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Population Status Assessment and Potential Biological Removal (PBR) for the Atlantic Harbour Seal (*Phoca vitulina vitulina*) in Canadian Waters

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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

Aerial surveys were conducted between June and August of 2019–21 to assess harbour seal (*Phoca vitulina vitulina*) abundance and distribution in Atlantic Canada. The surveys covered three regions: the Gulf of St. Lawrence (GSL), the Scotian Shelf (SS), and the Newfoundland and Labrador Shelves (NLS). These surveys counted seals at haul-out sites in each region. A total of 10,327 individuals were counted, with 55%, 23%, and 22% of the individuals counted in the GSL, SS, and NLS, respectively. To estimate abundance, these counts were adjusted for the proportion of seals which were at sea during the time of the survey and were, therefore, unavailable to be counted. We applied correction factors (CF) of 2.55 (coefficient of variation [CV]: 16.02%) and 1.64 (CV: 8.67%) for surveys taking place during the pupping and moulting periods, respectively, as developed in a companion study based on recent telemetry data and CFs reported in the literature. Applying these CFs to survey counts yielded a total estimated harbour seal abundance for Atlantic Canadian waters for 2019–21 of 25,183 individuals (95% CI 22,548–28,126). The GSL, SS, and NLS regions accounted for 58%, 24%, and 19% of the total estimated abundance, respectively. These are likely minimum estimates as a result of seals entering the water prior to the count due to disturbance, imperfect detection of hauled out seals, and a lack of coverage in some areas. The uncertainty around the abundance estimate may also be underestimated since there was no reported uncertainty in survey counts and data to develop CFs for the study area were limited. The Potential Biological Removal (PBR) for Atlantic Canada’s harbour seal population, based on this abundance estimate, was 720 individuals.

INTRODUCTION

The harbour seal, *Phoca vitulina*, is the most widely distributed pinniped in coastal regions. It occupies a wide variety of habitats and climatic zones across the Northern Hemisphere (Boulva and McLaren 1979; Härkönen and Heide-Jørgensen 1990; Burns 2009; Liu et al. 2022). Three subspecies are known to inhabit Canadian waters: the North Pacific harbour seal, *P. v. richardsi* (Gray 1864); the North Atlantic harbour seal, *P. v. vitulina* (Linnaeus 1758, previously *P. v. concolor*), found along the Arctic and Atlantic coasts; and the Lacs des Loup Marins harbour seal, *P. v. mellonae* (Doutt 1942), which is a small population endemic to a chain of freshwater lakes in Nunavik (northern Quebec).

While the Lac des Loup Marins harbour seal population is listed as “Endangered” by both the Committee on the Status of Endangered Wildlife Canada (COSEWIC 2018) and the International Union for the Conservation of Nature (IUCN, Lowry 2016), the other two sub-species are listed as “Not at Risk” by COSEWIC (COSEWIC 2007) and as “Least Concern” by the IUCN (Lowry 2016).

Information about the distribution and abundance of pinnipeds is essential to guide management decisions, understand the effects of harvest (e.g., Hammill et al. 2017; Hammill et al. 2021), estimate impacts on prey of commercial or conservation concern (Swain and Benoît 2015; Swain and Benoît 2017), and evaluate the repercussions of anthropogenic activities (maritime transport, fishing, industrial developments, etc.) on pinniped populations (Lesage et al. 1995; Olesiuk 2010). Harbour seals are year-round residents of Atlantic Canada and are typically associated with coastal areas, isolated sandy beaches, small islands, and rocks and reefs exposed at low tide (Boulva and McLaren 1979). They are relatively sedentary (e.g., Sharples et al. 2012; Rosing-Asvid et al. 2020), although extensive movements can occur (Lesage et al. 2004). While their nearshore coastal distribution and site fidelity have facilitated numerous studies on diet, physiology, and behaviour in Atlantic Canada (Bowen and Harrison 1996; Dubé et al. 2003; Lesage et al. 2004; Heaslip et al. 2014), efforts to assess harbour seal population distribution and abundance in Atlantic Canadian waters have been limited both spatially and temporally.

Historical records indicate that harbour seals were abundant in Atlantic Canada in the early 20 century (Fisher 1949; Scott and Fisher 1958; Boulva and McLaren 1979; Stobo and Fowler 1994). However, bounty programs implemented between 1927 and 1976 resulted in significant declines in abundance and notable disappearances from areas where harbour seals had typically been observed (Boulva and McLaren 1979; Stobo and Fowler 1994; Hammill et al. 2010). Using bounty return records and information collected from interviews and questionnaires, Boulva and McLaren (1979) estimated the population abundance of harbour seals in Atlantic Canada south of Labrador at approximately 12,700 individuals in 1973, including 4,690 in the Gulf of St. Lawrence (GSL), 5,970 on the Scotian Shelf (SS; including 1,250 on Sable Island, Nova Scotia) and 2,040 on the Newfoundland Shelf (including 300 on the islands of St. Pierre and Miquelon, France). Following the prohibition of hunting in 1979, efforts to estimate the abundance of harbour seals in Atlantic Canada were infrequent and restricted to limited geographical areas. Aerial surveys conducted in the Bay of Fundy and along southwestern Nova Scotia (SWNS) between 1985–92 and along portions of the St. Lawrence Estuary (SLE) and GSL between 1995–2001 suggested that harbour seal abundance had increased since the end of the bounty program (Stobo and Fowler 1994; Lesage et al. 1995; Robillard et al. 2005). Likewise, count and tagging data showed that harbour seal pup production increased on Sable Island from 1978 until 1989 (Bowen et al. 2003). However, a sharp decline in abundance to very low numbers was observed on Sable Island during the 1990s as a result of increased inter-specific competition with grey seals and increased mortality of pups and adult females attributed to increased predation by sharks (Lucas and Stobo 2000; Bowen et al. 2003). Local vessel and shore-based surveys combined with interviews with local fishers conducted in the early 2000s indicated that harbour seal abundance in Newfoundland and Labrador had increased at some sites along the south coast, with stable or decreasing abundance for sites in the north and north-eastern parts of Newfoundland compared to Bouvla and McLaren's estimates for 1973 (Boulva and McLaren 1979; Sjare et al. 2005). Since the early 2000s, there have been no efforts to estimate the abundance of harbour seals in Atlantic Canadian waters and, thus, there is no data on recent population trends.

In contrast to Atlantic Canada, the harbour seal population in US waters has been periodically assessed since 1981 based on aerial surveys conducted along the coast of Maine during the pupping period (Gilbert et al. 2005; Hayes et al. 2022; Sigourney et al. 2022). Harbour seal abundance in Maine increased until the early 2000s and then declined through to 2012 (Sigourney et al. 2022). Between 2012 and 2018, the population appears to have remained stable with a 2018 estimate of 61,340 individuals (Hayes et al. 2022; Sigourney et al. 2022). Although harbour seals along the Maine coast have experienced increased competition from grey seals (Wood et al. 2020; den Heyer et al. 2021), increased predation by white sharks (Curtis et al. 2014) and Unusual Mortality Events (UME) in 2011, 2018 and 2022 linked to infectious disease epidemics, there is no evidence of rapid changes in overall abundance along the Maine coast since the early 2000s (Sigourney et al. 2022).

In 2019, 2020, and 2021, aerial surveys of the GSL, the SS, and the Newfoundland-Labrador Shelves (NLS; Figure 1), respectively, were conducted by Fisheries and Oceans Canada (DFO) as the first ever attempt to obtain survey-based counts of harbour seals over their entire range in Atlantic Canadian waters. Full details on the survey coverage and counts obtained for each region can be found in Mosnier et al. (2023b) for the GSL, (Lidgard et al. 2023) for the SS, and Hamilton et al. (2023) for the NLS. Here, we combine results from these surveys and apply appropriate haul-out correction factors (CFs) (Irani et al. 2024) to:

1. provide an estimate of the current distribution and abundance of harbour seals in Atlantic Canadian waters, and
2. provide an estimate of Potential Biological Removal (PBR) for harbour seals in Atlantic Canadian waters as required under the US Marine Mammal Protection Act (MMPA) bycatch provisions (NOAA 2016).

METHODS

STUDY AREA

Gulf of St Lawrence (GSL)

The survey region included the entire coastline and islands of the St. Lawrence Estuary (SLE, including the lower portion of the Saguenay River) and the GSL (Figure 2). It was divided into four areas:

1. the SLE from Île d'Orléans to Pointe des Monts on the north shore and Sainte-Anne-des-Monts on the south shore, including the lower Saguenay River from Cap à l'Est to Tadoussac;
2. the Southern Gulf which extends from Sainte-Anne-des-Monts to Cape North on Cape Breton Island, including the Magdalen Islands, Brion Island, Corps-Mort, Rocher-Aux-Oiseaux and Prince Edward Island;

3. the Northern Gulf which extends from Pointe des Monts to Blanc-Sablon, including Anticosti Island, and
4. the west coast of Newfoundland from Flowers Cove to Cape Ray.

Scotian Shelf (SS)

The survey region included the coastline, islands, and the downstream portion of major rivers of Nova Scotia (NS) and New Brunswick (NB) excluding the west coast of Cape Breton Island and the North Shore of NS, which were included as part of the survey of the GSL (Figure 3). Five areas were considered:

1. The Bay of Fundy, including the Saint John River up to Hog Island but excluding the areas of extensive mudflats which occur in the northeastern (Chignecto Bay) and northwestern (Minas Basin) areas of the Bay as they are unsuitable habitat for harbour seals;
2. Southwest Nova Scotia (SWNS) which extends from the southern tip of Long Island (including St. Mary's Bay) to the northwest corner of St. Margaret's Bay;
3. the Eastern Shore which extends from the northwest corner of St. Margaret's Bay to the Canso Causeway which connects mainland NS to Cape Breton Island;
4. the east coast of Cape Breton Island from the causeway to Cape North; and
5. Sable Island, NS.

Newfoundland and Labrador Shelves (NLS)

Coastal surveys in the NLS were completed only in areas that harbour seals were known to occupy or have occupied in the past, based on interviews with science staff, fishermen, and DFO Conservation and Protection conducted in the spring of 2021 (see Hamilton et al. 2023). The survey region included the coastline and islands of three areas (Figure 4):

1. the south coast of Newfoundland from Burgeo to St. John's, including coverage of the French archipelago of Saint Pierre et Miquelon (SPM);
2. the northeast coast of Newfoundland between Willis Island (Bonavista Bay) and the Fogo Islands, and between the Grey Islands and Belle Island;
3. Sandwich Bay, Labrador.

