	(5-156)	917.9	1.039	0.00024	(0.00022-0.00025)	0.0004	(0.0004-0.0004)	2	(2-2)
22st02Ese08	JA	Outside	5	27.8	8	72.0	14	(3-76)	218.5	1.045	0.00011	(0.00011-0.00012)	0.0002	(0.0002-0.0002)	1	(1-1)
22st02Ese09	JA	Outside	35	460.5	57	1228.7	97	(31-308)	3916.8	0.645	0.00078	(0.00074-0.00084)	0.0014	(0.0014-0.0014)	1	(1-1)
22st02Ese10	JA	Outside	20	150.9	32	402.6	56	(17-176)	1283.5	0.645	0.00045	(0.00042-0.00048)	0.0008	(0.0008-0.0008)	1	(1-1)
Southwestern GSL																
22st02Wse01	AM	SWGSL	0	0.0	0	0.0	0	(0-0)	-	0	0	(0-0)	0	(0-0)	0	(0-0)
22st02Wse02	AM	SWGSL	6	35.2	7	54.7	12	(2-66)	166	1.045	0.00018	(0.00017-0.0002)	0.0003	(0.0003-0.0003)	1	(1-1)
22st02Wse03	AM	SWGSL	20	152.8	25	245.6	43	(14-138)	782.8	0.645	0.00064	(0.00061-0.00069)	0.0012	(0.0012-0.0012)	1	(1-1)
22st02Wse04	JA	SWGSL	51	915.9	113	4558.3	193	(63-596)	14,609.3	0.625	0.00159	(0.00142-0.00172)	0.0029	(0.0027-0.0029)	1	(1-1)
22st02Wse05	JA	SWGSL	20	153.9	45	765.4	77	(25-244)	2443.5	0.639	0.00063	(0.00032-0.00069)	0.0011	(0.0006-0.0012)	1.32	(1-1.33)
22st02Wse06	JA	SWGSL	20	156.6	45	778.9	78	(25-246)	2486.1	0.640	0.00065	(0.00061-0.00069)	0.0012	(0.0012-0.0012)	1	(1-1)

Year and strata	Period	Zone	Uncorrected abundance		Abundance corrected for availability bias only		Abundance corrected for both availability and perception				Density (whale/km^2)		Encounter rate (groups/km)		Expected group size	
			Value	Variance	Value	Variance	Value (95%CI)		Variance	CV						
22st02Wse07	JA	SWGSL	36	449.7	80	2238.4	137	(45-418)	7184.3	0.620	0.00113	(0.00107-0.00121)	0.0021	(0.0021-0.0021)	1.40	(1.4-1.4)
22st02Wse08	JA	SWGSL	46	639.8	101	3191.4	174	(60-504)	10,355.8	0.585	0.00144	(0.0013-0.00154)	0.0026	(0.0023-0.0026)	1	(1-1)
22st02Wse09	JA	SWGSL	5	26.7	11	131.8	19	(4-103)	400.1	1.033	0.00016	(0.00015-0.00017)	0.0003	(0.0003-0.0003)	1	(1-1)
22st02Wse10	SN	SWGSL	10	52.8	18	164.7	31	(8-112)	514.9	0.739	0.00032	(0.0003-0.00034)	0.0006	(0.0006-0.0006)	1	(1-1)

Table 3. A Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis, observations made from the transect line during systematic surveys and during the associated closing procedures. The three periods are April-May (AM), June-August (JA) and September-November (SN), and were used in conjunction with the Zone (either inside the southwestern Gulf of St. Lawrence (GSL) strata [SWGSL] or outside of that strata [Outside]) to determine the availability bias correction to apply for each survey of each strata (see Methods and Appendix 1 for details regarding availability bias corrections).

Period	Zone	Mean availability bias	CV	SE	Number of closings
AM	SWGSL	0.810	0.419	0.113	9
AM	Outside	0.576	0.656	0.126	9
JA	SWGSL	0.451	0.762	0.032	115
JA	Outside	0.626	0.594	0.081	21
SN	SWGSL	0.572	0.497	0.059	23
SN	Outside	0.758	0.426	0.057	32

FIGURES

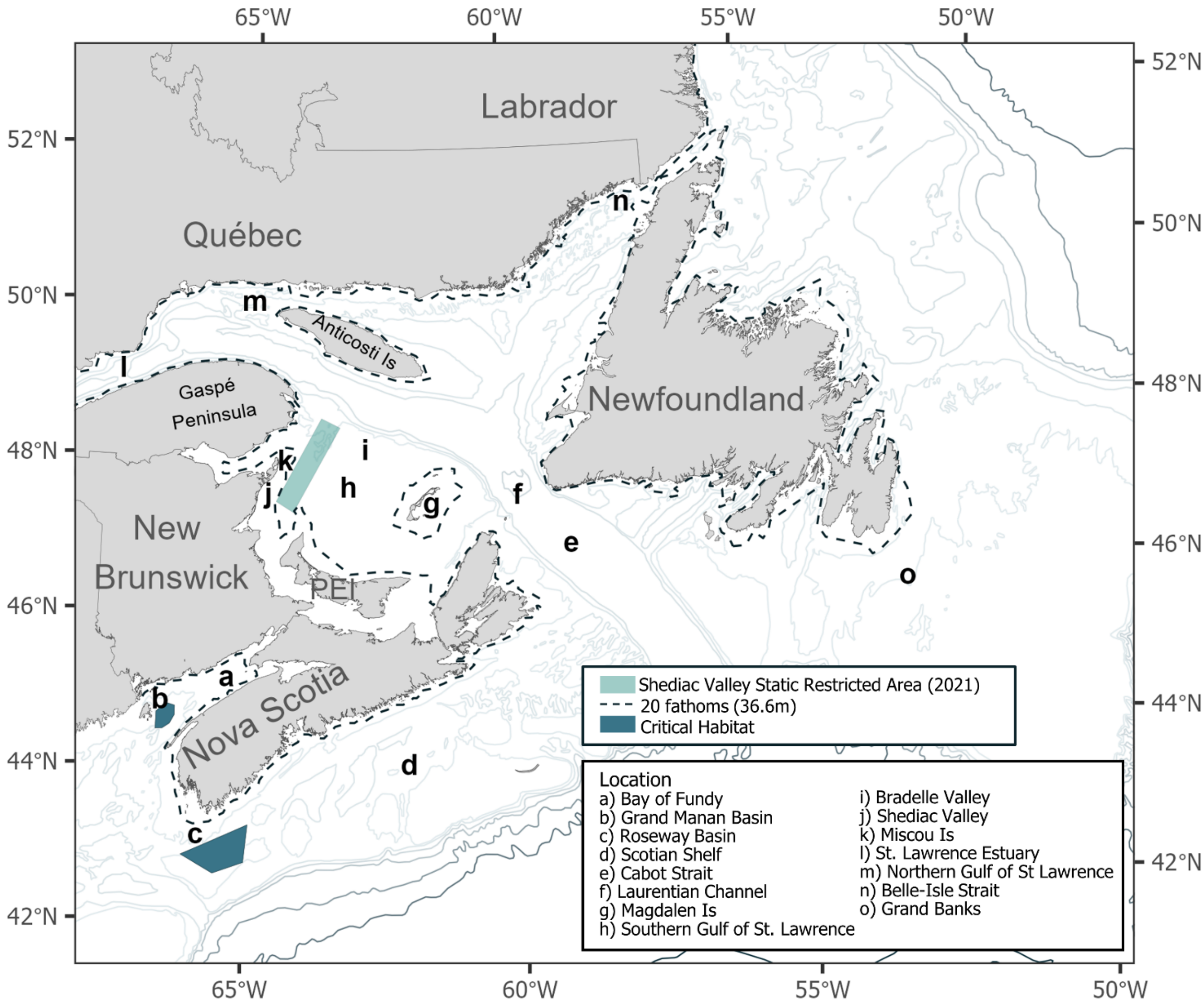


Figure 1. Areas generally covered by the systematic survey design, main geographic features, and legally designated critical habitats for North Atlantic right whales (NARW), Eubalaena glacialis*, in eastern Canadian waters. The area delimited by the Shediac Valley Static Restricted Area represents the 2021 area identified for management purposes.*

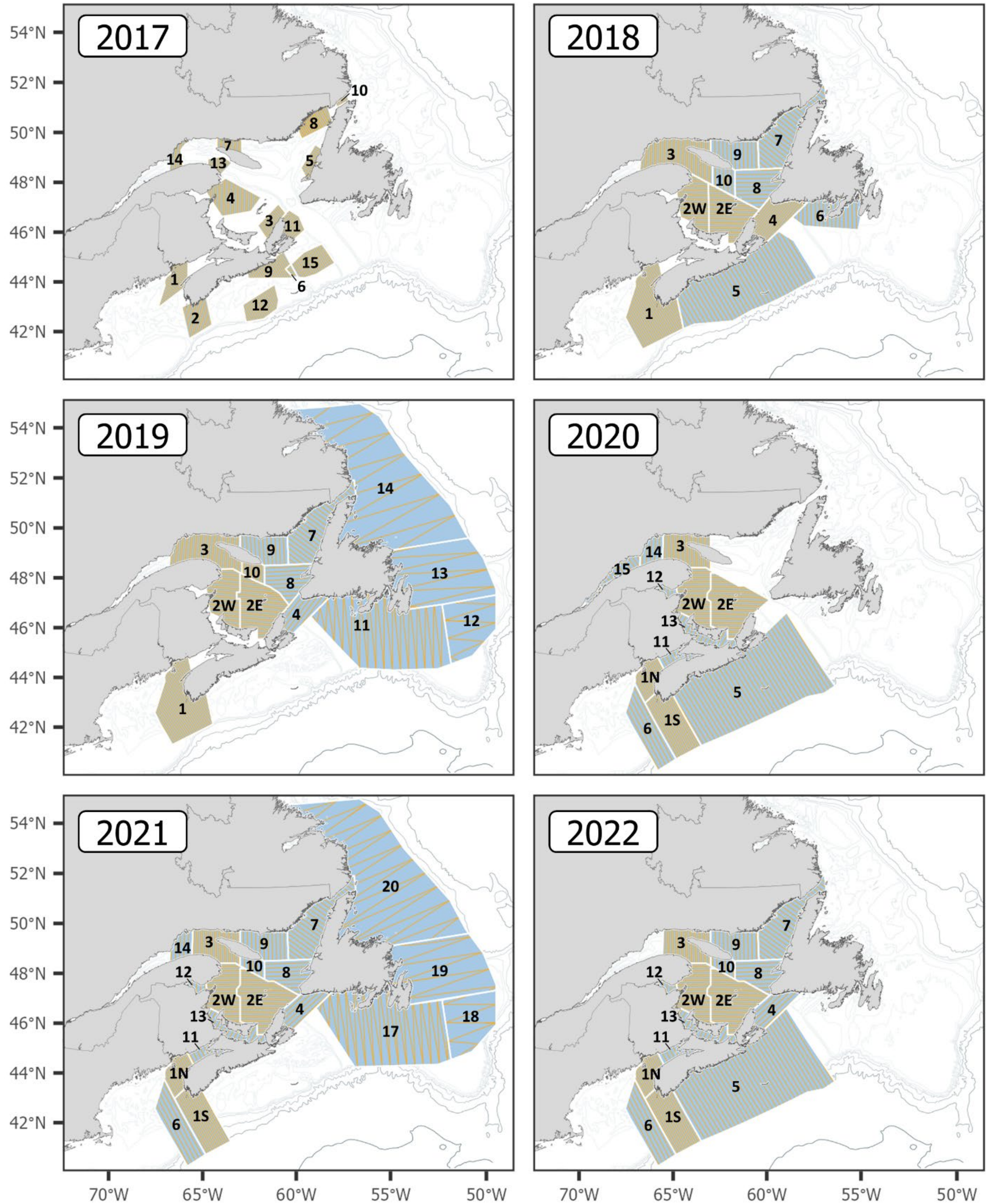


Figure 2. Design of the systematic aerial survey for the North Atlantic right whale (NARW), Eubalaena glacialis*, from 29 August 2017 to 6 November 2022, covering fifteen to eighteen strata each year. All strata are identified in blue, with yellow lines overlaid indicating transect lines. Note that transect lines are distributed within each stratum with a parallel spacing of 5 nautical miles (ex, stratum 2W in 2022), a parallel spacing of 10 nautical miles (ex.: stratum 5 in 2022), or a zigzag design (ex.: stratum 19 in 2021).*