SURVEY COVERAGE AND METHODS

Due to logistical constraints, the Atlantic Canada wide survey was conducted over a three year period (2019–21, Table 1). The survey of each region (GSL, SS, NLS) was completed in a single year with the exception of the survey of Sable Island (eastern SS, Figure 1) which was completed one year after the survey of the mainland coast of the SS (Table 1). The timing and duration of the survey windows varied by region (Table 1). The GSL survey was conducted over a 26 d period from June 4–30, 2019 while the mainland coast of the SS was surveyed over a 32 d period from June 14–July 16, 2020. These survey windows were selected to coincide with the pupping season for harbour seals during which they are known to spend more time hauled out and are, therefore, more likely to be detected during aerial surveys (Bowen et al. 1992; Olesiuk 1999; Dubé et al. 2003). The NLS survey was conducted over a 44 d period from July 6–August 19, 2021. This period was selected as conditions are generally more suitable for flying aerial surveys in the NL region (low winds, <20 km/h and low probability of fog). The NLS survey coincided with the end of the pupping period (late lactation, survey window: July 6–14) and the subsequent moulting period (survey window: July 24–August 19; Table 1) for harbour seals, a period in which harbour seals also spend a greater proportion of the time hauled out. In all regions, particular attention was paid to areas where high numbers had been reported or observed in previous surveys (Boulva and McLaren 1979; Colbourne and Terhune 1991; Stobo and Fowler 1994; Jacobs and Terhune 2000; Robillard et al. 2005; Sjare et al. 2005).

Full details on the survey coverage and methods for each region can be found in Mosnier et al. (2023b) for GSL, Lidgard et al. (2023) for SS, and Hamilton et al. (2023) for NLS. In brief, the aerial surveys were conducted using a Bell 429 helicopter flying at a ground speed of 70–80 knots at an altitude of 150 m and within 300 m of the coastline. With the exception of areas within the southern GSL where the tidal range was considered minimal (<1 m, see Figure 3 in Mosnier et al. 2023b), surveys were timed to occur in the range of -2 h to +2 h on either side of peak low tide since the highest numbers of harbour seals are typically hauled out on land during this period (Olesiuk 1999; Dubé et al. 2003; Robillard et al. 2005). For the areas in the southern GSL with minimal tidal range, aerial survey flights were conducted within a 4 h period centered on noon. Surveys were flown on days with good weather conditions defined as days with no rain, no fog, and low wind speed (<20 km/h). The helicopter position was recorded in real time on tablets or laptops using Bluetooth linked GPS recorders and QGIS or Memory Map (Memory-Map Inc., Ithaca, NY, USA) software. Complete survey tracks for each region are shown in Figures 2–4. With the exception of two survey areas in the GSL where a camera mounted on the underside of the helicopter was used to collect images (Lower North shore and Brion Island, see Mosnier et al. 2023b), all aerial surveys were flown with two observers located on the left side of the helicopter, one in the co-pilot seat and one in the forward-facing seat located directly behind the co-pilot seat. The pilot maintained the position of the helicopter such that observers were always facing the coastline or haul-out. For each haul-out observers recorded (either manually or on digital voice recorders) the species, counts, and whether or not seals entered the water as the helicopter approached. All observers were equipped with handheld digital cameras equipped with zoom lenses (250–300 mm focal length). Photographs were taken of haul-outs for confirmation of counts and species identification (grey seals may be hauled out in the same locations as harbour seals, depending on area and time of year). Images were taken at the highest possible resolution and in JPEG format.

All photographs of haul-outs were reviewed for species identification and count. Seals in the water immediately adjacent to a haul-out were included in the counts when it was indicated in the survey notes that seals had recently entered the water due to disturbance from the helicopter. In each survey region, to check for perception bias, a subset of photographs were counted by two readers and compared against a consensus count (see Mosnier et al. 2023b, Lidgard et al. 2023 and Hamilton et al. 2023, for details). Based on the analyses of the comparison counts, survey counts obtained from photographs were not corrected for perception bias.

Low altitude flights were prohibited in some areas of the GSL due to the presence of nesting birds: Kouchibouguac National Park (NB, Parks Canada), Île-Bonaventure-et-du-Rocher-Percé National Park (QC, Sépaq), Fjord-du-Saguenay National Park (QC, Sépaq) and Île aux Perroquets (Mingan Archipelago National Park Reserve, QC, Parks Canada). For these areas, counts were obtained from either vessel-based observations or drone imagery following protocols consistent with those used in the aerial surveys (see Mosnier et al. 2023b). Based on its distance from shore (approximately 300 km from Halifax, NS) and the low number of harbour seals expected to be present (Bowen et al. 2003), the survey of Sable Island was conducted from shore using an All-Terrain vehicle which circumnavigated the island in a single survey window within the range of -2 h to +2 h on either side of peak low tide (Lidgard et al. 2023).

CORRECTION FACTORS AND ESTIMATES OF ABUNDANCE

To estimate abundance, survey counts must be adjusted for the proportion of animals that were at sea during the time of the survey and were, therefore, unavailable to be counted. To account for this, haul-out CFs were developed by (Irani et al. 2024), using:

1. data collected during the pupping period from satellite telemetry deployments on harbour seals in the SLE in 2021–22; and
2. published literature values for the northwest Atlantic pupping and moulting periods.

In short, to calculate a CF for the pupping period, 12 harbour seals (combination of adults/juveniles and pups) were instrumented with satellite transmitters in the SLE, providing data on their haul-out behaviour during survey-like condition in the period of interest (May 15–June 30, 2022). Due to concerns about the low sample size, biased representation of different age-sex classes in the sample, and limited geographic coverage, the estimated proportion of individuals hauled out calculated from the SLE satellite telemetry data was combined with three estimates from the literature for the northwest Atlantic pupping period using a weighted mean approach, where the proportion hauled out from each study was weighted by the estimated variance in the proportion hauled out (see Irani et al. 2024 for details). The calculated weighted mean proportion of the population hauled out (*P*) during the pupping period was 0.39 (95% confidence interval (CI): 0.27–0.52, CV: 0.160), resulting in a CF of 2.55 (CF = 1/*P*). For areas surveyed during the moulting period, four published estimates of the proportion hauled out during the moulting periods, from the northeast and northwest Atlantic, were combined using the same weighted mean approach as above to calculate a mean proportion of the population hauled out of 0.61 (95% CI: 0.50–0.71, CV: 0.087), resulting in a CF of 1.64.

The total population abundance was estimated by multiplying the counts from the pupping and moulting periods by their corresponding CF and summing across regions (Table 1). The counts obtained from the photos were considered to be total, exact counts since no corrections for perception bias were applied (see above). To account for the binomial nature of count data and the fact that counts were reported without associated variance, the variance of the abundance estimate, *var(A),* was calculated using the following equation adapted from equation 6 in Thompson and Seber (1994), for an estimated constant availability (in this case, the proportion hauled out):

Equation 1:

$$var(A) = A * \frac{(1-P)}{P} + A^2 * \frac{var(P)}{P^2}$$

where *A* represents the population abundance estimate, and *P* represents the proportion hauled out and its associated variance *var(P)*.

POTENTIAL BIOLOGICAL REMOVAL (PBR)

Under the precautionary approach in the Atlantic Seal Management Strategy (Stenson and Hammill 2011), sustainable removals of data poor populations, such as Atlantic harbour seals in Canadian waters, are estimated using the PBR approach. The PBR is calculated as:

Equation 2:

$$PBR = 0.5 \cdot R_{max} \cdot F_R \cdot N_{min}$$

where R_{max} is the maximum rate of population increase, with a default value for pinnipeds set at 12% (Wade and Angliss 1997; NMFS 2023), F_R is a recovery factor (between 0.1 and 1), and

N_{min} is the estimated population size using the 20 percentile of the log-normal distribution of the most recent population estimate (Wade 1998), where

Equation 3:

$$N_{min} = \frac{Abundance}{exp(\, z\sqrt{\ln(1 + \ (CV_{Abundance})^2)}\,)}$$

where *z* is a standard normal variate and thus equals 0.842 for the 20 percentile. The F_R that is applied depends on our understanding of stock status (DFO 2018).

RESULTS

COUNTS AND TRENDS

Counts by survey area for each region are shown in Table 1. No correction for perception bias was applied to the counts in any of the surveyed regions (see Methods). Counts obtained during the pupping and moulting periods in the NLS region are shown separately (see Estimates of Abundance, below).

The total count for Atlantic Canadian waters was 10,327 individuals (Table 1). The GSL, SS, and NLS regions accounted for 55%, 23%, and 22% of the total count, respectively. A total of 674 seals were counted in SPM. These seals are not included in the total count for the NLS region (Table 1). Figures 5–7 show the distribution of counts for each survey region presented as spatially clustered points based on a threshold of 10 km. Detailed counts and locations for individual haul-outs within the GSL, SS, and NLS can be found in Mosnier et al. (2023b), Lidgard et al. (2023), and Hamilton et al. (2023), respectively.

In the GSL, the SLE accounted for 37% of the total counts for the region (Table 1). Harbour seal density (the number of individuals sighted per km of coastline surveyed) in the SLE (1.4 km^{-1}) was between 2.8 and 7.0 times higher than for any of the other areas surveyed in Atlantic Canada (Table 2). In the SLE, harbour seals were found hauled out in all parts of the estuary, with the largest groups found near Parc National du Bic (QC, Sépaq), Métis-sur-Mer, QC and Pointe-aux-Outardes, QC (Figure 5). The number of harbour seals sighted in the SLE in 2019 (2,140) was more than four times greater than the counts obtained during the June 1995, 1996, and 2000 surveys of the same areas (410, 467, and 530 individuals, respectively; Robillard et al 2005), representing a 7.0% annual rate of increase between 1995 and 2019 for the SLE (Mosnier et al. 2023b).

For the areas of the GSL outside of the SLE, total counts were highest for the Southern Gulf with the largest counts occurring along the northeast coast of the Gaspé Peninsula (Forillon National Park, QC, Parks Canada) and the south coast of Prince Edward Island (PEI; Figure 5). In the northern Gulf, harbour seals were found predominantly around Anticosti Island, QC and in the Mingan Archipelago National Park Reserve (QC, Parks Canada; Figure 5). On the west coast of Newfoundland, the largest groups were found on the southwest coast of St. George's Bay and in the area of Gros Morne National Park (NL, Parks Canada; Figure 5). Density was lower in the northern Gulf (0.3 km^{-1}) compared to both the southern Gulf and the west coast of Newfoundland (0.5 km^{-1} in both areas; Table 2). A small portion of the areas in the northern and southern Gulf surveyed in 2019 were previously surveyed (using the same methods) in either June 1996 (Mingan Archipelago National Park Reserve, Anticosti Island, and Îles de la Madeleine) or June 2001 (PEI; see Robillard et al. 2005). Harbour seal counts were higher in 2019 than in 1996 for Mingan Islands National Park (269 *vs.* 9, respectively) and Anticosti Island (639 vs. 308, respectively), but were comparable for Îles de la Madeleine (23 vs. 32, respectively). Compared to 2001, harbour seal counts were higher on PEI in 2019 (423 vs. 696, respectively).

On the SS, counts from haul-outs in the Bay of Fundy and SWNS accounted for 72% of the total counts for the region (Table 1). In the Bay of Fundy, harbour seals were predominantly observed in the area of Grand Manan Island and along the northwest coast of the lower Bay of Fundy (Passamaquoddy Bay to the Musquash Ledges, NB; Figure 6). In SWNS, harbour seals were found hauled out in relatively small groups along the south coast with larger groups observed towards the northeast in the areas near Lunenburg, NS (Figure 6). Densities were higher in the Bay of Fundy (0.4 km^{-1}) and along SWNS (0.5 km^{-1}) than along either the Eastern Shore or the east coast of Cape Breton (0.2 km^{-1} in both areas; Table 2). As a result of differences in survey coverage, timing and methodology, it is difficult to make direct comparisons to harbour seal counts obtained from previous surveys in the Bay of Fundy or along the coast of SWNS (Colbourne and Terhune 1991; Stobo and Fowler 1994; Jacobs and Terhune 2000; Lidgard et al. 2023). Along the Eastern Shore the largest groups were found in the Eastern Shore Islands Wilderness Area (between Clam Harbour and Marie Joseph, NS; Figure 6). On Cape Breton Island, harbour seals were only encountered on the southeast side of the island with the largest groups occurring around Fourchu, NS (Figure 6). Only four adults and two pups were sighted on Sable Island, NS (Table 1) which is a decline from the 625 pups counted in 1989 and the eight pups counted in 2002 (Bowen et al. 2003).

On the NLS, counts from haul-outs on the south coast (1,963 individuals) accounted for 86% of the total counts for the region (Table 1) with the largest counts occurring on the southeast coast of the Avalon Peninsula (St. Mary’s Bay, Trepassey Bay) and in Placentia Bay (Figure 7). A total of 674 seals were counted in the SPM archipelago (Figure 7). The seals counted in SPM are not included in the counts for the NLS region (Table 1). On the northeast coast, the largest groups were found in the Grey Islands; no harbour seals were sighted in the area surveyed between Bonavista Bay and the Fogo Islands (Figure 4, Figure 7). Density was only slightly higher on the south coast (0.4 km^{-1}) compared to the northeast coast (0.3 km^{-1}, Table 2). No harbour seals were sighted in Sandwich Bay, Labrador (Figure 7). As a result of differences in survey coverage and methodology, it is not possible to make direct comparisons between counts obtained during the 2021 aerial survey and those obtained from a limited number of vessel, aerial, and onshore surveys conducted between 2001–03 along parts of the south coast of Newfoundland (Sjare et al. 2005).

ESTIMATES OF ABUNDANCE

Estimates of harbour seal abundance for each survey region by area are presented in Table 1. For the NLS Region, the survey windows on the south coast spanned two different time periods corresponding to the pupping period (July 6–8 survey dates) and the moulting period (July 24–August 19 survey dates). Therefore, counts for the NLS south coast survey area were split by survey window prior to the application of the haul-out correction factors calculated by Irani et al. 2024 for the pupping and moulting periods respectively (Table 1).

The total estimated harbour seal abundance for Atlantic Canadian waters for 2019–21 was 25,183 (95% CI: 22,548–28,126) individuals (Table 1). The GSL, SS, and NLS accounted for 58%, 24%, and 19% of the total estimated abundance, respectively.

POTENTIAL BIOLOGICAL REMOVAL (PBR)

The total population abundance, combining the counts from each region corrected for the proportion of animals hauled out (Table 1), was used to calculate PBR. The value of N_{min} was estimated as 24,016 seals.

The guidelines for application of recovery factors (DFO 2018) were used to determine the value to use for F_R in the context of Atlantic harbour seals in Canadian waters. Although historical records indicate that harbour seals were abundant in Atlantic Canada in the early 20 century (Fisher 1949; Scott and Fisher 1958; Boulva and McLaren 1979; Stobo and Fowler 1994), there is no estimate of historical population size. At a total estimated abundance of 25,183 (95% CI: 22,548–28,126), the Atlantic harbour seal population in Canadian waters was classified as 'abundant' under the DFO recovery factor guidelines. Given limited demographic data and the lack of overall trend data (trend 'unknown') for the Atlantic harbour seal population in Canadian waters, a recovery factor (F_R) of 0.5 was used for calculation of PBR.

Using these parameters, the PBR for Atlantic harbour seals in Canadian waters was estimated as 720 individuals.

DISCUSSION

The present study is the first effort to assess the abundance and distribution of harbour seals in Atlantic Canadian waters. Total harbour seal abundance for 2019–21 was estimated at 25,183 (95% CI: 22,548–28,126) individuals. The GSL, SS, and NLS accounted for 58%, 24%, and 19% of the total estimated abundance, respectively (Table 1). Within the GSL, the SLE accounted for only 16% of the regional survey effort but 37% of the total estimated abundance for the region (Tables 1 and 2). Harbour seals were found hauled out in all parts of the SLE (Figure 5) and the estimated density (number of individuals sighted per km of coastline surveyed) for this area was between 2.8 and 7.0 times higher than for any of the other survey areas in Atlantic Canada (Table 2). Compared to the SLE, harbour seals were sighted less frequently in the southern Gulf, northern Gulf, and along the west coast of Newfoundland, with larger haul-outs concentrated in a few areas (Table 2, Figure 5). On the SS, estimated densities were highest for the Bay of Fundy and SWNS (Table 2, Figure 6) which, combined, accounted for 71% of the regional abundance (Table 1). On the NLS, estimated densities were highest for the south coast (Table 2, Figure 7) which accounted for 82% of total estimated abundance for the region (Table 1).

The counts obtained during the aerial surveys and the resulting abundance estimates should be considered minimum values, as a consequence of the imperfect detection of hauled out seals and of seals entering the water prior to the count after being disturbed by the helicopter. While harbour seals may be found hauled out in larger groups in some areas, they are more typically found hauled out individually or in small groups at a relatively low density (Baird 2001; Lesage et al. 2004; Hamilton et al. 2023; Lidgard et al. 2023; Mosnier et al. 2023b). Combined with the fact that the pelage of harbour seals can closely resemble the rocky substrates in many locations, this can make them difficult to detect. As noted for both the current (Hamilton et al. 2023; Lidgard et al. 2023; Mosnier et al. 2023b) and previous (Robillard et al. 2005) surveys, harbour seals sometimes respond to the presence of the helicopter by entering the water. Although seals in the water near a haul-out were included in the counts when it was indicated in the survey notes that the approaching helicopter disturbed seals, it is likely some animals were missed. This is particularly true for areas with complex coastline topography where haul-outs may not have been observed before the animals were disturbed by the sound of the approaching helicopter. Harbour and grey seals also share haul-out sites to variable extents throughout Atlantic Canada (Hamilton et al. 2023; Lidgard et al. 2023; Mosnier et al. 2023b). Seals entering the water in response to the helicopter's arrival also made species identification difficult in some areas (e.g., see Hamilton et al. 2023), potentially leading to an undercount or overcount for specific haul-out sites. These factors combined likely contributed to some individuals being missed during the surveys.

The counts presented here were predominantly obtained from surveys conducted during the pupping period (Table 1). When the phenology of pupping is known, surveys can be timed to minimize the proportion of pups not yet born at the time the survey is flown and/or correction factors can be generated to account for the proportion of pups missed (Bowen et al. 1987; Myers and Bowen 1989; Olesiuk 2010; den Heyer et al. 2021; Mosnier et al. 2023a). In Atlantic Canada, information on the phenology of pupping is available for only limited portions of the survey area. In the SLE first births start in mid-May, with a median date of pupping of May 25–28 and a median date of weaning of June 25 to July 1 (Dubé et al. 2003; Van de Walle 2013; Renaud et al. 2023). This timing is similar to what was observed on Sable Island prior to the decline in abundance experienced in the 1990s (Bowen et al. 2003). If this timing is typical throughout Atlantic Canada, we can expect that very few pups were born after the surveys were flown. Pups may also become unavailable to the survey as a result of post-weaning dispersal. In the SS (the only region where pups were counted separately), pups made up a smaller proportion of the count in areas surveyed in July compared to those surveyed in June (Lidgard et al. 2023). However, spatial variation in pup production, changes in pup haul-out behavior, pup dispersal and pup mortality may all have contributed to the reduced proportion of pups observed later in the season (e.g., Blanchet et al. 2016).

Ideally, instrument deployments to obtain haul-out correction factors should (1) occur in the same region and within the same time period as the aerial survey and (2) include a representative cross section of the population by sex and age class. Although efforts were made to deploy satellite tags in the various regions, data corresponding to the survey period were only available from 12 harbour seals (one adult female, six adult males and five newly weaned pups) in the SLE in 2021–22 (see Irani et al. 2024). As a result, the only haul-out correction factor for the pupping period in Atlantic Canada corresponding to the survey period originates from a single area within Atlantic Canada and was limited by an unbalanced sex-age sample of tagged animals. Recognizing these limitations, the average proportion of the population hauled out obtained from the 2021–22 telemetry data (0.33) was combined with three published CF values covering the pupping period in the northwest Atlantic to calculate a weighted mean of the proportion hauled out of 0.39, resulting in a CF of 2.55 (CV 16.02%). A portion of the NLS survey (representing 55% of the observed counts for the NLS) was flown during the moulting period (Table 1). Obtaining data on the haul-out behaviour of moulting animals is challenging due to the loss of instruments early in the moult period. Only one of the seven instruments deployed on adults in the SLE in the fall of 2021 collected data in the subsequent moulting period (Irani et al. 2024). Therefore, to calculate a haul-out CF for the moulting period, a weighted mean was calculated from four published correction factors from previous studies in the northwest and northeast Atlantic, resulting in a CF of 1.67 (CV 8.67%) (see Irani et al. 2024). Additional instrument deployments will be required in all regions to estimate CFs for harbour seals specific to Atlantic Canadian waters.

The uncertainty around our abundance estimate is likely underestimated and should be approached with caution. The errors around the survey counts (resulting from perception bias, variation in pupping phenology, or issues with species identification) were not estimated in any of the regional surveys and, thus, could not be accounted for in the uncertainty around the abundance estimate. However, we feel that this source of uncertainty is much smaller than the uncertainty associated with the CF. Due to data limitations in Atlantic Canada, the estimated CFs were calculated from a combination of values from studies in the northwest and/or northeast Atlantic. While the approach of combining estimates of CFs from multiple studies incorporated data from a larger number of individuals over a broader area, the resulting variance may be underestimated (see Irani et al. 2024).