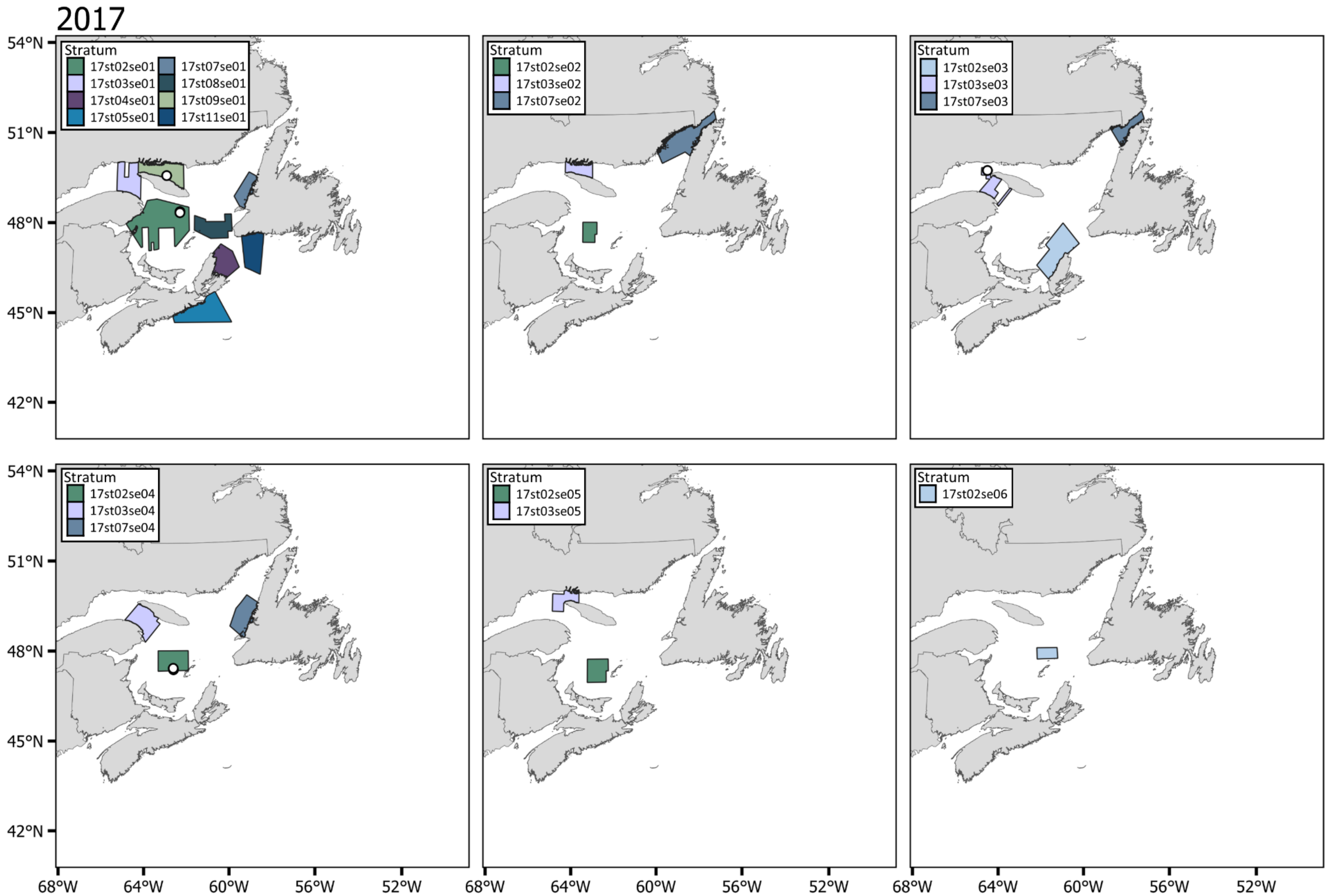


Figure 3. Survey strata, and locations of North Atlantic right whales (NARW), Eubalaena glacialis*, detected along transect lines during systematic surveys of eastern Canadian waters from 29 August 2017 to 6 November 2022.Refer to Table 1 for information regarding the dates on which each stratum was surveyed. Note that stratum names combine survey year (YY), stratum number (st##) and repetition number (se##). For strata that were separated into halves, the stratum number includes an additional letter (N, S, E, W) indicating the cardinal direction.*

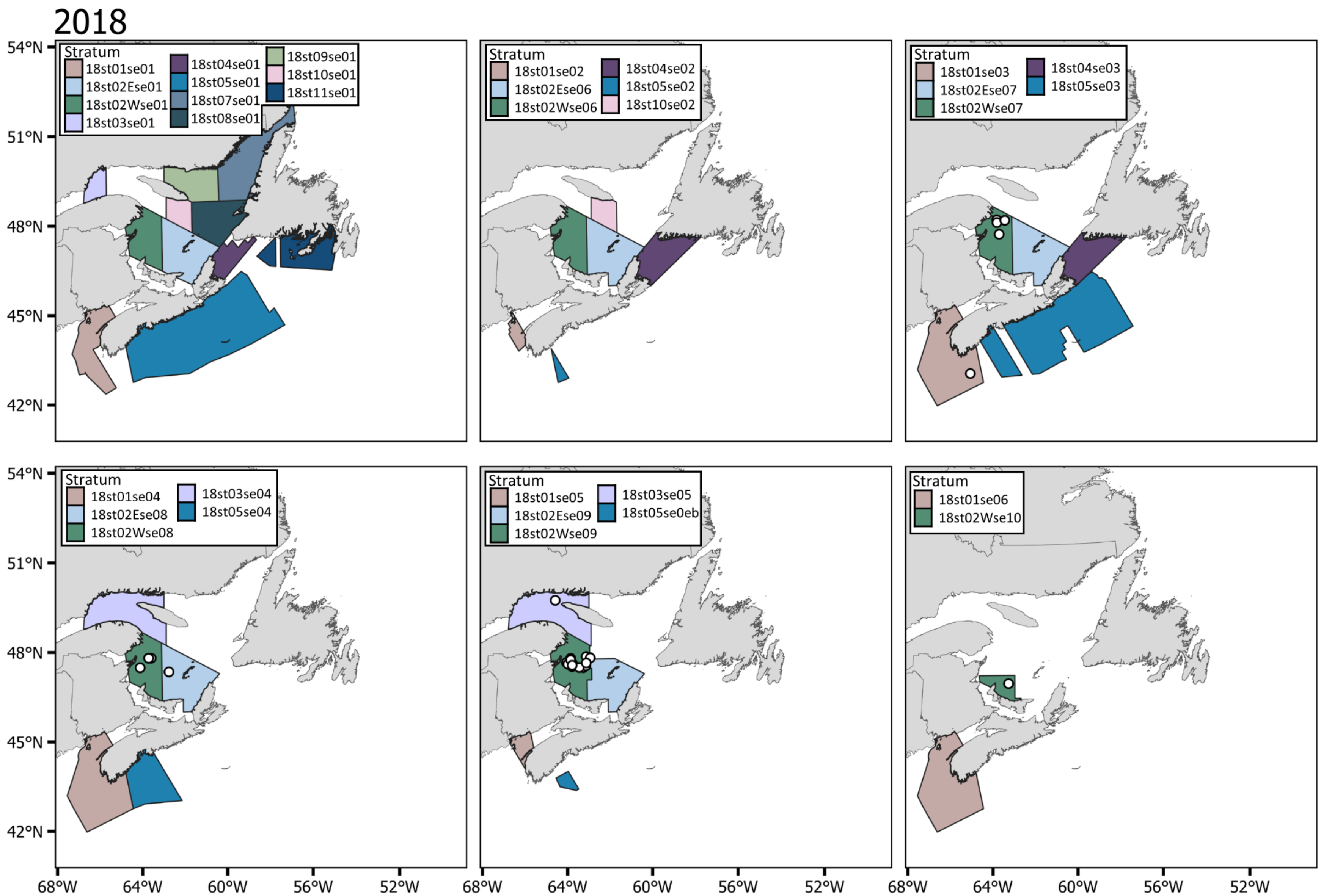
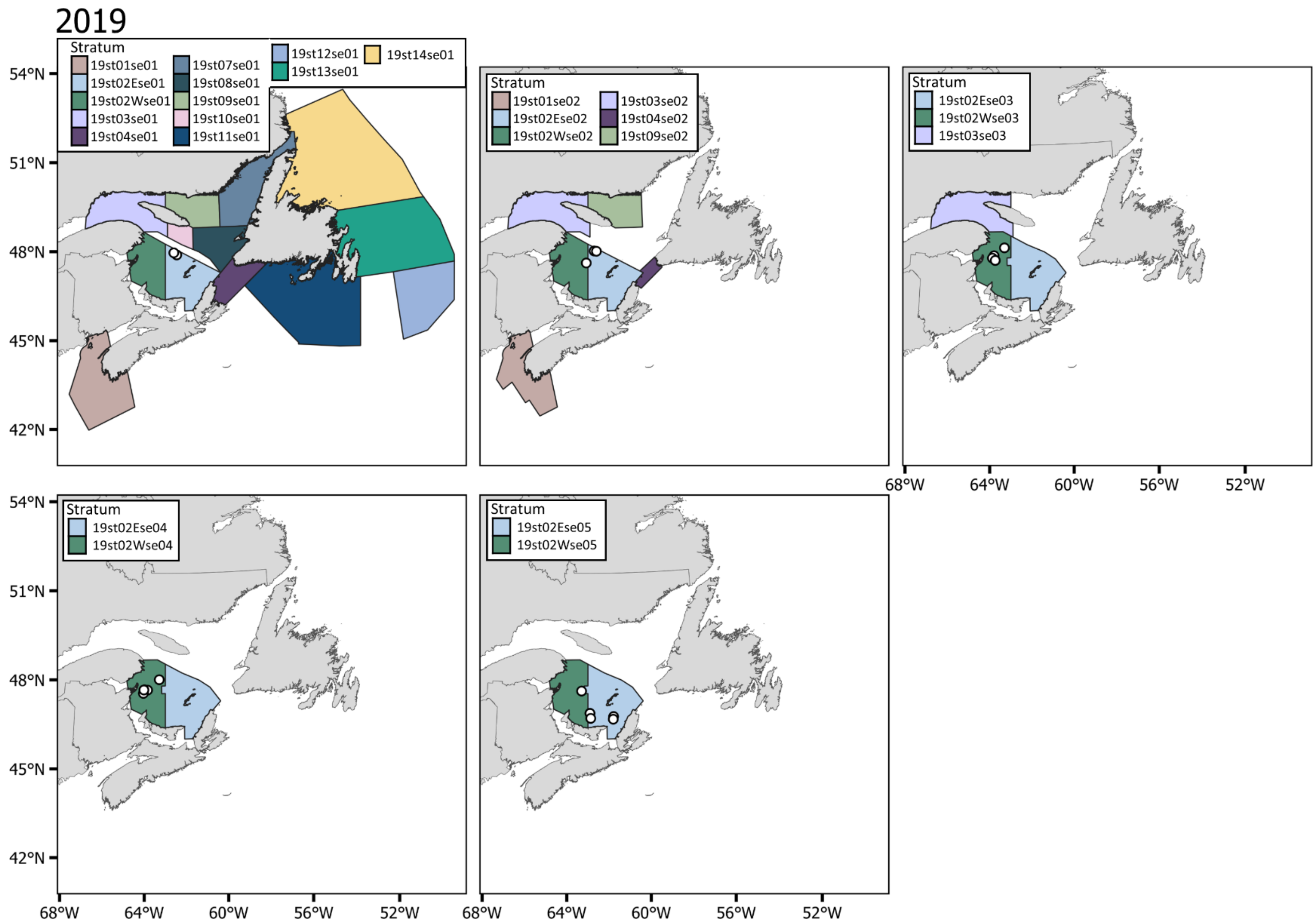


Figure 3. (cont.).



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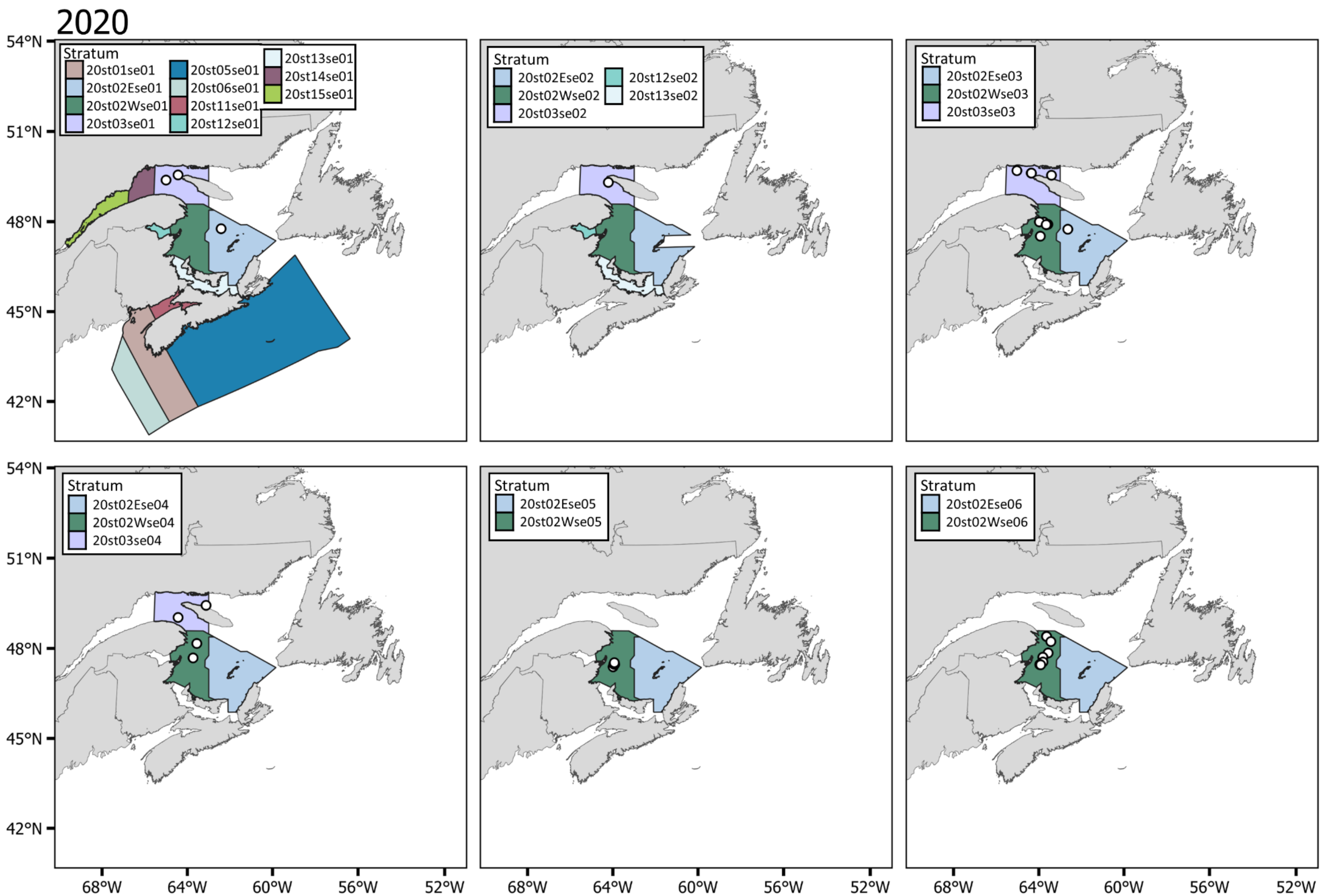


Figure 3. (cont.).