Although historical records indicate that harbour seals were abundant in Atlantic Canada in the early 20 century (Fisher 1949; Scott and Fisher 1958; Boulva and McLaren 1979; Stobo and Fowler 1994), there is no estimate of historical population size. Boulva and McLaren (1979) estimated the population abundance of harbour seals in Atlantic Canada south of Labrador at approximately 12,700 individuals in 1973. However, this estimate relied on available bounty return records and interviews with harvesters and fisheries officers, and should be approached with caution. Limited survey efforts conducted over parts of the Atlantic Canadian range between the 1980s and early 2000s (Stobo and Fowler 1994; Lesage et al. 1995; Robillard et al. 2005; Sjare et al. 2005) suggest that numbers increased in several areas following the end of the hunt in 1979. However, given that the vast majority of Atlantic Canada's coastline has not been surveyed for harbour seals more than once (current study), and that survey efforts between the 1980s and present were limited spatially and temporally, it is not possible to assess current population trends for most of Atlantic Canada. Observed counts in the SLE have increased since comparable surveys were conducted between 1995 and 2001, however, the gap between complete surveys of the SLE is substantial (18 years) and the underlying trend in overall abundance over this period is unknown. Mark-recapture analyses conducted at the two main breeding colonies of the SLE to estimate changes in pup abundance between 1998 and 2019 indicates that overall pup production at these colonies has been increasing since 2010 (Renaud et al. 2023). The gap between surveys conducted in other areas of the GSL is also large (18–23 years) and, given the limited coverage of the earlier surveys (Robillard et al. 2005), whether differences between the earlier counts and the ones obtained in 2019 represent changes in abundance or distribution is uncertain. With the exception of the dramatic decline observed on Sable Island in the 1990s (Bowen et al. 2003), from which there has been no recovery, trends in abundance are unknown for the remainder of the SS. Similarly, there are no data on overall trends for the NLS. Systematic, range-wide surveys conducted over regular intervals will be required to assess trends in abundance and potential changes in distribution.

We have presented a single PBR for harbour seals in Atlantic Canadian waters. Broadscale genetic analysis indicates that harbour seals from the northwest Atlantic (US and Atlantic Canada) form a distinct genetic cluster which is differentiated from both the Atlantic Arctic (Greenland, Iceland and Svalbard) and the northeastern Atlantic (Liu et al. 2022). However, detailed studies of local and regional populations in the Pacific and northeast Atlantic have shown that harbour seal populations may exhibit significant genetic differentiation across relatively fine geographical scales (Westlake and O'Corry-Crowe 2002; Andersen et al. 2011; Olsen et al. 2014; Olsen et al. 2017) as a result of strong site fidelity and limited dispersal (Härkönen and Harding 2001; Cunningham et al. 2009; Dietz et al. 2013; Cordes and Thompson 2015). Whether the level of population substructure which has been noted in other regions also occurs in the northwest Atlantic is unknown. Although telemetry data are limited, long distance movements between regions have been noted for both adults and juveniles in the northwest Atlantic (Lesage et al. 2004, X. Bordeleau, unpub. data). Given the broad distribution and proximity of harbour seal haul-outs across the Atlantic Canadian range (this study, Figures 5–7), and the absence of geographic barriers to dispersal, it is reasonable to assume that harbour seals in Atlantic Canadian waters form a single population. Additional telemetry data and detailed genetic studies within and across regions will be required to evaluate this assumption.

The DFO guidelines for application of recovery factors (DFO 2018) were used to determine the value of F_R to use in the calculation of PBR for harbour seals in Atlantic Canadian waters. At a total estimated abundance of 25,183 (95% CI: 22,548–28,126) we considered the Atlantic harbour seal population in Canadian waters to be 'abundant' (as opposed to 'small'). Recovery factors of both 0.75 (abundant, limited trend data) and 0.5 (abundant, trend unknown or declining) were considered. Under the guidelines, the justification for an F_R of 0.75 is 'abundant, survey effort limited' and for an F_R of 0.5 it is 'abundant, limited data'. We did not find these justifications to be helpful for determining which F_R to apply and suggest that additional refinements of the F_R criteria are warranted. There are no trend data for much of the range and there has been only a single range-wide survey of harbour seal abundance and distribution in Atlantic Canada. Therefore, we selected a recovery factor (F_R) of 0.5 for calculation of PBR. Using this F_R, the PBR for Atlantic harbour seals in Canadian waters was estimated at 720 individuals.

Seasonal, transboundary movements of seals which breed in US or French waters are not accounted for in our population estimate or PBR for Atlantic Canadian waters. Although the survey of the NLS included coverage of haul-out sites in the archipelago of SPM, France (with a total count of 674 seals), these counts were not included in the total count for the NLS region. The harbour seal population in US waters is assessed based on aerial surveys conducted along the coast of Maine during the pupping period (Gilbert et al. 2005; Hayes et al. 2022; Sigourney et al. 2022). As a result, the abundance estimate and associated PBR for the US population does not include individuals which breed in Canadian waters. Based on the estimated abundance for 2018 (the most recent survey) of 61,336 individuals, the PBR for harbour seals in US waters is 1,729 (Hayes et al. 2022).

The abundance of sympatric grey seals has increased 30 fold in Atlantic Canada since the 1960s (Hammill et al. 2023). Grey seals appear to have played an important role in the decline of harbour seals on Sable Island and, as their numbers increase elsewhere in the region, they may also impact harbour seals directly or indirectly in other areas where they overlap (see Hamilton et al. 2023; Lidgard et al. 2023; Mosnier et al. 2023b) due to competition for haul-out space and available prey. Studies have found high levels of dietary overlap between the two species although each species targets different size ranges of prey (Hammill and Stenson 2000; Planque et al. 2021). There is also some evidence that grey seals actively prey on harbour seals (van Neer et al. 2015; Mosnier et al. 2023b). Harbour seals may also be exposed to increases in predation from other marine predators such as white sharks *(Carcharodon carcharias*)*,* whose numbers appear to be increasing in the southern part of the harbour seal distribution (Bowlby et al. 2022, H. Bowlby and X. Bordeleau, unpub. data), or from killer whales (*Orcinus orca*) whose numbers appear to be increasing in the NLS region (Lawson and Stevens 2014). Harbour seals have also shown considerable sensitivity to infectious disease outbreaks such as phocine distemper virus and highly pathogenic avian flu strains in both Europe and Maine (Thompson and Miller 1992; Duignan et al. 1993; Puryear et al. 2023). In the Spring of 2022, the highly pathogenic H5N1 strain of avian flu was linked to mortalities of harbour seals in the SLE (J.F. Gosselin, unpub. data). To date, there is no evidence of mortalities related to the presence of H5N1 in other areas of Atlantic Canada.

The present study represents the first range-wide survey to assess the abundance and distribution of harbour seals in Atlantic Canadian waters. Due to logistical constraints the overall survey was completed over multiple years and, as a result of delays due to COVID-19 restrictions (SS) and variation in prevailing weather conditions, the regional surveys varied in their temporal coverage. Although harbour seals are relatively sedentary, long-distance movements do occur, particularly in pups (Lesage et al. 2004; Cunningham et al. 2009; Blanchet et al. 2016). Ideally, surveying all areas in a single year and with similar temporal coverage would reduce the chance of movement between areas. We have outlined above the factors which may have influenced our estimation of abundance and its associated uncertainty. A greater understanding of pupping phenology in harbour seals across Atlantic Canada would enable corrections to be made for the proportion of pups born at the time of the survey. Additional improvements such as combining infra-red and visible light sensors should also be examined to reduce perception bias. Methods to increase photograph resolution might also allow the helicopter to fly greater distances from the coast or at higher altitudes, reducing potential disturbance. Overall, the haul-out CF is the most important contributor to our total abundance estimate and our survey uncertainty. We suggest that increased telemetry effort in all regions are essential to improve our estimates of CF and the associated uncertainty and, thus, our understanding of harbour seal abundance in Atlantic Canada.

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REFERENCES CITED

Andersen, L.W., Lydersen, C., Frie, A.K., Rosing-Asvid, A., Hauksson, E., and Kovacs, K.M. 2011. A population on the edge: genetic diversity and population structure of the world's northernmost harbour seals (*Phoca vitulina*). Biol. J. Linn. Soc. 102(2): 420–439.

Baird, R.W. 2001. Status of harbour seals, *Phoca vitulina*, in Canada. Can. Field-Nat. 115(4): 663–675.

Blanchet, M.A., Lydersen, C., Ims, R.A., and Kovacs, K.M. 2016. Making it through the first year: Ontogeny of movement and diving behavior in harbor seals from Svalbard, Norway. Mar. Mamm. Sci. 32(4): 1340–1369.

Boulva, J., and McLaren, I.A. 1979. Biology of the harbor seal, *Phoca vitulina*, in eastern Canada. J. Fish. Res. Board Can. 200: 1–24.

Bowen, W., and Harrison, G. 1996. Comparison of harbour seal diets in two inshore habitats of Atlantic Canada. Can. J. Zool. 74: 125–135.

Bowen, W., Myers, R., and Hay, K. 1987. Abundance Estimation of a Dispersed, Dynamic Population: Hooded Seals (*Cystophora cristata*) in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 44: 282–295.

Bowen, W.D., McMillan, J., and Mohn, R. 2003. Sustained exponential population growth of grey seals at Sable Island, Nova Scotia. ICES J. Mar. Sci. 60(6): 1265–1274.

Bowen, W.D., Oftedal, O.T., and Boness, D.J. 1992. Mass and Energy Transfer during Lactation in a Small Phocid, the Harbor Seal (*Phoca vitulina*). Physiol. Zool. 65(4): 844–866.

Bowlby, H.D., Joyce, W.N., Winton, M.V., Coates, P.J., and Skomal, G.B. 2022. Conservation implications of white shark (*Carcharodon carcharias*) behaviour at the northern extent of their range in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 79(11): 1843–1859.

Burns, J.J. 2009. Harbor seal and spotted seal: *Phoca vitulina* and *P. largha*. Encyclopedia of Marine Mammals. Elsevier. 533–542.

Colbourne, P., and Terhune, J. 1991. Harbour seals (*Phoca vitulina*) do not follow herring movements in the Bay of Fundy, Canada. Ophelia. 332: 105–112.

Cordes, L.S., and Thompson, P.M. 2015. Mark-resight estimates of seasonal variation in harbor seal abundance and site fidelity. Pop. Ecol. 57: 467–472.

COSEWIC. 2007. COSEWIC assessment and update status report on the harbour seal Atlantic and Eastern Arctic subspecies *Phoca vitulina concolor* and Lacs des Loups Marins subspecies *Phoca vitulina mellonae* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 40 pp.

COSEWIC. 2018. COSEWIC status appraisal summary on the Harbour Seal Lacs des Loups Marins subspecies *Phoca vitulina mellonae* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiv pp.