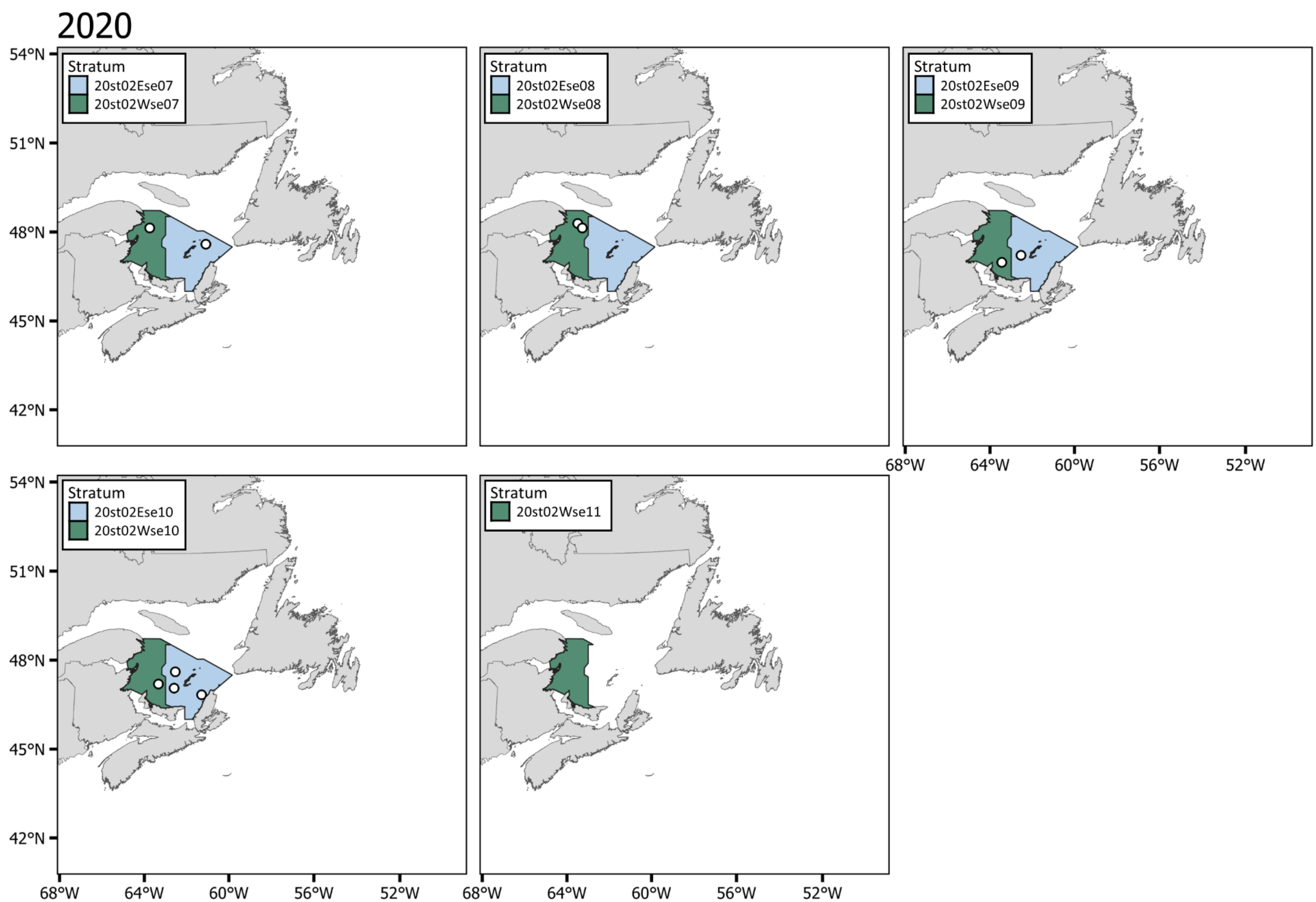
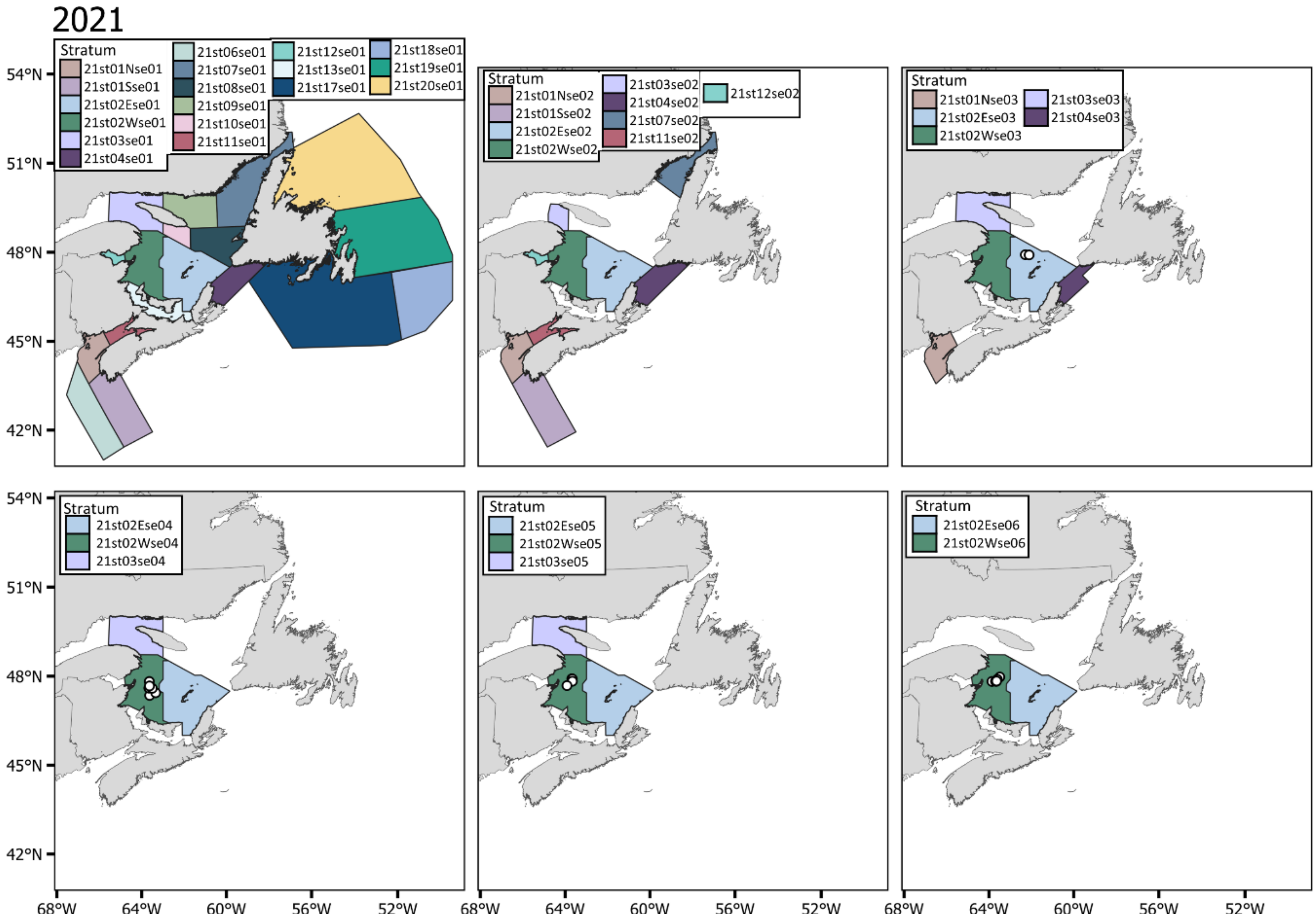


Figure 3. (cont.).



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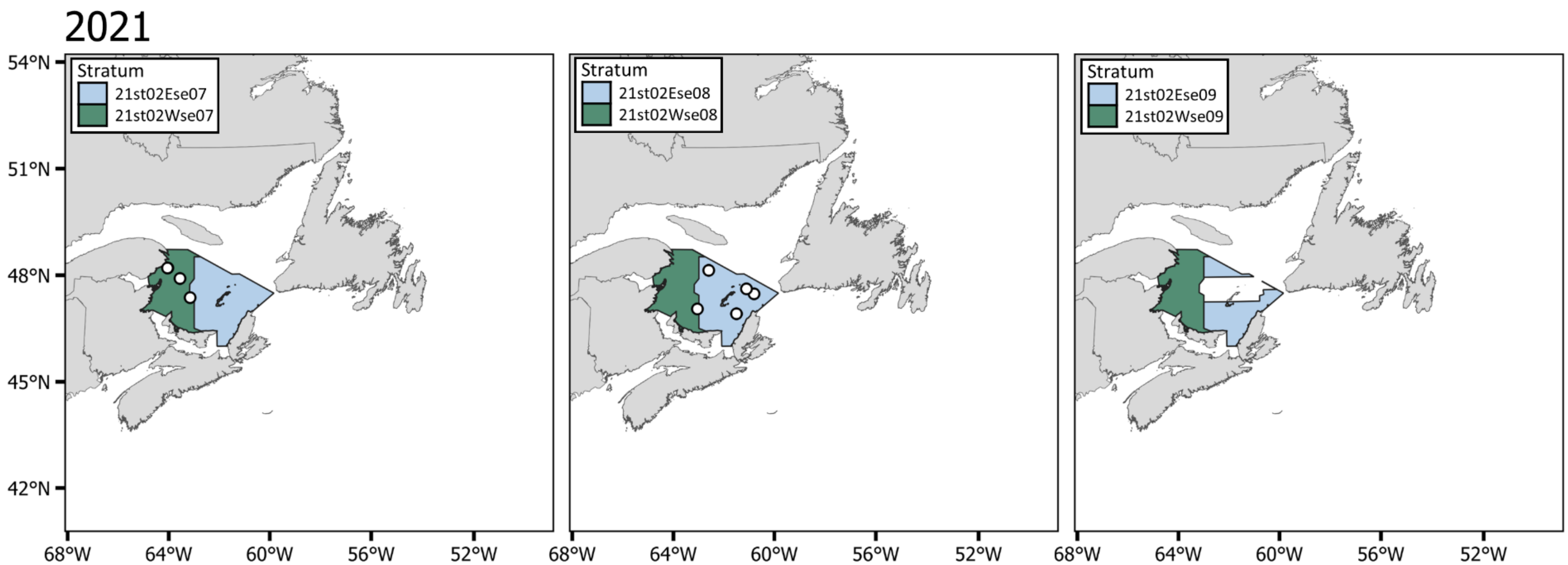

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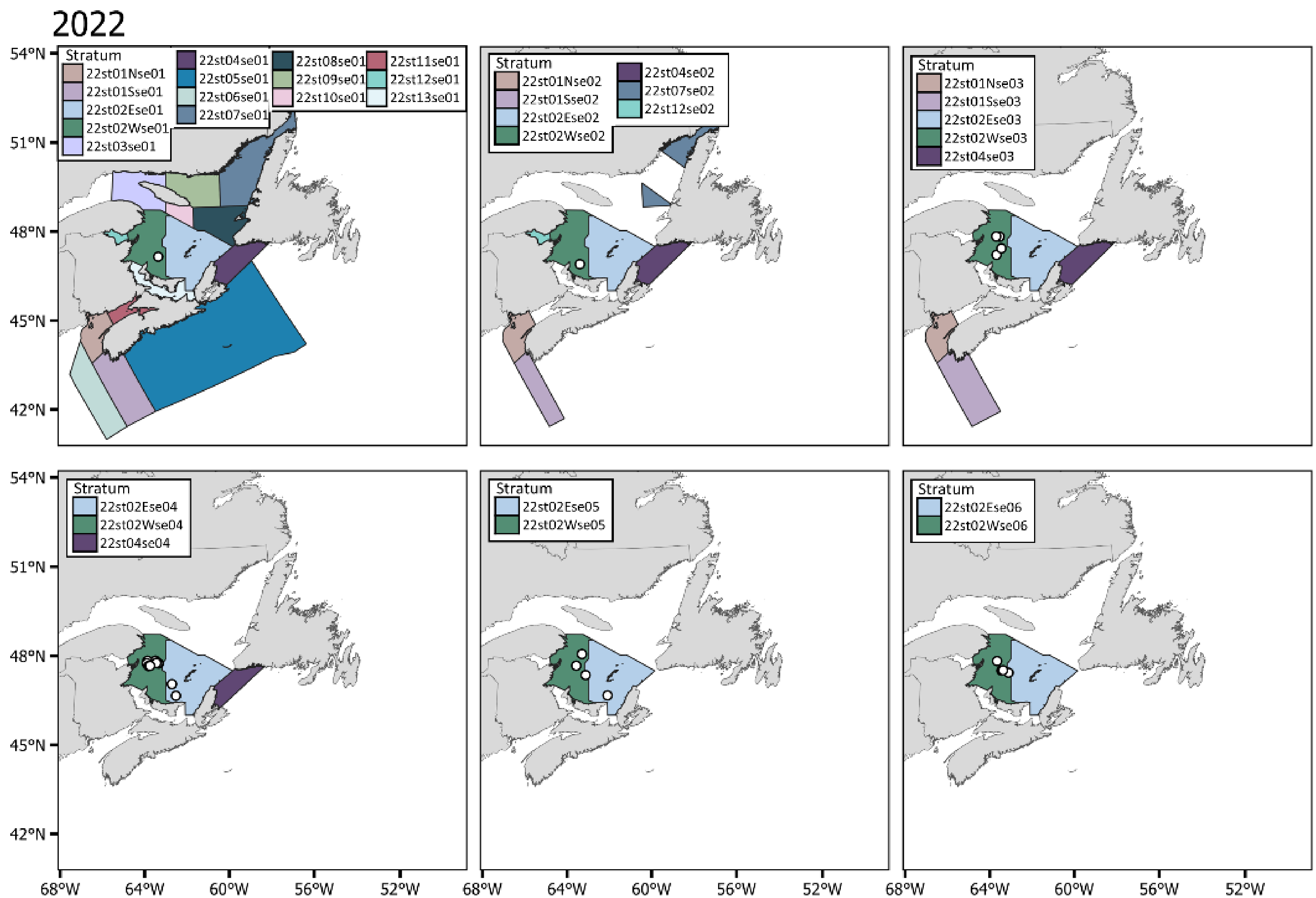