Cunningham, L., Baxter, J.M., Boyd, I.L., Duck, C.D., Lonergan, M., Moss, S.E., and McConnell, B. 2009. Harbour seal movements and haul-out patterns: implications for monitoring and management. Aquat. Conserv.: Mar. Freshwat. Ecosyst. 19(4): 398–407.

Curtis, T.H., McCandless, C.T., Carlson, J.K., Skomal, G.B., Kohler, N.E., Natanson, L.J., Burgess, G.H., Hoey, J.J., and Pratt Jr, H.L. 2014. Seasonal Distribution and Historic Trends in Abundance of White Sharks, *Carcharodon carcharias*, in the Western North Atlantic Ocean. PloS ONE. 9: e99240.

den Heyer, C.E., Bowen, W.D., Dale, J., Gosselin, J.F., Hammill, M.O., Johnston, D.W., Lang S.L., Murray, K.T., Stenson, G.B., and Wood, S.A. 2021. Contrasting trends in gray seal (*Halichoerus grypus*) pup production throughout the increasing northwest Atlantic metapopulation. Mar. Mamm. Sci. 37(2): 611–630.

DFO. 2018. Harvest advice for eastern and western Hudson Bay Beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/008. (Erratum : September 2020

Dietz, R., Teilmann, J., Andersen, S.M., Rigét, F., and Olsen, M.T. 2013. Movements and site fidelity of harbour seals (*Phoca vitulina*) in Kattegat, Denmark, with implications for the epidemiology of the phocine distemper virus. ICES J. Mar. Sci. 70(1): 186–195.

Dubé, Y., Hammill, M.O., and Barrette, C. 2003. Pup development and timing of pupping in harbour seals (*Phoca vitulina*) in the St. Lawrence River estuary, Canada. Can. J. Zool. 81(2): 188–194.

Duignan, P.J., Sadove, S., Saliki, J.T., and Geraci, J.R. 1993. Phocine distemper in harbor seals (*Phoca vitulina*) from Long Island, New York. J. Wildl. Dis. 29(3): 465–469.

Fisher, H. 1949. Harbour seals. Fisheries Research Board of Canada Atlantic Biological Station Annual Report: 104–106.

Gilbert, J.R., Waring, G.T., Wynne, K.M., and Guldager, N. 2005. Changes in abundance of harbor seals in Maine, 1981–2001. Mar. Mamm. Sci. 21(3): 519–535.

Hamilton C.D., Goulet, P.J., Stenson, G.B., and Lang, S.L.C. 2023. Counts and spatial distribution of harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) from an aerial survey of the coast of the Newfoundland Shelf and Sandwich Bay, Labrador during the summer of 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3566 : v + 39 p.

Hammill, M.O., den Heyer, C.E., Bowen, W.D., and Lang, S.L.C. 2017. Grey Seal Population Trends in Canadian Waters, 1960-2016 and harvest advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/052. v + 30 p.

Hammill, M.O., and Stenson, G. B. 2000. Estimated Prey Consumption by Harp seals (*Phoca groenlandica*), Hooded seals (*Cystophora cristata*), Grey seals (*Halichoerus grypus*) and Harbour seals (*Phoca vitulina*) in Atlantic Canada. J. Northwest Atl. Fish. Sci. 26: 1–23.

Hammill, M.O., Bowen, W.D., and Sjare, B. 2010. Status of harbour seals (*Phoca vitulina*) in Atlantic Canada. NAMMCO Scientific Publications. 8: 175–189.

Hammill, M.O., Rossi, S.P., Mosnier, A., den Heyer, C.E., Bowen, W.D., and Stenson, G.B. 2023. Grey Seal Abundance in Canadian Waters and Harvest Advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/053. iv + 40 p.

Hammill, M.O., Stenson, G.B., Mosnier, A. and Doniol-Valcroze, T. 2021. Trends in abundance of harp seals, *Pagophilus groenlandicus*, in the Northwest Atlantic, 1952-2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/006. iv + 30 p.

Härkönen, T., and Harding, K. 2001. Spatial structure of harbour seal populations and the implications thereof. Can. J. Zool. 79(12): 2115–2127.

Härkönen, T., and Heide-Jørgensen, M-P. 1990. Comparative life histories of East Atlantic and other harbour seal populations. Ophelia. 32(3): 211–235.

Hayes, S.H., Josephson, E., Maze-Foley, K., Rosel, P.E., and Wallace, J. 2022. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2021. NOAA Technical Memorandum NMFS-NE-288.

Heaslip, S.G., Bowen, W.D., and Iverson, S.J. 2014. Testing predictions of optimal diving theory using animal-borne video from harbour seals (*Phoca vitulina concolor*). Can. J. Zool. 92(4): 309–318.

Irani, A.I., Bordeleau, X., Hamilton, C.D., Lidgard, D.C., den Heyer, C.E., Mosnier, A., and Hammill, M.O. 2024. Harbour Seal (*Phoca vitulina vitulina*) Haulout Behaviour and Correction Factors for Aerial Surveys Conducted in Atlantic Canada from 2019 to 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2024/048. iv + 26 p.

Jacobs, S., and Terhune, J. 2000. Harbor Seal (*Phoca vitulina*) Numbers Along the New Brunswick Coast of the Bay of Fundy in Autumn in Relation to Aquaculture. Northeast. Nat. 7(3): 289–296.

Lawson, J.W., and Stevens, T.S. 2014. Historic and current distribution patterns, and minimum abundance of killer whales (*Orcinus orca*) in the northwest Atlantic. J. Mar. Biol. Assoc. UK. 94(6): 1253–1265.

Lesage, V., Hammill, M.O., and Kovacs, K.M. 1995. Harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) abundance in the St Lawrence Estuary. Fish. Aquat. Sci. 1–19.

Lesage, V., Hammill, M.O., and Kovacs, K.M. 2004. Long-distance movements of harbour seals (*Phoca vitulina*) from a seasonally ice-covered area, the St. Lawrence River estuary, Canada. Can. J. Zool. 82(7): 1070–1081.

Lidgard D., Dispas A., Mosnier A., Varkey P., Kehler, D. and den Heyer, C. 2023. Distribution and counts of harbour (Phoca vitulina) and grey seals (*Halichoerus grypus*) on the Atlantic coast of Nova Scotia and Bay of Fundy from aerial and land surveys, 2019-2021. Can. Tech. Rep. Fish. Aquat. Sci. 3569 : vi + 88 p.

Liu, X., Rønhøj Schjøtt, S., Granquist, S.M., Rosing-Asvid, A., Dietz, R., Teilmann, J., Galatius, A., Cammen, K., O'Corry-Crowe, G., Harding, K., Härkönen, T., Hall, A., Carroll, E. L., Kobayashi, Y., Hammill, M., Stenson, G., Kirstine Frie, A., Lydersen, C., Kovacs, K. M. Anderson, L.W., Hoffman, J.I., Goodman, S.J., Vieira, F.G., Heller, R. Moltke, I., and Tange Olsen, M. 2022. Origin and expansion of the world's most widespread pinniped: Range-wide population genomics of the harbour seal (*Phoca vitulina*). Mol. Ecol. 31(6): 1682–1699.

Lowry, L. 2016. *Phoca vitulina*. The IUCN Red List of Threatened Species 2016.

Lucas, Z., and Stobo, W.T. 2000. Shark-inflicted mortality on a population of harbour seals (*Phoca vitulina*) at Sable Island, Nova Scotia. J. Zool. 252: 405–414.

Mosnier, A., den Heyer, C.E., Stenson, G.B., and Hammill, M.O. 2023a. A Bayesian birth distribution model for grey seals and an evaluation of the timing of harvest. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/052. iv + 34 p.

Mosnier, A., Dispas, A., and Hammill, M.O. 2023b. Spatial distribution and count of harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) in the Estuary and Gulf of St. Lawrence from an aerial survey conducted in June 2019. Can. Tech. Rep. Fish. Aquat. Sci. 3541 : v + 60 p.

Myers, R., and Bowen, W. 1989. Estimating bias in aerial surveys of harp seal pup production. The J. Wildl. Manag. 53(2): 361–372.

NOAA. 2016. Fish and Fish Product Import Provisions of the Marine Mammal Protection Act. Federal Register. 81(157): 54390–54419.

NMFS. 2023. Guidelines for Preparing Stock Assessment Reports Pursuant the Marine Mammal Protection Act. NOAA.

Olesiuk, P.F. 1999. An assessment of the status of harbour seals (*Phoca vitulina*) in British Columbia. DFO. Can. Sci. Advis. Sec. Res. Doc. 1999/33. 71 p.

Olesiuk, P.F. 2010. An assessment of population trends and abundance of harbour seals (*Phoca vitulina*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/105. vi + 157 p.

Olsen, M.T., Andersen, L.W., Dietz, R., Teilmann, J., Härkönen, T., and Siegismund, H.R. 2014. Integrating genetic data and population viability analyses for the identification of harbour seal (*Phoca vitulina*) populations and management units. Mol. Ecol. 23(4): 815–831.

Olsen, M.T., Islas, V., Graves, J.A., Onoufriou, A., Vincent, C., Brasseur, S., Frie, A.K., and Hall, A.J. 2017. Genetic population structure of harbour seals in the United Kingdom and neighbouring waters. Aquat. Conserv.: Mar. Freshwat. Ecosyst. 27(4): 839–845.

Planque, Y., Spitz, J., Authier, M., Guillou, G., Vincent, C., and Caurant, F. 2021. Trophic niche overlap between sympatric harbour seals (*Phoca vitulina*) and grey seals (Halichoerus grypus) at the southern limit of their European range (Eastern English Channel). Ecol. Evol. 11(15): 10004–10025.

Puryear, W., Sawatzki, K., Hill, N., Foss, A., Stone, J.J., Doughty, L., Walk, D., Gilbert, K., Murray, M., Cox, E. Patel, P., Mertz, Z., Ellis, S., Taylor, J., Fauquier, D., Smith, A., DiGiovanni, R. A., Jr, van de Guchte, A., Gonzalez-Reiche, A. S., Khalil, Z., van Bakel, H., Torchetti, M.K., Lantz, K., Lenoch, J.B., and Runstadler, J. 2023. Highly pathogenic avian influenza A (H5N1) virus outbreak in New England seals, United States. Emerg. Infect. Dis. 29(4): 786–791.

Renaud, L-A., Pigeon, G., Van de Walle, J., Bordeleau, X., Hammill, M.O., and Pelletier, F. 2023. Spatiotemporal variation in pup abundance and preweaning survival of harbour seals (*Phoca vitulina*) in the St. Lawrence Estuary, Canada. Can. J. Zool. 101(11): 956–966.