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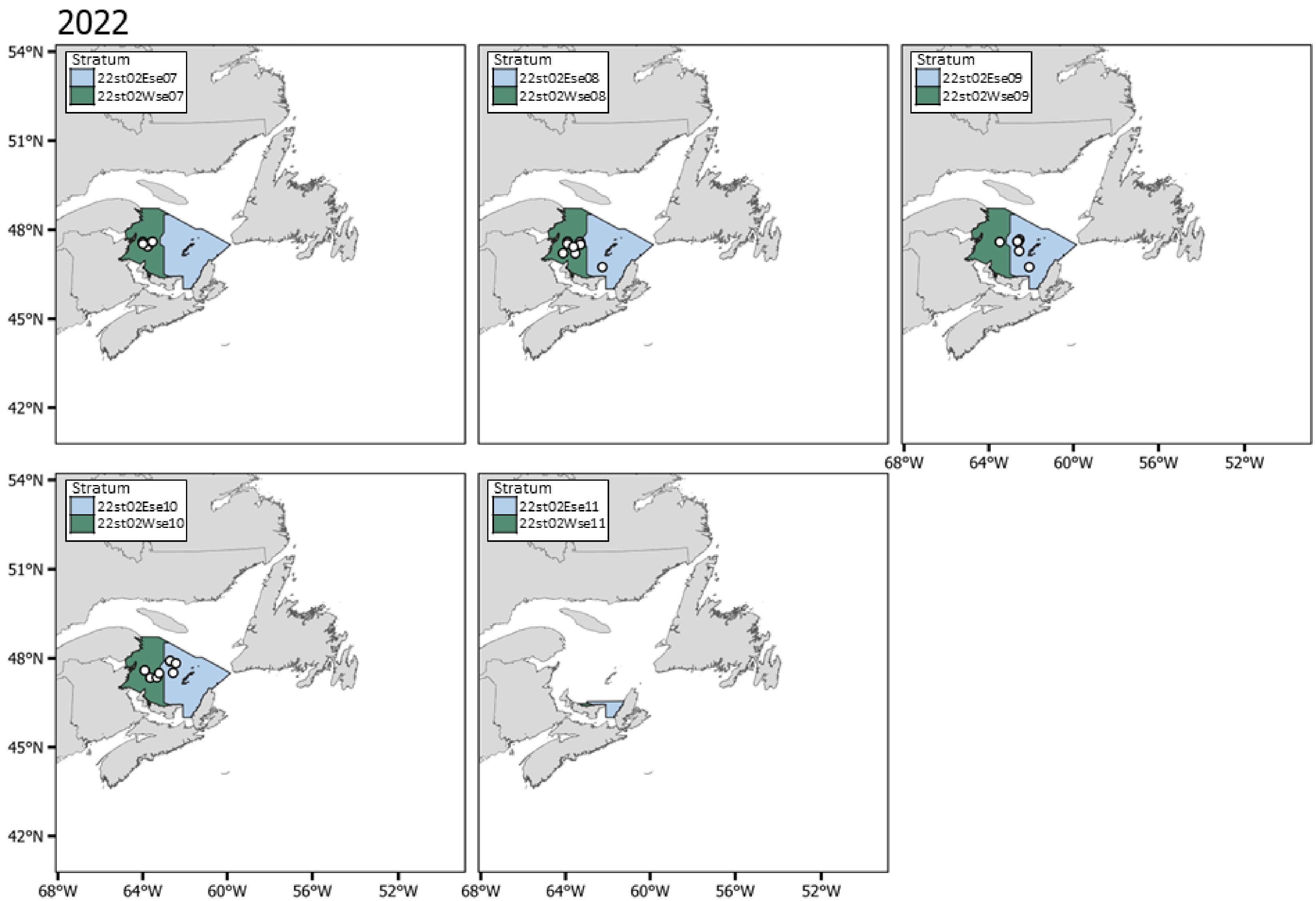

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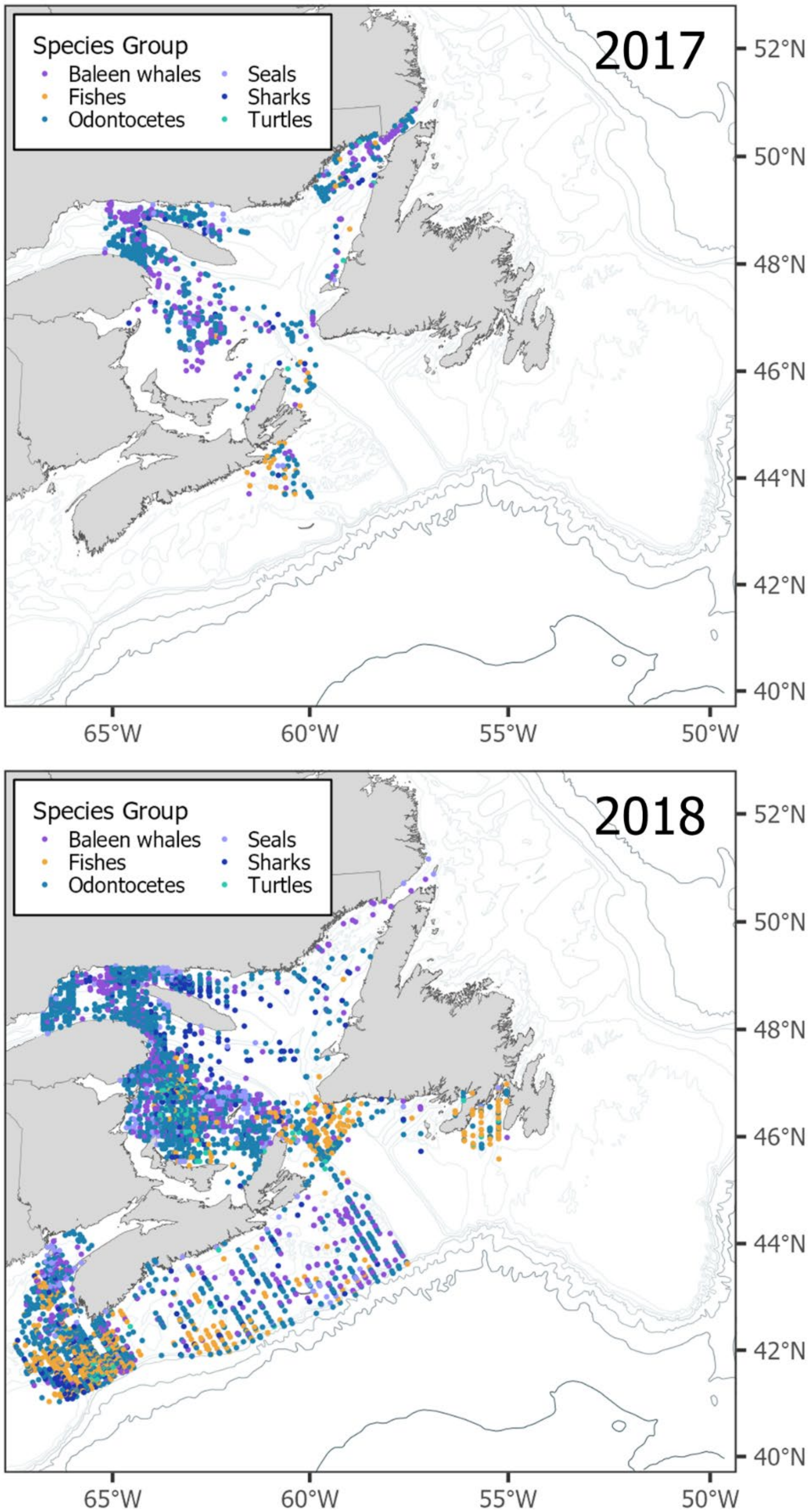

Figure 4. Sightings of marine megafauna, including marine mammals, large fishes and sea turtles, detected along transect lines during systematic surveys of eastern Canadian waters from 29 August 2017 to 6 November 2022. Refer to Table 1 and Figure 3 for the period and area covered within each year.

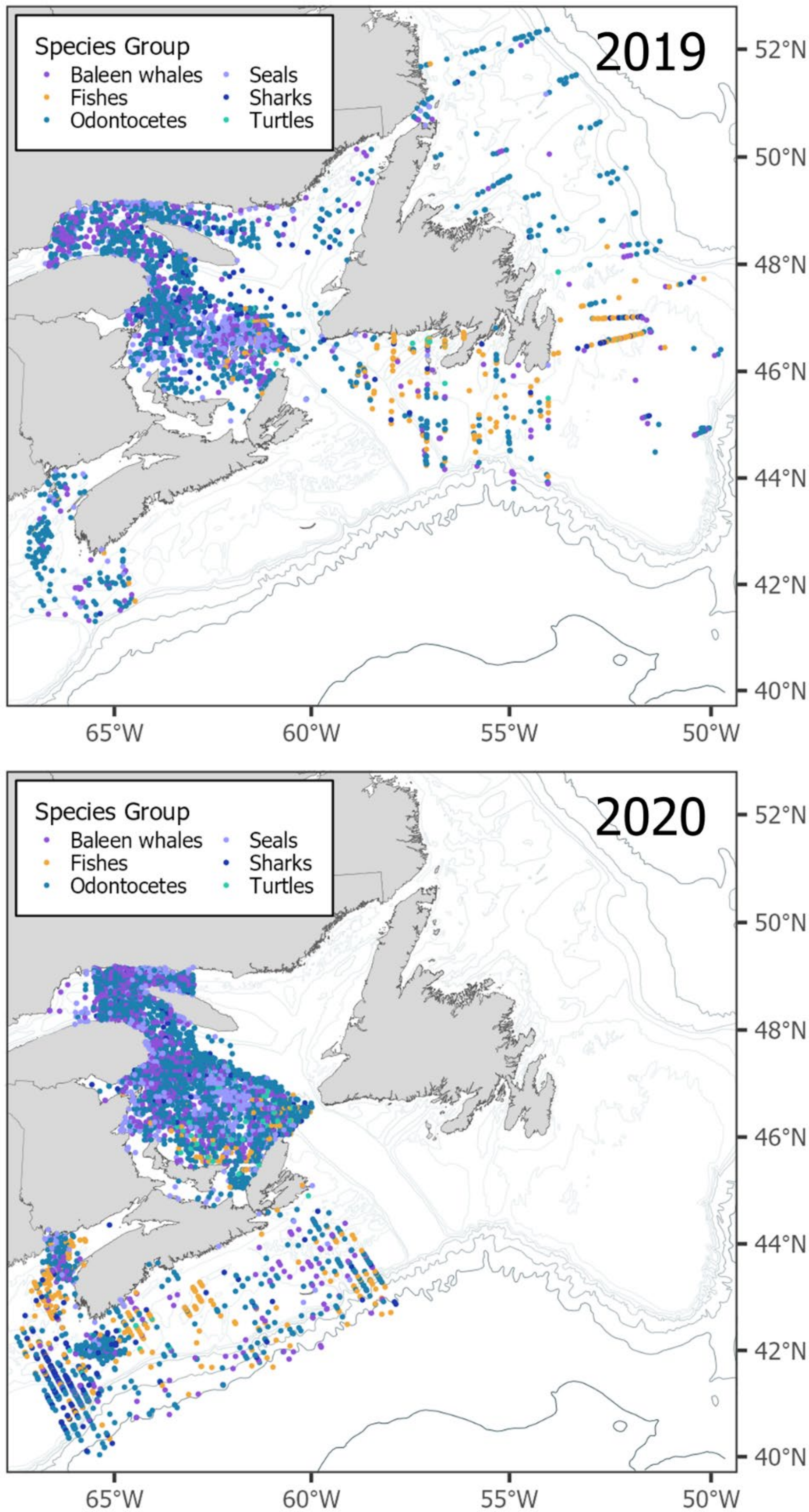

Figure 4. (cont.).

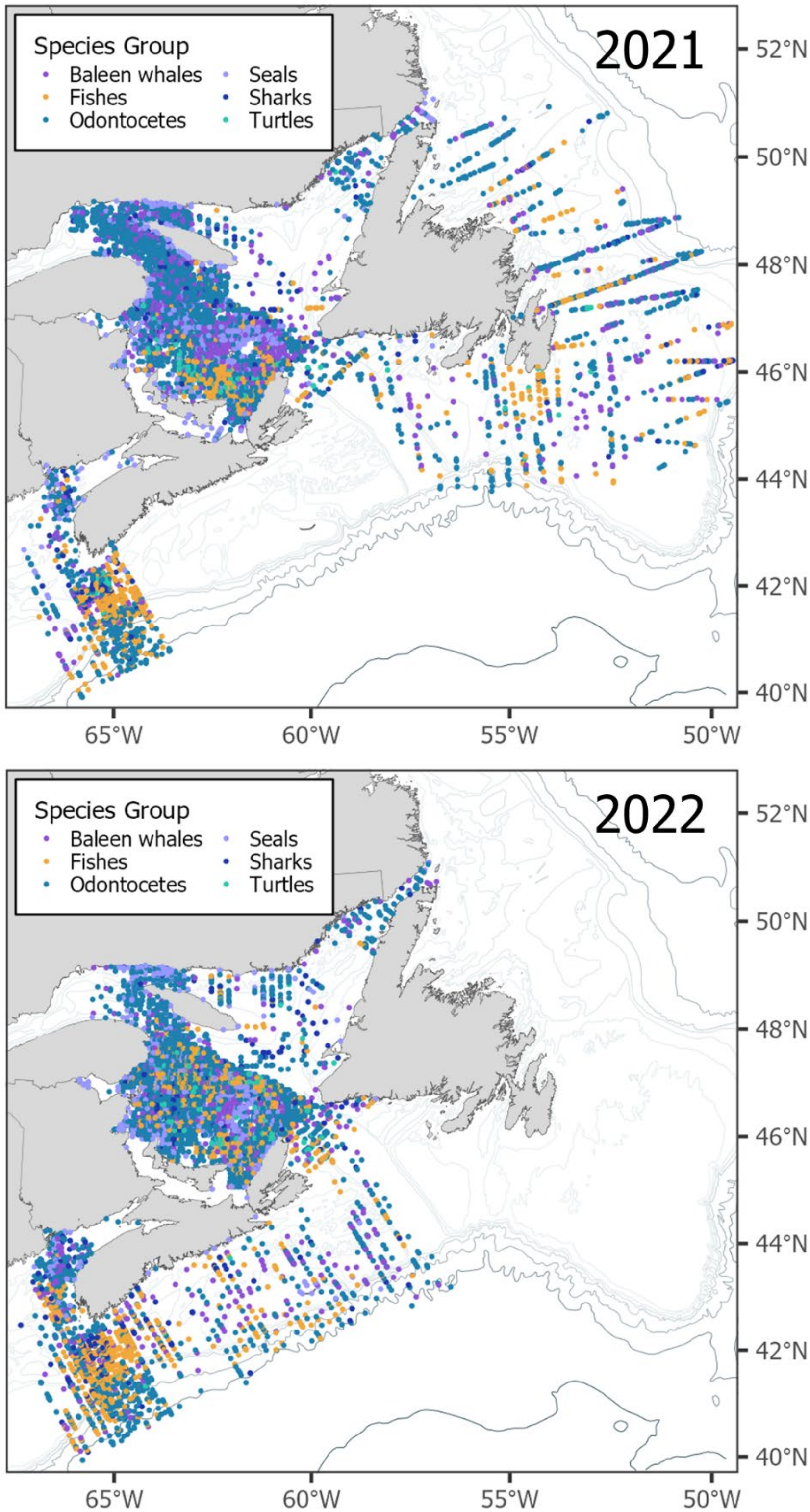

Figure 4. (cont.).