Robillard, A., Lesage, V., and Hammill, M.O. 2005. Distribution and abundance of harbour seals (*Phoca vitulina concolor*) and grey seals (*Halichoerus grypus*) in the Estuary and Gulf of St. Lawrence, 1994–2001. Can. Tech. Rep. Fish. Aquat. Sci. 2613: 152 pp.

Rosing-Asvid, A., Teilmann, J., Olsen, M.T., and Dietz, R. 2020. Deep diving harbor seals (*Phoca vitulina*) in South Greenland: Movements, diving, haul-out and breeding activities described by telemetry. Polar Biol. 43: 359–368.

Scott, D., and Fisher, H. 1958. Incidence of the ascarid *Porrocaecum decipiens* in the stomachs of three species of seals along the southern Canadian Atlantic mainland. J. Fish. Res. Board Can. 15(4): 495–516.

Sharples, R.J., Moss, S.E., Patterson, T.A., and Hammond, P.S. 2012. Spatial variation in foraging behaviour of a marine top predator (*Phoca vitulina*) determined by a large-scale satellite tagging program. PLoS ONE. 7(5): e37216.

Sigourney, D.B., Murray, K.T., Gilbert, J.R., Ver Hoef, J.M., Josephson, E., and DiGiovanni Jr, R.A. 2022. Application of a Bayesian hierarchical model to estimate trends in Atlantic harbor seal (*Phoca vitulina vitulina*) abundance in Maine, USA, 1993–2018. Mar. Mamm. Sci. 38(2): 500–516.

Sjare, B.L., Lebeuf, M., and Veinott, G. 2005. Harbour Seals in Newfoundland and Labrador, a Preliminary Summary of New Data on Aspects of Biology, Ecology and Contaminant Profiles. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/30. ii + 38 p.

Stenson, G.B. and Hammill, M.O. 2011. Improving the management of Atlantic seals under the precautionary approach. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/135 iv + 13 p.

Stobo, W.T., and G.M. Fowler. 1994. Aerial surveys of seals in the Bay of Fundy and off southwest Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1943: 57 p.

Swain, D.P., and Benoît, H.P. 2015. Extreme increases in natural mortality prevent recovery of collapsed fish populations in a Northwest Atlantic ecosystem. Mar. Ecol. Prog. Ser. 519: 165–182.

Swain, D.P. and Benoît, H.P. 2017. Recovery potential assessment of the Gulf of St. Lawrence Designatable Unit of Winter Skate (*Leucoraja ocellata Mitchill*), January 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/119. xviii + 131 p.

Thompson, P.M., and Miller, D. 1992. Phocine distemper virus outbreak in the Moray Firth common seal population: an estimate of mortality. Sci. Total Environ. 115(1–2): 57–65.

Thompson, S.K., and Seber, G.A. 1994. Detectability in conventional and adaptive sampling. Biometrics. 50(3): 712–724.

Van de Walle, J. 2013. De la naissance au sevrage: influence des conditions environnementales et des caractéristiques individuelles chez le phoque commun (*Phoca vitulina*) du St-Laurent. Master's thesis. Université Laval.

van Neer, A., Jensen, L.F., and Siebert, U. 2015. Grey seal (*Halichoerus grypus*) predation on harbour seals (*Phoca vitulina*) on the island of Helgoland, Germany. J. Sea Res. 97: 1–4.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14(1): 1–37.

Wade, P.R., and Angliss, R.P. 1997. Guidelines for assessing marine mammal stocks: Report of the GAMMS Workshop, April 3-5, 1996, Seattle, Washington. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-OPR-1593 p.

Westlake, R.L., and O'Corry-Crowe, G.M. 2002. Macrogeographic structure and patterns of genetic diversity in harbor seals (*Phoca vitulina*) from Alaska to Japan. J. Mammal. 83(4): 1111–1126.

Wood, S.A., Murray, K.T., Josephson, E., and Gilbert, J. 2020. Rates of increase in gray seal (*Halichoerus grypus atlantica*) pupping at recolonized sites in the United States, 1988–2019. J. Mammal. 101(1): 121–128.

TABLES

Table 1. Counts and estimated abundances by survey regions and areas for the 2019–21 Atlantic Canada wide harbour seal survey. Counts for the South Coast of the Newfoundland and Labrador Shelves (NLS) are split into those obtained during the pupping and moulting periods, respectively. All other counts were obtained during the pupping period. CF, haul-out correction factor.

Region	Survey Year	Survey Area	Survey Window	CF[4]	Counts	Abundance (95% CI)	
Gulf of St. Lawrence [1] (GSL)	2019	St. Lawrence Estuary (SLE)	June 13–21	2.55 (CV 16.02%)	2,140	5,452	(3,984–7,461)
	2019	Southern Gulf	June 4–11	"	1,799	4,583	(3,348–6,274)
	2019	Northern Gulf	June 22–28	"	979	2,494	(1,819–3,420)
	2019	West Coast NL	June 29–30	"	796	2,028	(1,478–2,783)
	2019	**Total**	-	-	**5,714**	**14,557**	**(12,288–17,245)**
Scotian Shelf [2] (SS)	2020	Bay of Fundy	June 14–18	2.55 (CV 16.02%)	638	1,625	(1,183–2,233)
	2020	SWNS	June 18–25; July 5–7	"	1,043	2,657	(1,938–3,643)
	2020	Eastern Shore	June 19; July 2–17	"	308	785	(568–1,085)
	2020	Cape Breton	June 26; July 4–16	"	331	843	(611–1,165)
	2021	Sable Island	June 2	"	6	15	(8–30)
	2020–21	**Total**	-	**-**	**2,326**	**5,926**	**(4,971–7,064)**
Newfoundland and Labrador Shelves [3, a] (NLS)	2021	South Coast [b]	July 6–8	2.55 (CV 16.02%)	706	1,799	(1,310–2,470)
	2021	South Coast [c]	July 24-August 19	1.64 (CV 8.67%)	1,257	2,076	(1,746–2,468)
	2021	Northeast Coast	July 9–July 14	2.55 (CV 16.02%)	324	825	(598–1,140)
	2021	Sandwich Bay, Labrador	July 14	"	0	0	-
	2021	**Total**	-	-	**2,287**	**4,700**	**(5,033–6,714)**
Atlantic Canada	**2019–21**	**Total**	-	-	**10,327**	**25,183**	**(22,548–28,126)**

Sources: [1] Mosnier et al. 2023b, [2] Lidgard et al. 2023, [3] Hamilton et al. 2023, [4] Irani et al. 2024
[a] counts obtained from the archipelago of Saint Pierre et Miquelon (SPM), France (674 seals) are not included in the totals for the NLS
[b] pupping period
[c] moulting period

Table 2. Estimated density of individuals sighted per km of surveyed coastline by survey regions and areas for the 2019–21 Atlantic Canada wide harbour seal survey.

Region	Survey Area	Counts	Survey Coverage (km)	Density (# of individuals sighted km^{-1})
Gulf of St. Lawrence [1] (GSL)	St. Lawrence Estuary (SLE)	2,140	1,560	1.4
	Southern Gulf	1,799	3,983	0.5
	Northern Gulf	979	2,942	0.3
	West Coast NL	796	1,499	0.5
	Total	**5,714**	**9985**	**0.6**
Scotian Shelf [2] (SS)	Bay of Fundy	638	1,781	0.4
	SWNS	1,043	1,967	0.5
	Eastern Shore	308	1,668	0.2
	Cape Breton	331	1,576	0.2
	Total	**2,326**	**6,992**	**0.3**
Newfoundland and Labrador Shelves [3, a] (NLS)	South Coast	1,963	4,475	0.4
	Northeast Coast	324	1,209	0.3
	Sandwich Bay, Labrador	0	607	0.0
	Total	**2,961**	**6,291**	**0.5**

Sources: [1]Mosnier et al. 2023b, [2]Lidgard et al. 2023, [3]Hamilton et al. 2023

[a] counts obtained from the archipelago of Saint Pierre et Miquelon (SPM), France (674 seals) are not included in the totals for the NLS

FIGURES

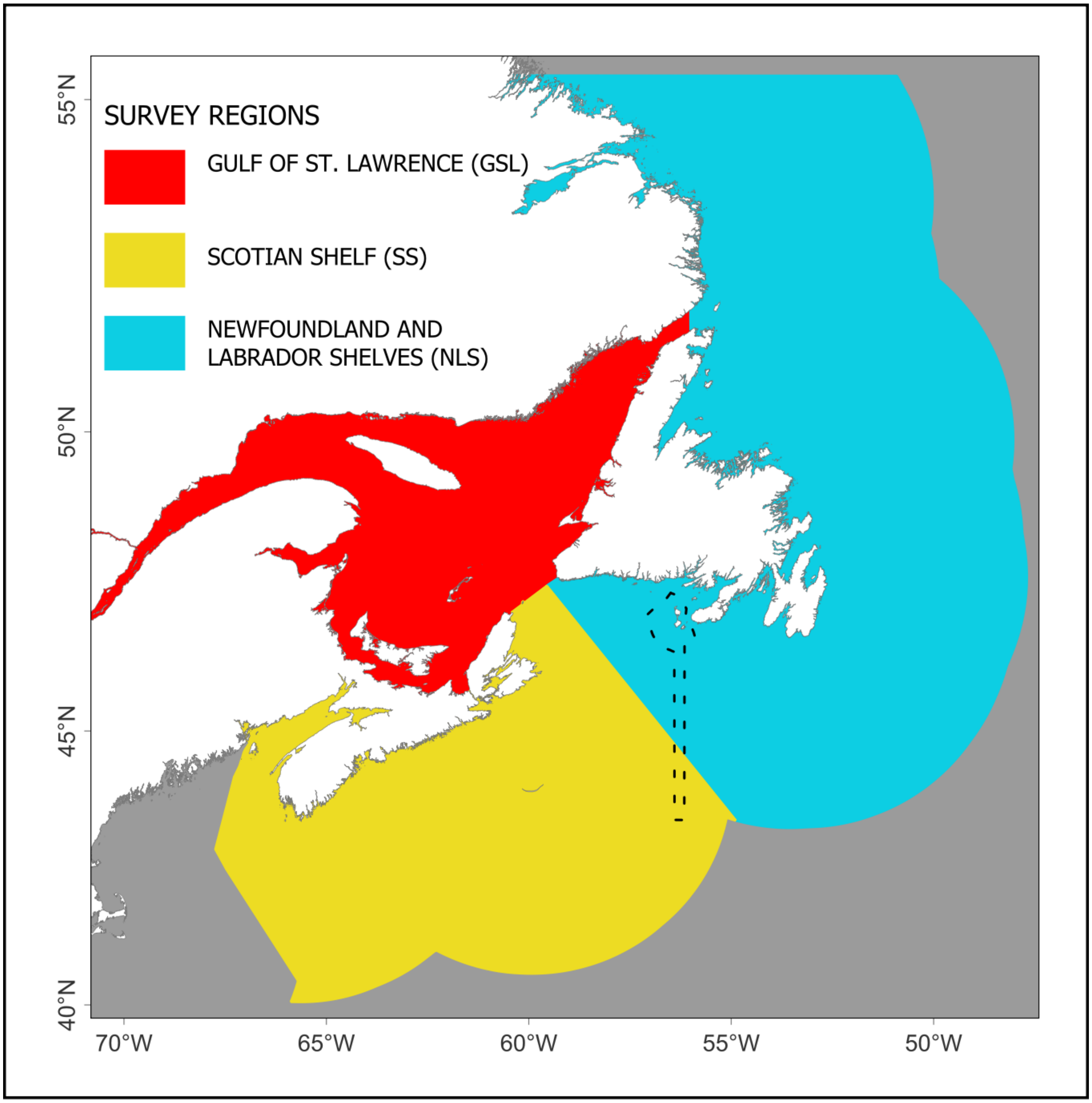

Figure 1. Regional map showing the three regions surveyed during the 2019–21 Atlantic Canada wide harbour seal survey. Dotted line indicates the boundary for the Exclusive Economic Zone (EEZ) of France (Saint Pierre et Miquelon).