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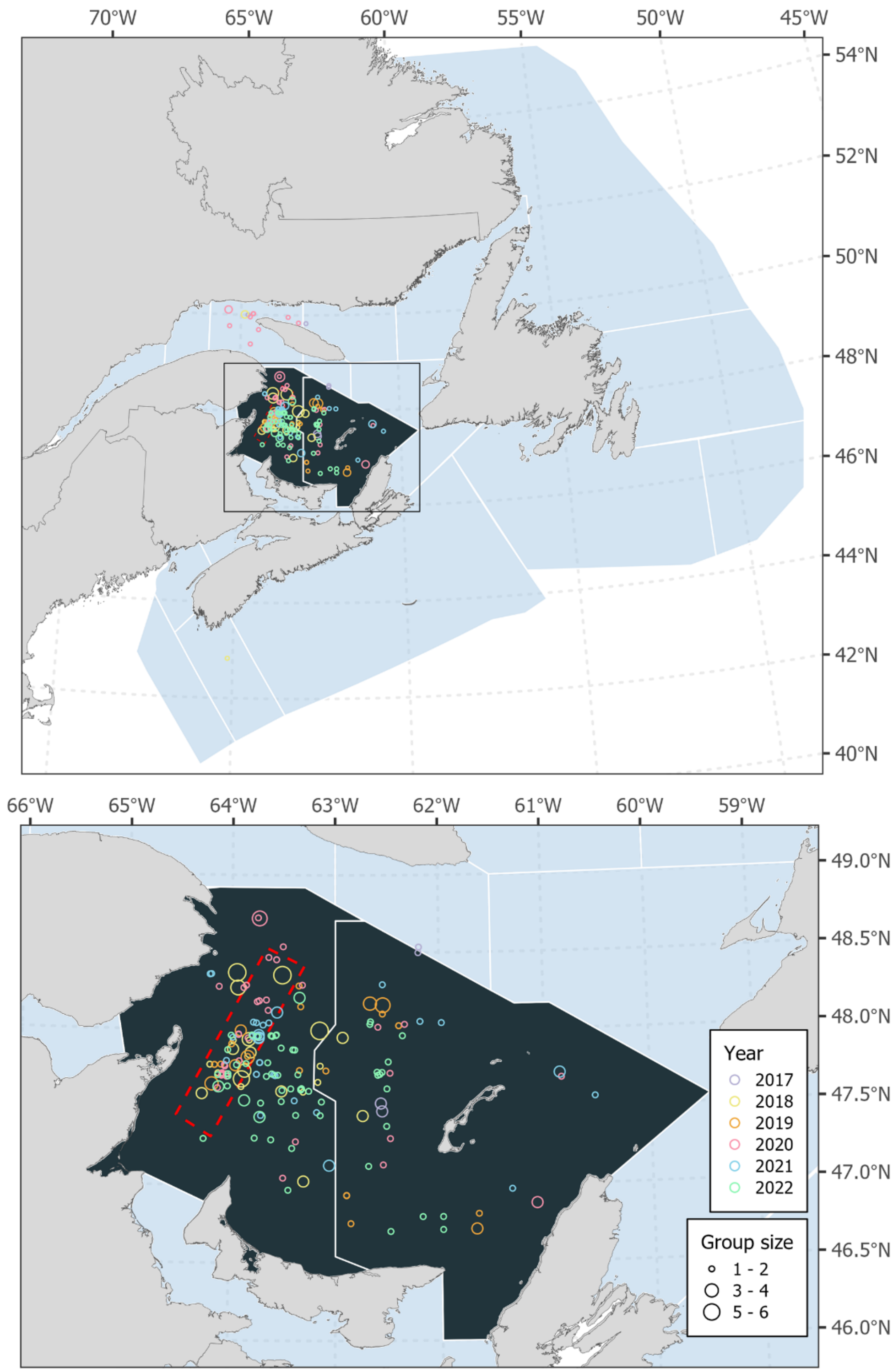


Figure 5. Locations and group sizes of North Atlantic right whales (NARW), Eubalaena glacialis, *detected along transect lines during systematic surveys of Canadian waters, from 29 August 2017 to 6 November 2022. The red dashed line represents the Shediac Valley Static Restricted Area delimited in 2021. Only primary observations recorded while in passing mode and on-effort are presented here (see Methods).*

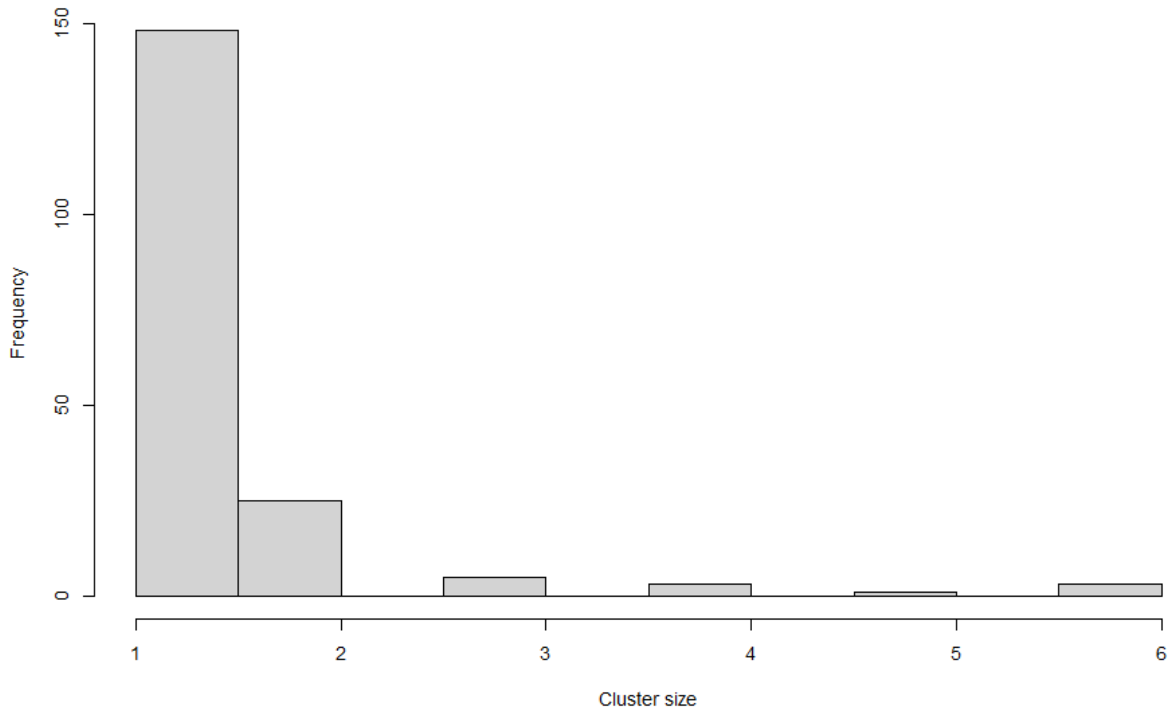


Figure 6. Frequency distribution of the cluster sizes for the 185 groups of North Atlantic right whales (NARW), Eubalaena glacialis*, detected during systematic surveys of eastern Canadian waters from 29 August 2017 to 6 November 2022.*

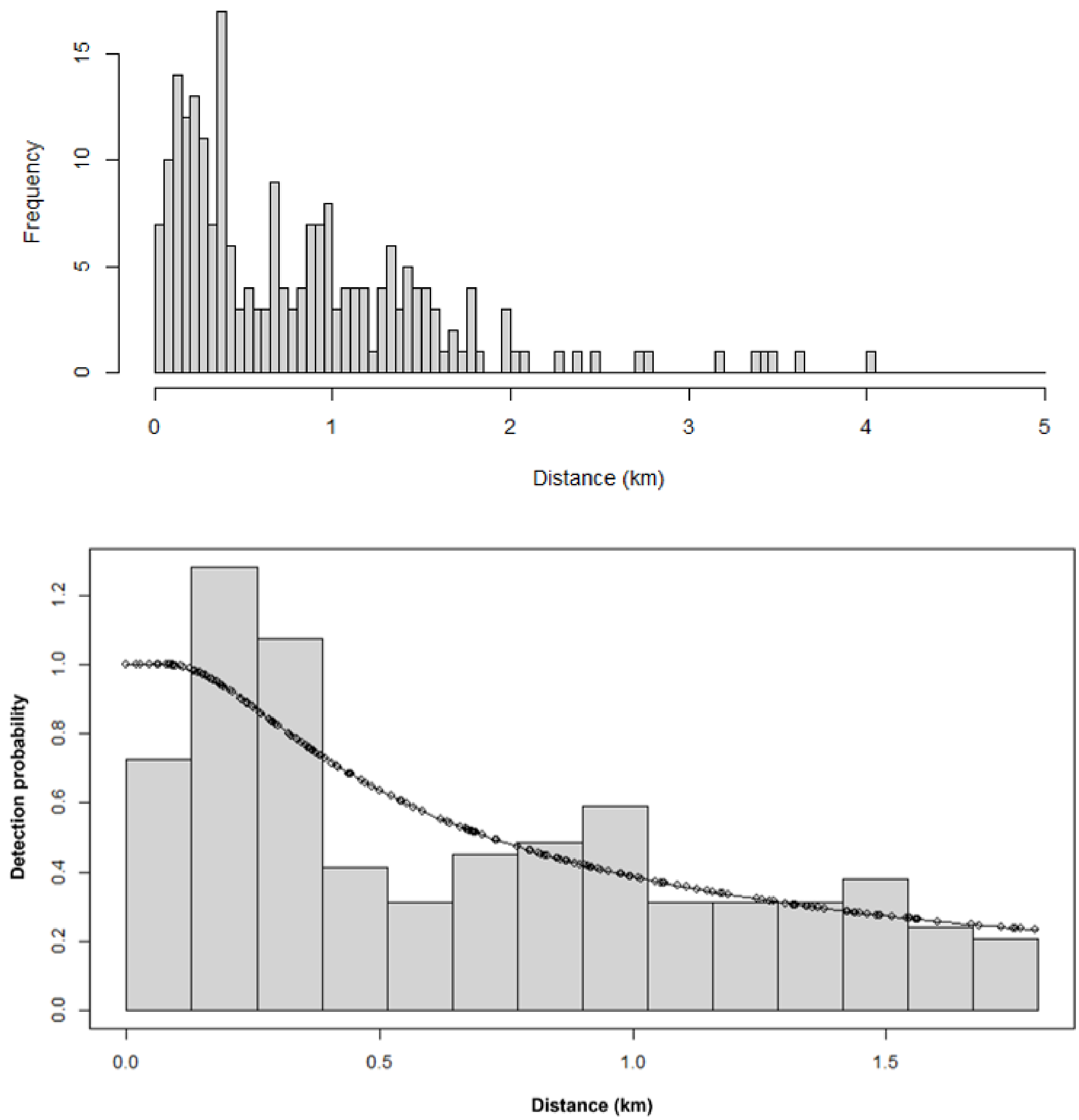


Figure 7. Top: Frequency distribution of perpendicular distances of 222 groups of North Atlantic right whales (NARW), Eubalaena glacialis*, detected by primary observers during systematic surveys of eastern Canadian waters and during fisheries monitoring efforts from 29 August 2017 to 6 November 2022. Bottom: Hazard rate detection curve fitted to 205 groups of NARW (after truncation at 1,800 m), providing an effective strip half-width of 916 m (95% CI: 856-973 m). The perpendicular distances are grouped in bins, but the model was fitted to the ungrouped data.*

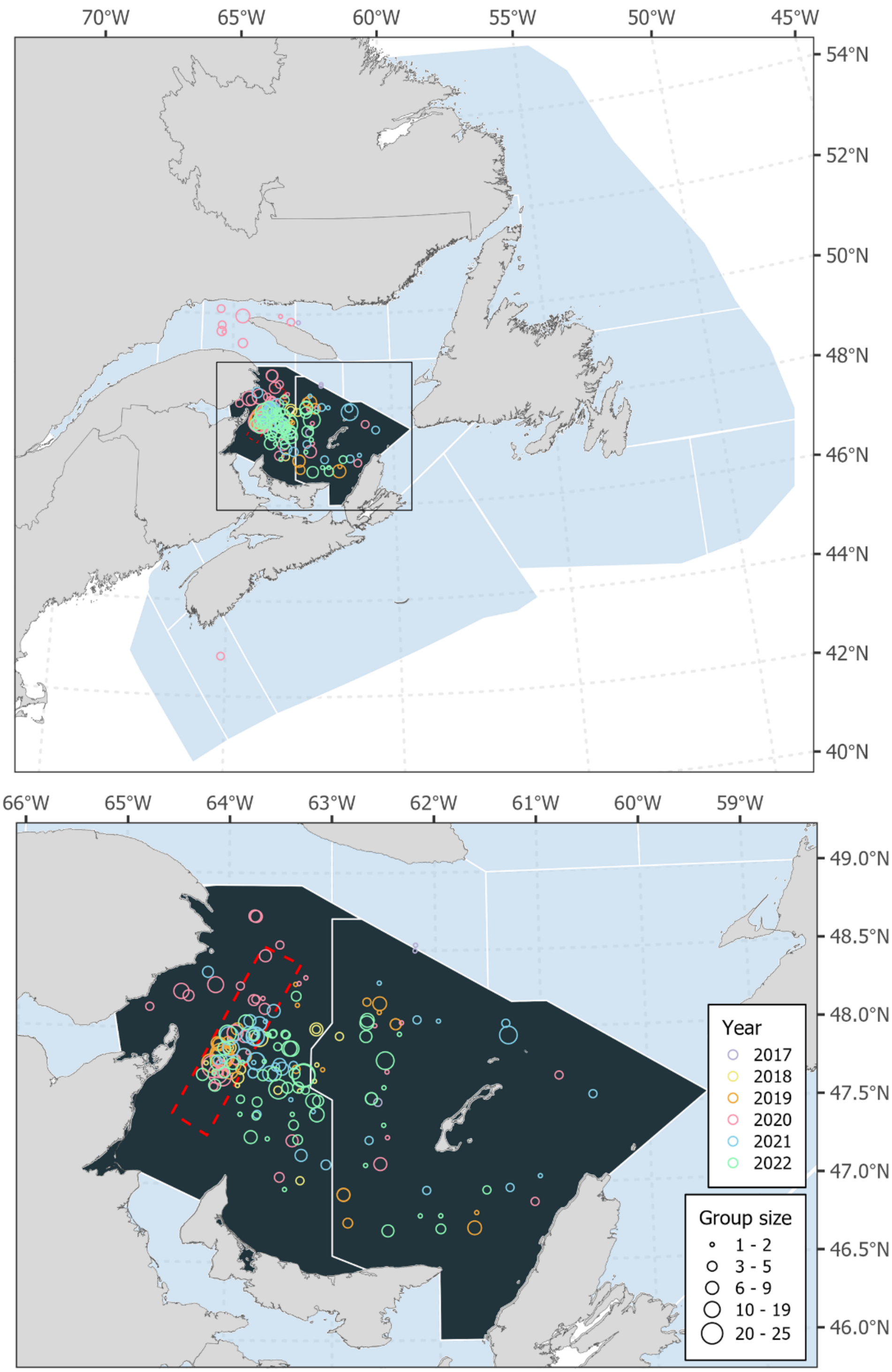


Figure 8. Locations and group sizes of North Atlantic right whales (NARW), Eubalaena glacialis, *detected during closing procedures during systematic surveys of Canadian waters, from 29 August 2017 to 6 November 2022. The red dashed line represents the Shediac Valley Static Restricted Area as delimited in 2021.*