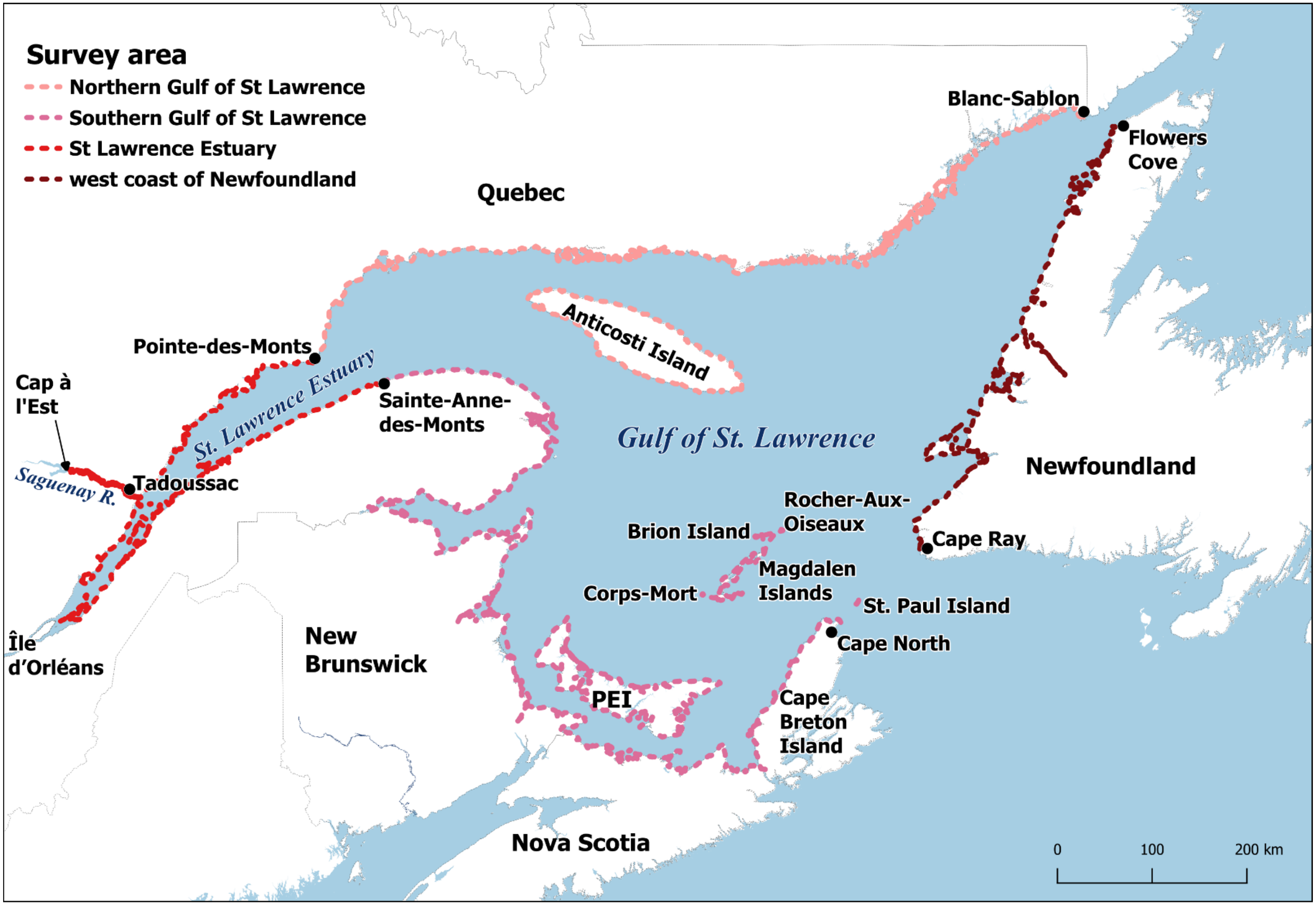

Figure 2. Map of the realized survey coverage in the Gulf of St. Lawrence (GSL) region in 2019, showing the four survey areas.

Figure 3. Map of the realized survey coverage in the Scotian Shelf (SS) region in 2020, showing the four survey areas along the mainland coast and the 2021 Sable Island survey (land-based, see Methods).

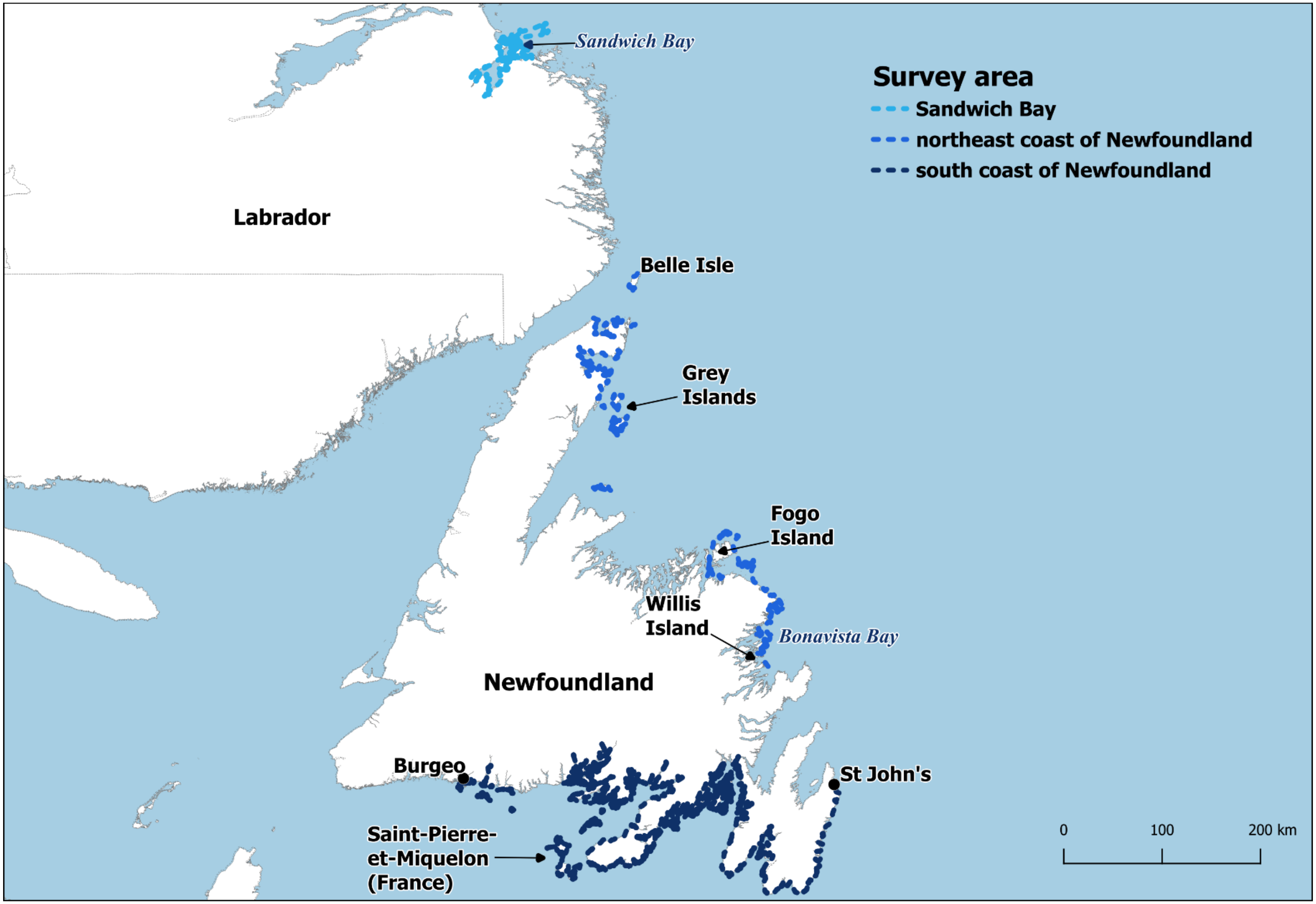

Figure 4. Map of the realized survey coverage in the Newfoundland and Labrador Shelves (NLS) region in 2021, showing the three survey areas.

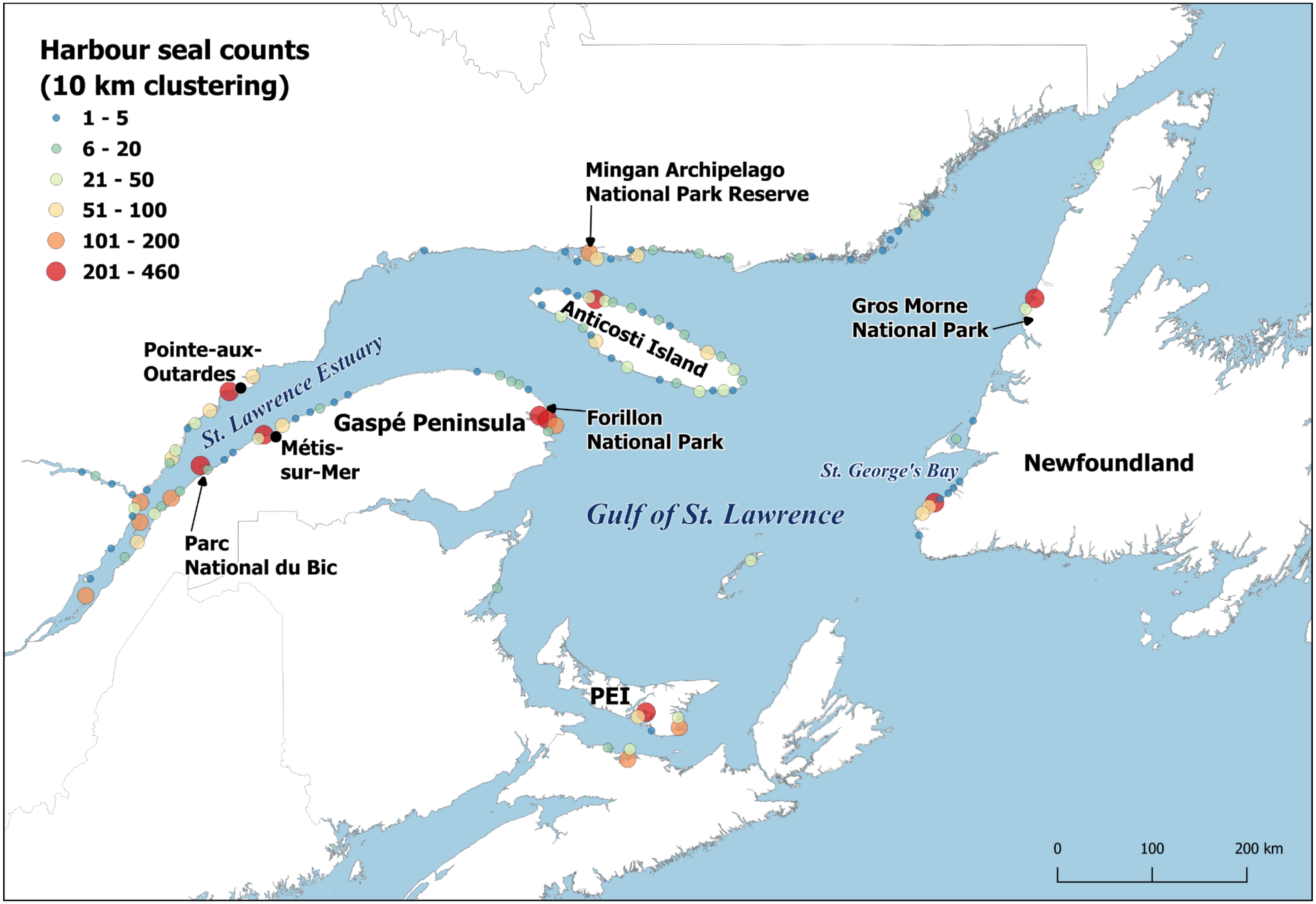

Figure 5. Position and counts of harbour seals detected during the survey of the Gulf of St. Lawrence region (GSL) in 2019 presented as spatially clustered points based on a threshold of 10 km.

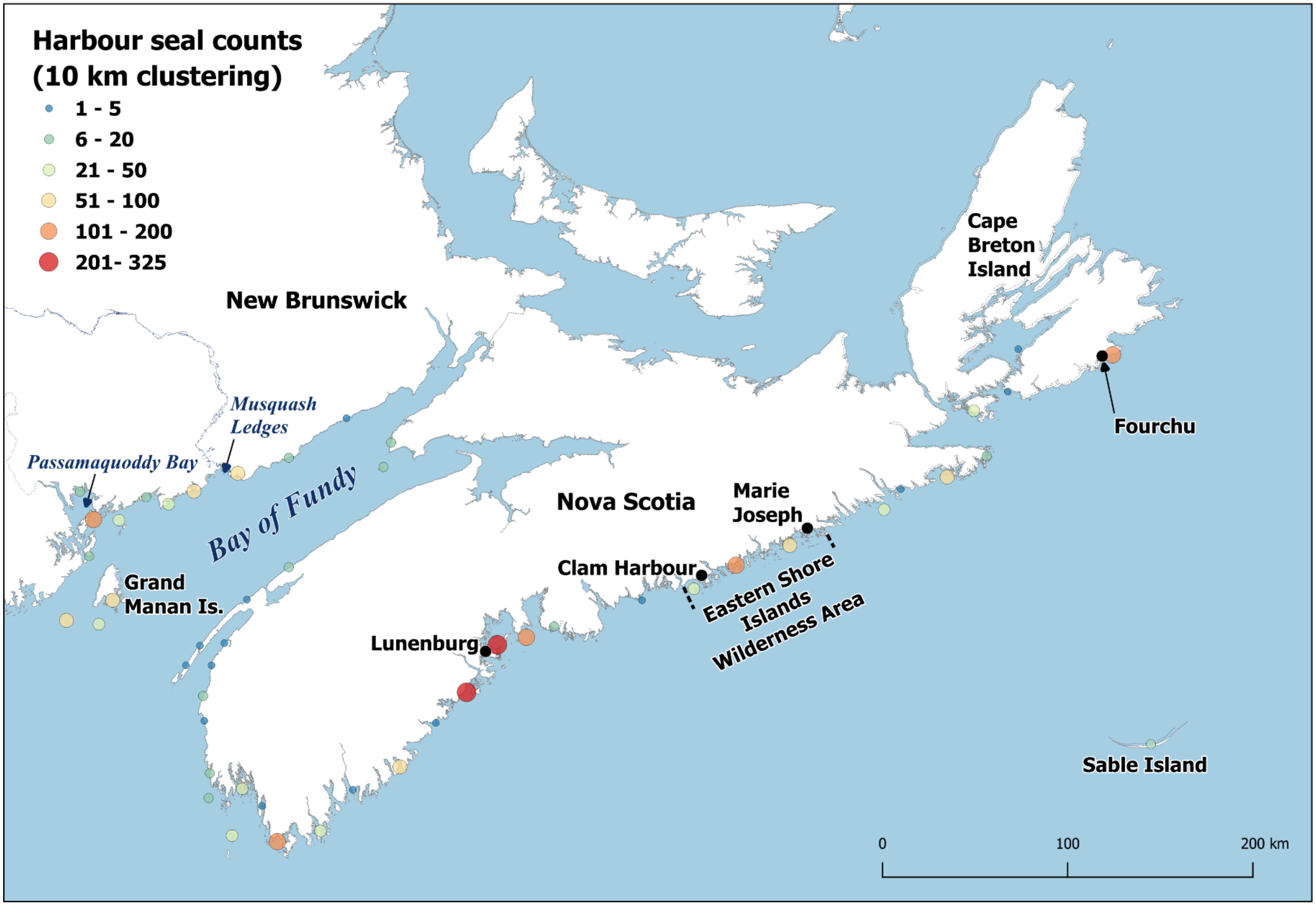

Figure 6. Position and counts of harbour seals detected in the Scotian Shelf region (SS) during the 2020 survey of the mainland coast and 2021 survey of Sable Island presented as spatially clustered points based on a threshold of 10 km.

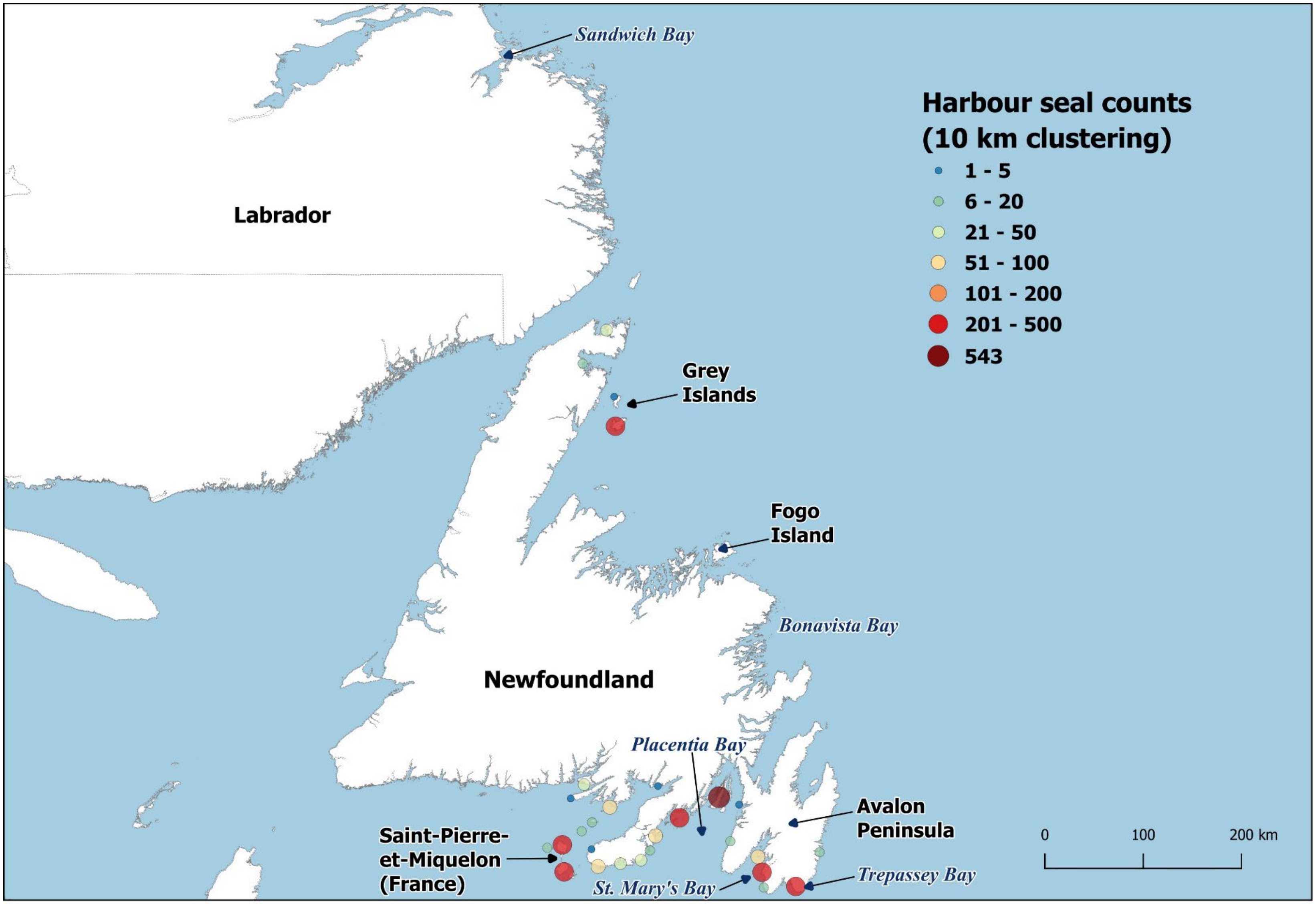

Figure 7. Position and counts of harbour seals detected during the survey of the Newfoundland and Labrador Shelves region (NLS) in 2021 presented as spatially clustered points based on a threshold of 10 km. Counts of harbour seals on Saint Pierre et Miquelon (France) were not included in the total counts for the NLS region.