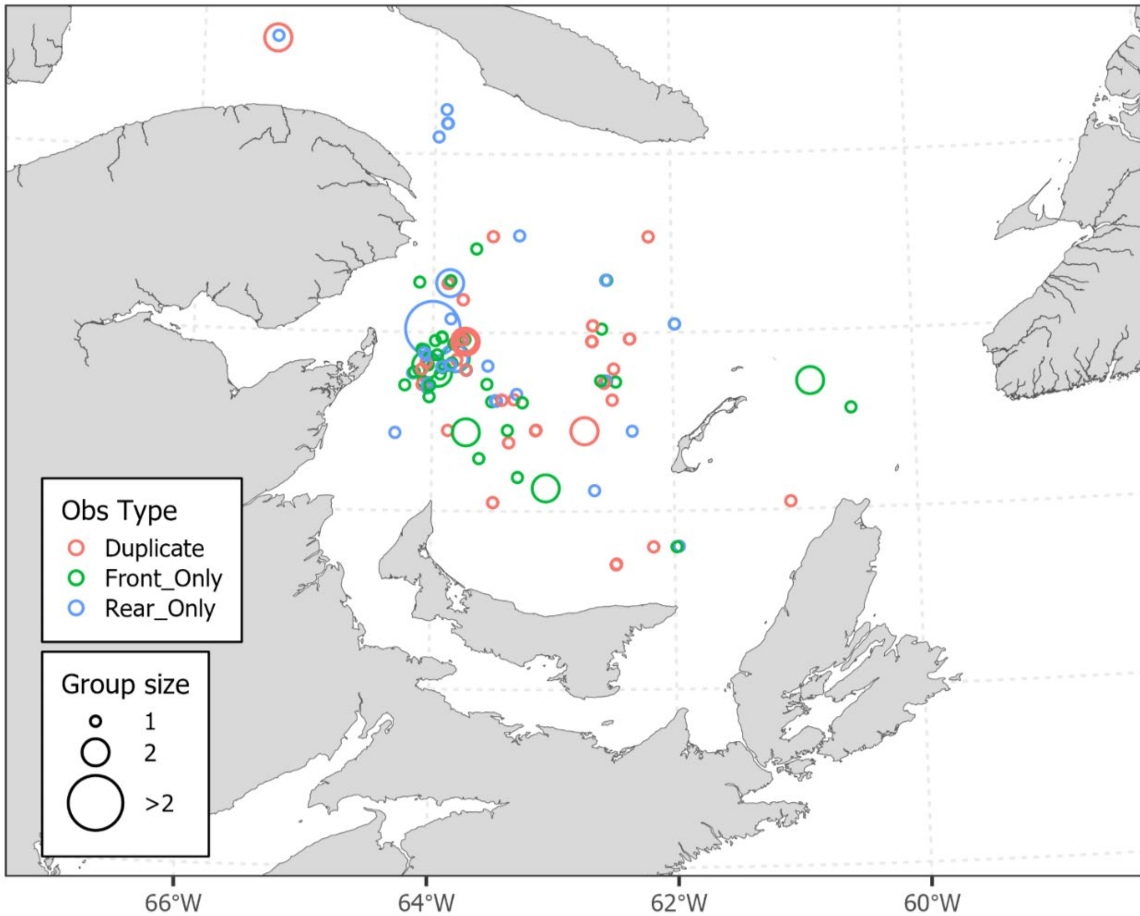


Figure 9. Locations and group sizes of North Atlantic right whales (NARW), Eubalaena glacialis*, detected by observers on the right side of the plane only, along transect lines during systematic surveys of Canadian waters, from 29 August 2017 to 6 November 2022. These observations were used for duplicate identification for double-platform analyses (see Methods - Correction factors).*

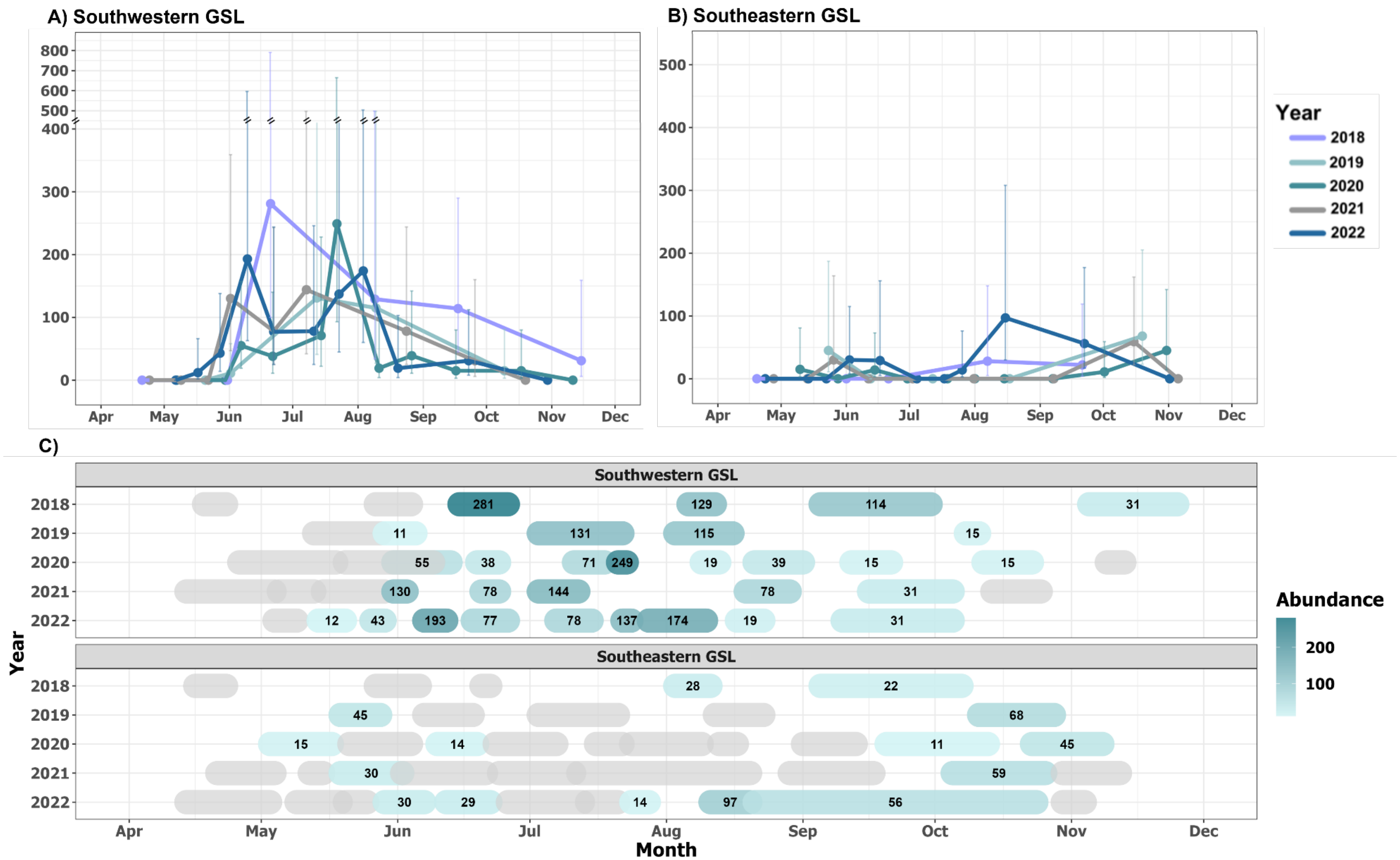


Figure 10. Abundance estimates of North Atlantic right whales (NARW), Eubalaena glacialis*, corrected for both availability and perception biases, for each survey of the southeastern and southwestern Gulf of St. Lawrence (GSL) strata, between 10 April 2018 to 6 November 2022. Surveys conducted in 2017 are excluded from this figure due to their limited coverage of the southern GSL. Panels A and B show the corrected abundance estimates and their 95% CI, while panel C presents the corrected abundance and the duration of each survey. Shaded oblong shapes in panel C identify the dates during which each survey was flown, with gray shapes indicating that no NARW were observed (abundance of zero).*

APPENDIX 1. AVAILABILITY BIAS CORRECTION FACTORS

The proportion of NARW available to be detected was calculated as the number of animals detected from the survey transect line for each specific sighting (*i*) divided by the total number of animals observed during the closing procedures triggered by that sighting. Availability bias correction factors (â) were calculated by averaging these proportions based on the timing of surveys and/or geographical locations. Four factors were considered when averaging the availability values:

- **Year**: to account for potential temporal variations in NARW behavior among years.
- **Period**: to account for potential variations in NARW behavior within a year. Surveys were divided into three periods to account for times where most whales are assumed to be travelling (i.e., from the start of the surveys in April until end of May, and from September to the end of surveys in November) and times where most whales are observed forming aggregations mainly in the Shediac Valley (June to August) because migrating right whales can be more challenging to detect visually (Firestone et al. 2008, Whitt et al. 2013).
- **Strata**: to account for potential differences in behaviours (ex; feeding, travelling) in different areas. Observations were divided by strata for the two strata with the most NARW observations (i.e., the southeastern Gulf of St. Lawrence (GSL) and the southwestern GSL).
- **Zone**: to account for potential differences in behaviours (ex; feeding, travelling) in different areas. Observations were divided into zones, i.e., 1) the southwestern GSL strata (where the Shediac Valley is situated and most NARW observations occur), and 2) the rest of the survey strata.

Across all survey years and strata, the availability bias averaged 0.548 (CV: 66%). The availability bias correction factors calculated considering each factor above, either individually or in combinations, are presented in Tables A1 to A7 below. See the Results section for justification of the values applied to abundance estimates.

Table A1.1. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by year.*

Year	Mean availability bias	CV	SE	Number of closings
2017	1.000	0.000	0.000	4
2018	0.433	0.967	0.081	27
2019	0.529	0.625	0.072	21
2020	0.575	0.646	0.049	57
2021	0.482	0.706	0.055	38
2022	0.566	0.652	0.047	62

Table A1.2. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by period: April-May (AM), June-August (JA) and September-November (SN).*

Period	Mean availability bias	CV	SE	Number of closings
AM	0.685	0.537	0.087	18
JA	0.478	0.738	0.030	136
SN	0.704	0.455	0.043	55

Table A1.3. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by stratum, considering only the southeastern GSL (SEGSL) and southwestern GSL (SWGSL) strata.*

Stratum	Mean availability bias	CV	SE	Number of closings
SEGSL	0.667	0.533	0.054	44
SWGSL	0.484	0.718	0.029	147

Table A1.4. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by year and by stratum, considering only the southeastern GSL (SEGSL) and southwestern GSL (SWGSL) strata.*

Year	Stratum	Mean availability bias	CV	SE	Number of closings
2018	SEGSL	NA	NA	NA	2
2018	SWGSL	0.433	0.967	0.087	23
2019	SEGSL	0.628	0.513	0.114	8
2019	SWGSL	0.468	0.713	0.093	13
2020	SEGSL	0.792	0.436	0.109	10
2020	SWGSL	0.456	0.768	0.059	35
2021	SEGSL	0.641	0.522	0.106	10
2021	SWGSL	0.425	0.775	0.062	28
2022	SEGSL	0.618	0.661	0.109	14
2022	SWGSL	0.550	0.654	0.052	48

Table A1.5. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by period (April-May (AM), June-August (JA) and September-November (SN)) and by year of survey (2018 to 2022).*

Period	Year	Mean availability bias	CV	SE	Number of closings
AM	2018	NA	NA	NA	1
AM	2019	0.750	0.471	0.250	2
AM	2020	1.000	NA	NA	1
AM	2021	0.630	0.593	0.141	7
AM	2022	0.673	0.665	0.169	7
JA	2018	0.117	0.314	0.011	12
JA	2019	0.512	0.687	0.094	14
JA	2020	0.489	0.724	0.056	40
JA	2021	0.392	0.842	0.067	24
JA	2022	0.520	0.702	0.054	46
SN	2017	1.000	0.000	0.000	4
SN	2018	0.750	0.471	0.094	14
SN	2019	0.490	0.604	0.132	5
SN	2020	0.736	0.486	0.090	16
SN	2021	0.643	0.408	0.099	7
SN	2022	0.735	0.437	0.107	9

Table A1.6. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by period (April-May (AM), June-August (JA) and September-November (SN)) and by stratum, considering only the southeastern GSL (SEGSL) and southwestern GSL (SWGSL) strata.*

Period	Stratum	Mean availability bias	CV	SE	Number of closings
AM	SEGSL	0.576	0.656	0.134	8
AM	SWGSL	0.810	0.419	0.113	9
JA	SEGSL	0.660	0.576	0.098	15
JA	SWGSL	0.451	0.762	0.032	115
SN	SEGSL	0.708	0.482	0.074	21
SN	SWGSL	0.572	0.497	0.059	23

Table A1.7. Mean availability bias (â) based on North Atlantic right whale (NARW), Eubalaena glacialis*, observations made from the transect line during systematic surveys and during the associated closing procedures, separated by period (April-May (AM), June-August (JA) and September-November (SN)) and by stratum, considering only and southwestern GSL (SWGSL) strata where aggregations were more frequent vs all other strata combined. This combination was selected to correct to abundance estimates (see Results section).*

Period	Zone	Mean availability bias	CV	SE	Number of closings
AM	SWGSL	0.810	0.419	0.113	9
AM	Outside	0.576	0.656	0.126	9
JA	SWGSL	0.451	0.762	0.032	115
JA	Outside	0.626	0.594	0.081	21
SN	SWGSL	0.572	0.497	0.059	23
SN	Outside	0.758	0.426	0.057	32

APPENDIX 2. OUTPUT OF THE SELECTED DETECTIN FUNCTION

Summary of model output for the selected model:

```
> summary(DF_Skey_NoCovar)

Summary for ds object
Number of observations :  205
Distance range         :  0  -  1.8
AIC                    :  200.3207
Optimisation           :  mrds (nlminb)

Detection function:
 Hazard-rate key function

Detection function parameters
Scale coefficient(s):
              estimate        se
(Intercept) -0.6844736 0.3902213

Shape coefficient(s):
              estimate        se
(Intercept) 0.04624462 0.2788081

                       Estimate          SE        CV
Average p             0.5068794  0.08204076 0.1618546
N in covered region 404.4354931 68.39909289 0.1691224
```

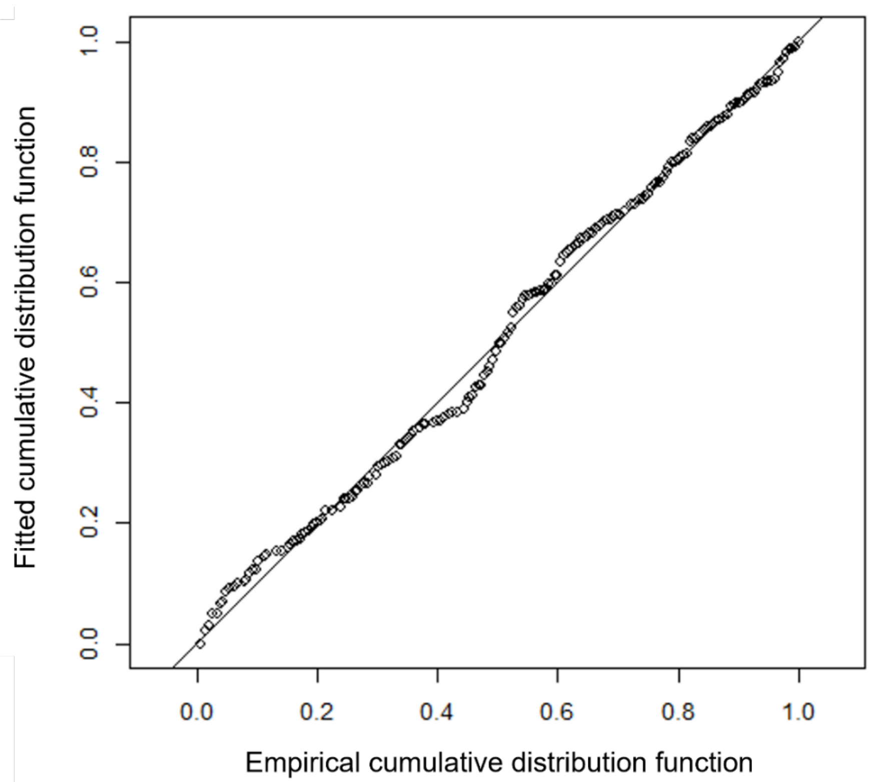


Figure A2.1. Quantile-quantile (Q-Q) plot for the selected fitted model (i.e., hazard rate detection curve, without covariates).

APPENDIX 3. LOCATIONS AND GROUP SIZES OF NARW BY TIME PERIOD

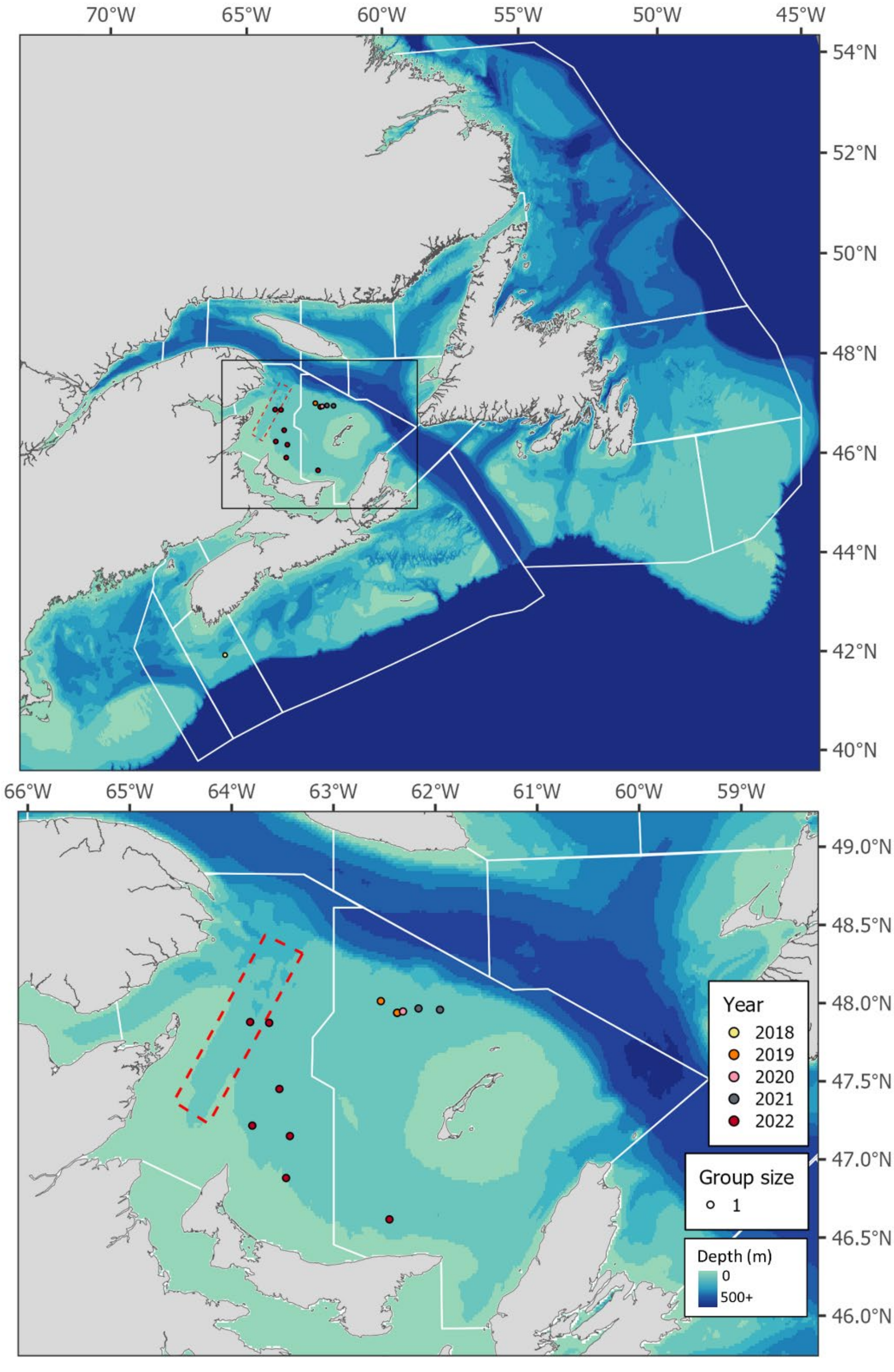
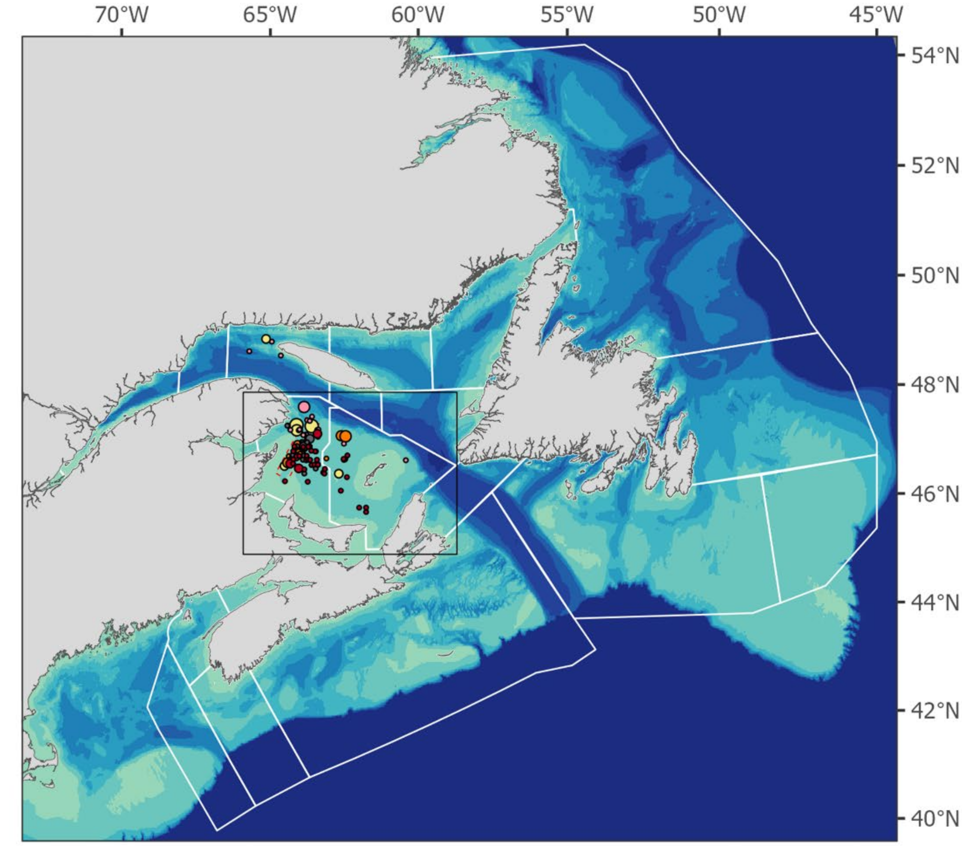


Figure A3.1. Locations and group sizes of North Atlantic right whales detected along transect lines during systematic surveys of Canadian waters, in April and May 2017-2022. The red dashed line represents the 2021 Shediac Valley Static Restricted Area. Only primary observations recorded while in passing mode and on-effort are presented here (see Methods).



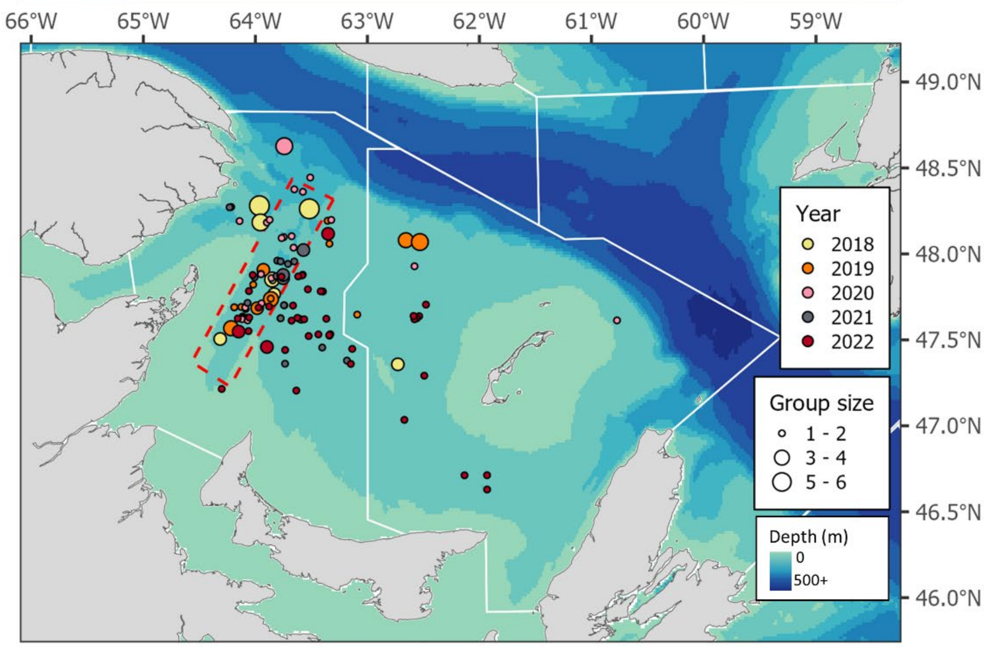


Figure A3.2. Locations and group sizes of North Atlantic right whales detected along transect lines during systematic surveys of Canadian waters, in June, July and August 2017-2022. The red dashed line represents the 2021 Shediac Valley Static Restricted Area. Only primary observations recorded while in passing mode and on-effort are presented here (see Methods).

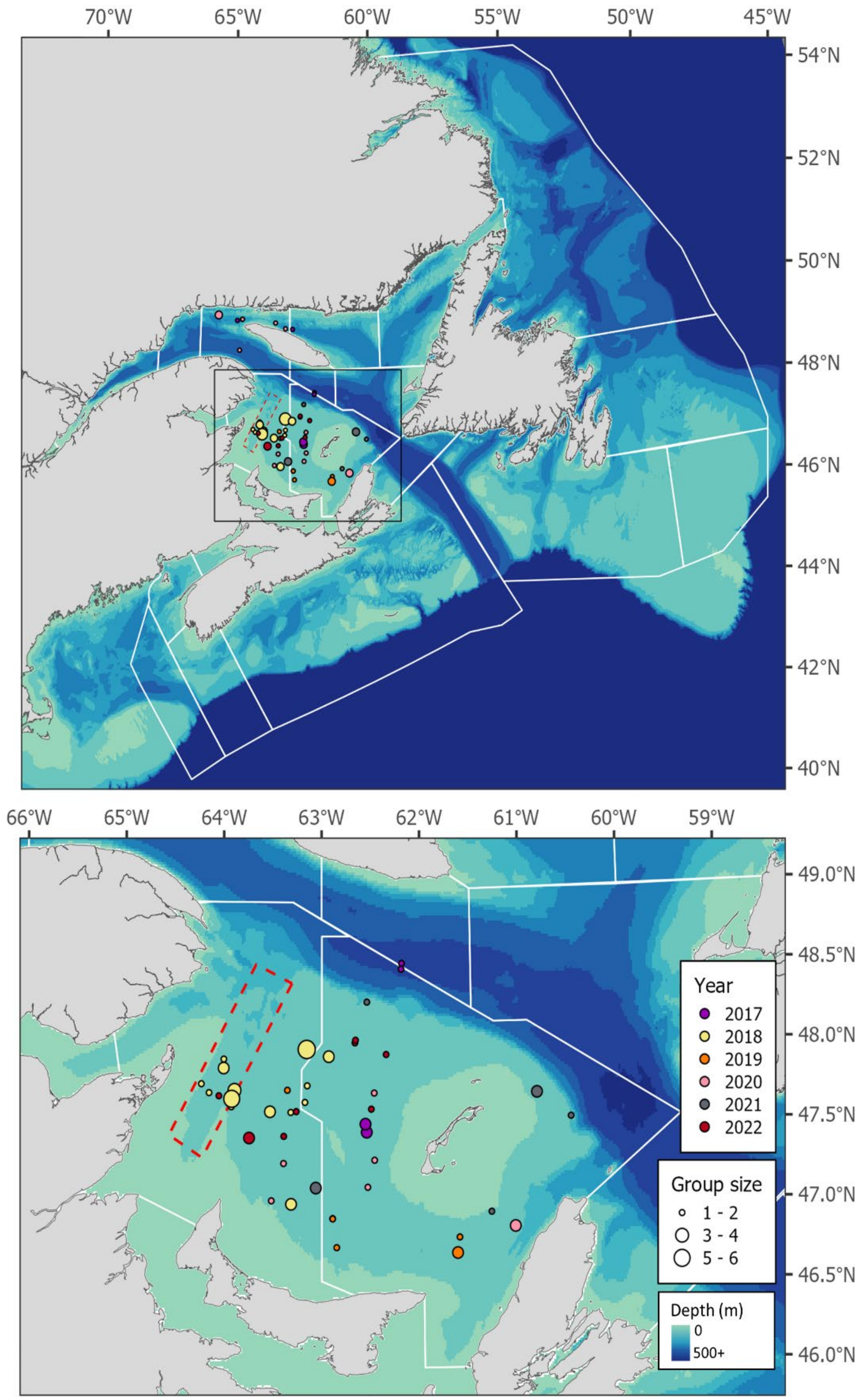


Figure A3.3. Locations and group sizes of North Atlantic right whales detected along transect lines during systematic surveys of Canadian waters, in September, October and November 2017-2022. The red dashed line represents the 2021 Shediac Valley Static Restricted Area. Only primary observations recorded while in passing mode and on-effort are presented here (see Methods).

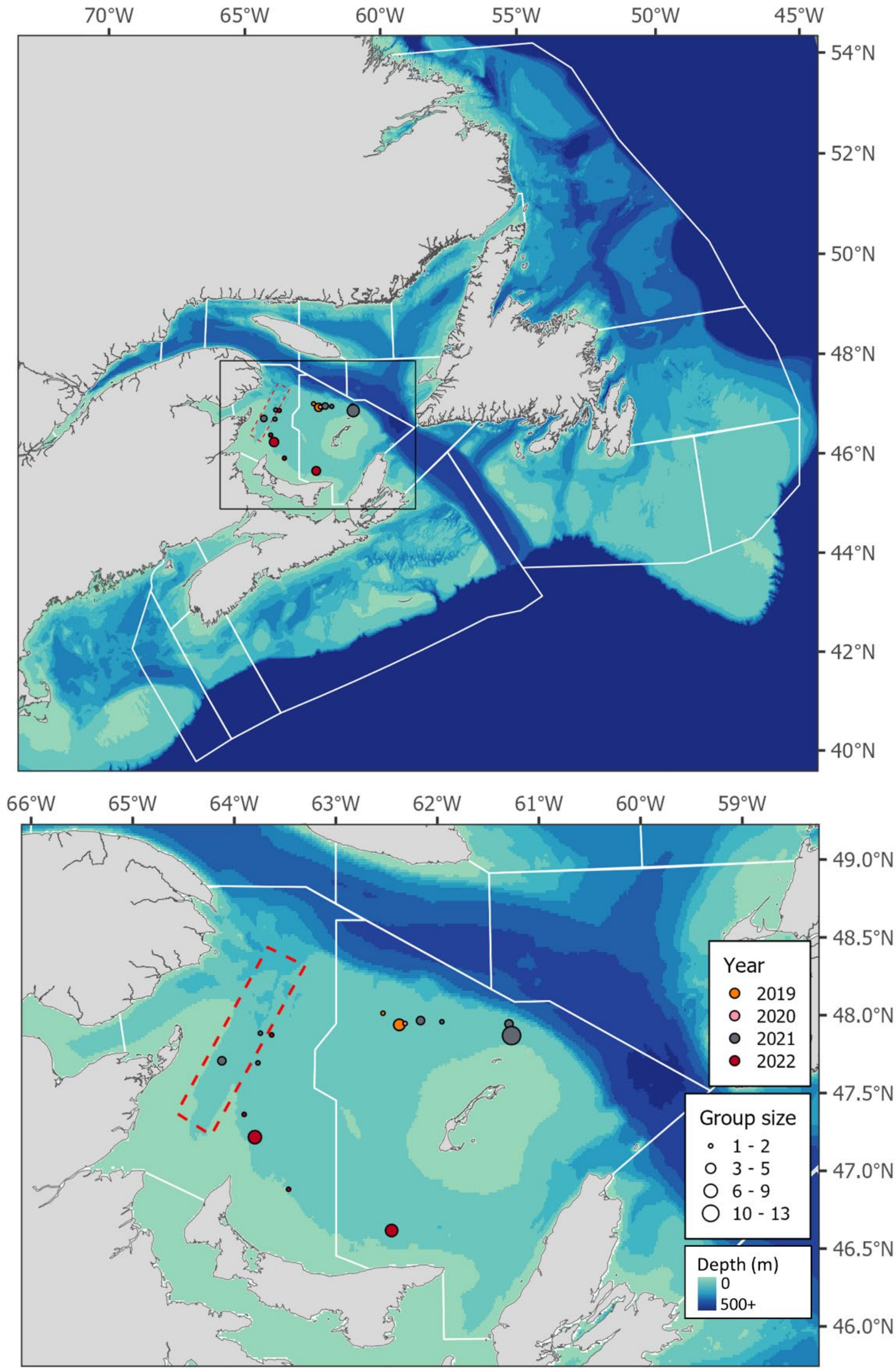


Figure A3.4. Locations and group sizes of North Atlantic right whales detected during closing procedures during systematic surveys of Canadian waters, in April and May 2017-2022. The red dashed line represents the 2021 Shediac Valley Static Restricted Area.

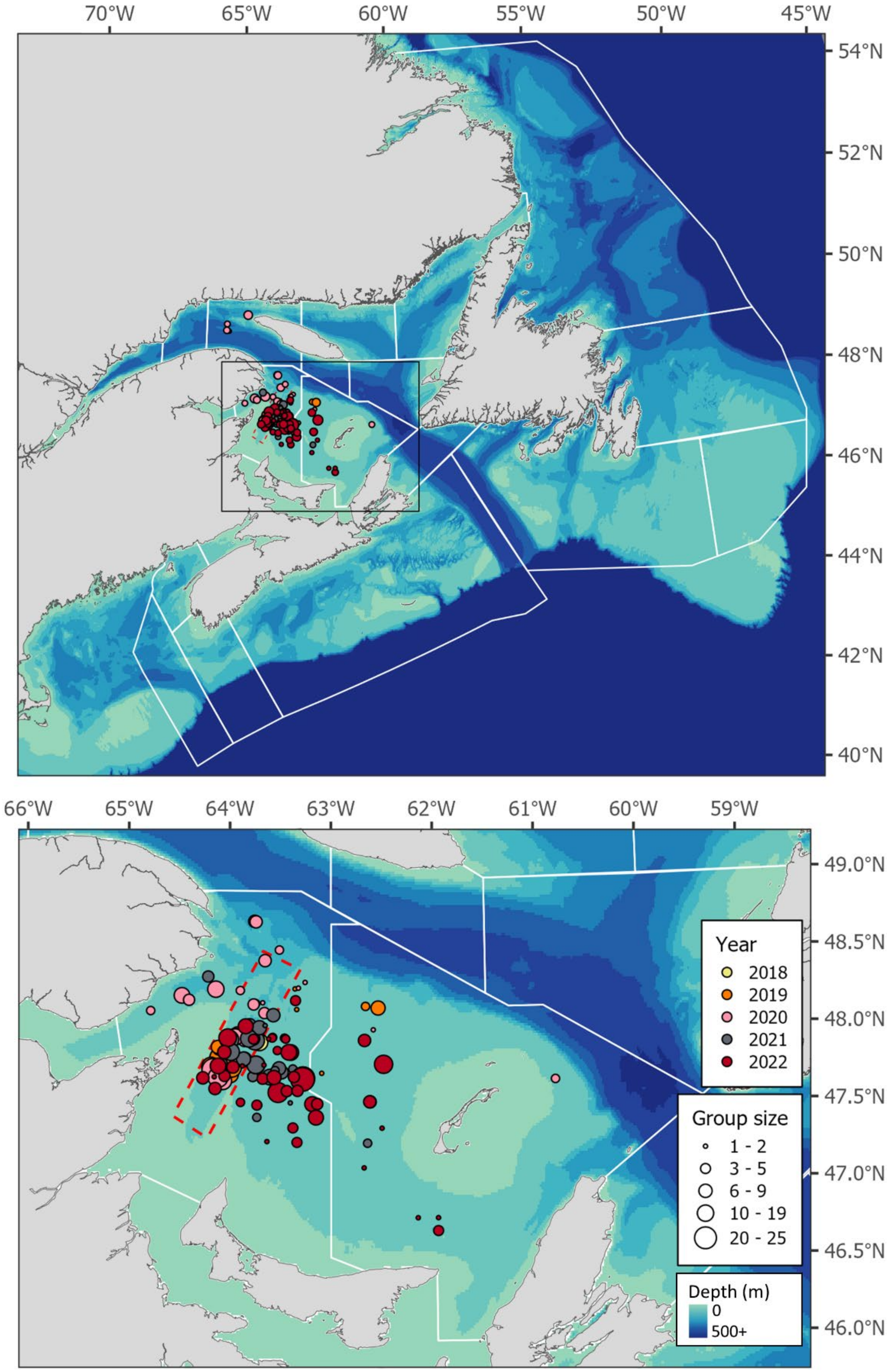


Figure A3.5. Locations and group sizes of North Atlantic right whales detected during closing procedures during systematic surveys of Canadian waters, in June, July and August 2017-2022. The red dashed line represents the 2021 Shediac Valley Static Restricted Area.

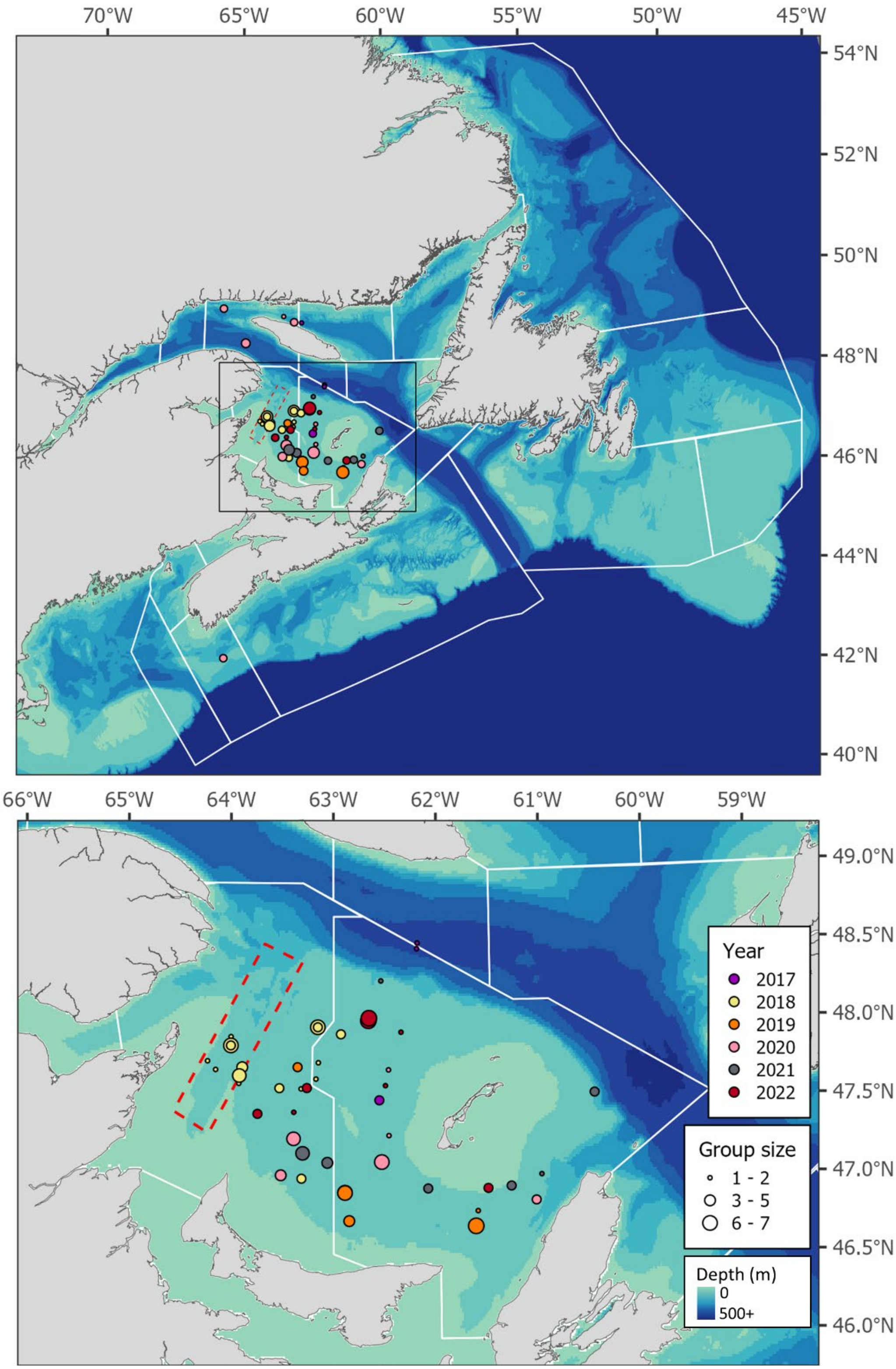


Figure A3.6. Locations and group sizes of North Atlantic right whales detected during closing procedures during systematic surveys of Canadian waters, in September, October and November 2017-2022. The red dashed line represents the 2021 Shediac Valley Static Restricted Area.