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

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ABSTRACT

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Our knowledge of the summer abundance and distribution of harbour and grey seals in eastern Canada is limited due to lack of surveys. Between 2019 and 2021, land and aerial surveys were conducted to determine the size and distribution of harbour and grey seal haulouts along the Atlantic coast of Nova Scotia (NS) and Bay of Fundy and in the Bras D'Or Lake, NS. The minimum count of adult and pup harbour seals was 2,161 and 165, respectively. Harbour seals were mostly observed close to shore, in small groups and concentrated in the Bay of Fundy and Southwest NS (SWNS). Only four adult and two pup harbour seals were counted on Sable Island. The minimum count of grey seals was 25,784 with 85% on Sable Island and the remainder mostly in SWNS and on the Eastern Shore. Grey seals tended to be found on rocks and islands further from shore and in larger groups compared with harbour seals. This is the first comprehensive seal survey for the Atlantic coast of NS and the Bay of Fundy and establishes a new time series for future population studies.

RÉSUMÉ

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.

Nos connaissances sur l'abondance et la répartition estivales du phoque commun et du phoque gris dans l'est du Canada sont limitées en raison d'une insuffisance de relevés. Entre 2019 et 2021, des relevés terrestres et aériens ont été effectués dans le but de déterminer la taille et la répartition des échoueries des phoques communs et gris le long de la côte de l'Atlantique en Nouvelle-Écosse (N.-É.) et de la baie de Fundy, ainsi que dans le lac Bras d'Or (N.-É.). Le nombre minimum de phoques communs adultes et de jeunes phoques communs était de 2 161 et 165, respectivement. Les phoques communs ont été observés pour la plupart près du rivage, en petits groupes et en concentration plus importante dans la baie de Fundy et le sud-ouest de la N.-É. Seuls quatre phoques communs adultes et deux jeunes phoques communs ont été dénombrés sur l'île de Sable. Le nombre minimum de phoques gris était de 25 784, soit 85 % sur l'île de Sable et 15 % principalement dans le sud-ouest de la N.-É. et la côte Est. En général, les phoques gris se trouvaient sur les rochers et les îles éloignées du rivage et en plus grands groupes que les phoques communs. Ce premier relevé complet des phoques de la côte atlantique de la N.-É. et de la baie de Fundy représente le début d'une nouvelle série chronologique pour les prochaines études sur la population

INTRODUCTION

Marine mammal populations have endured a history of resource exploitation (Bowen & Lidgard, 2013). Although there has been a notable shift from exploitation to conservation, many threats remain with incidental catches in fisheries (i.e. bycatch) being the current main source of direct human induced mortality (Avila et al., 2018; DeMaster et al., 2001; Harwood, 2001; Read et al., 2006). Current and reliable estimates of abundance and distribution are required to assess the impact of these threats (Hammond et al., 2021). This need has recently been elevated with the implementation of the United States Marine Mammal Protection Act (MMPA) Imports Provisions Rule (81 FR 54389) (NOAA, 2016; Williams et al., 2016). Through this legislation, countries that export fish or fish products to the USA that are not exempted by the National Oceanic and Atmospheric Administration (NOAA), must demonstrate that they meet the same standards as the USA for monitoring and mitigating marine mammal bycatch . Updated estimates of abundance and distribution are also needed to inform marine spatial and emergency response planning, the potential growth of wind farms and environmental impact assessments. Further, there has been a growing interest in ecosystem-based management and the role of seals in a re-wilding Northwest Atlantic, and how they may be impacted by or respond to changes in ocean conditions (Hooker & Gerber, 2004; Hazen et al., 2019).

The harbour seal (*Phoca vitulina*) is one of the most widely distributed pinniped species ranging from 30^0N to 80^0N in the eastern Atlantic region and 28^0N to 62^0N in the eastern Pacific (Burns, 2009). There are three subspecies distributed across the Atlantic and Pacific regions (Berta & Churchill, 2012): the North Pacific, *P. v. richardii* (Gray 1864); the North Atlantic, *P. v. vitulina* (Linnaeus 1758); and the Lacs des Loup Marins harbour seal, *P. v. mellonae* (Doutt 1942) that is restricted to the Ungava Peninsula in Northern Quebec. *P. v. mellonae* is currently listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2018) and the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Harvey, 2016) while the other two sub-species are listed as Not at Risk (COSEWIC, 2007) and as Least Concern by the IUCN (Lowry, 2016).The distribution of harbour seals in the Northwest Atlantic extends from the eastern Canadian Arctic south to New Jersey, USA (Hammill et al., 2010; Waring et al., 2010). Between New England and the Gulf of St. Lawrence (GSL), harbour seals give birth and raise their young in May through to July. Shortly after the breeding season, in late-July and early-August, they go through their annual moult (Boulva & McLaren, 1979; Temte et al., 1991; Dube et al., 2003). Given that a large proportion of the population spends significant amounts of time hauled-out on land during these two periods, and that the haul-outs may be distributed over a large geographical area, studies typically use aerial surveys during the breeding and moult seasons to obtain counts of individuals to assess population size. However, not all individuals are on land at one time, thus to extrapolate from the haul-out counts to a total population estimate, the fraction of the population not visible during the survey needs to be determined (Hammond et al., 2021). This fraction can be estimated from collecting data on the proportion of time individuals spend hauled-out using individuals either deployed with a satellite-linked or VHF transmitter, or identified from pelage patterns or other permanent markings (e.g., Gilbert et al., 2005). These individuals should be demographically representative of the population, i.e. diverse in age and sex, and observed in different regions of the survey area during the period when the survey is being conducted (e.g., Huber et al., 2001). The proportion of known individuals visible at the time of the survey on the haul-out(s) can then be equated to the proportion of the population on the haul-out(s). Given the cost and logistical challenges of acquiring these data, some studies use previously acquired data from the same or a different population (e.g., Sigourney et al., 2022), while others simply provide uncorrected population estimates (e.g., Robillard et al., 2005).

Along the Maine coastline, harbour seal abundance has been assessed using aerial surveys during the pupping period since the early 1980s (Gilbert et al., 2005; NOAA, 2021; Sigourney et al., 2022). The population in this region experienced an increase in abundance between 1981 and 2001 reaching a size of 80,484 individuals (CV = 0.07%), likely a consequence of a cessation of culls and hunts after the 1970s (Lelli et al., 2009). During the 2000s, the population declined to 61,336 individuals (CV = 0.08%) in 2018, which may in part be due to competition with an increasing grey seal (*Halichoerus grypus*) population (Wood et al., 2022).

In contrast to coastal Maine, abundance estimates for harbour seals in Eastern Canadian waters have been infrequent and/or restricted to a limited geographical area (Baird, 2001; Lowry, 2016; Blanchet et al., 2021). The lack of focused effort to obtain abundance estimates might be partly due to harbour seals being less of a threat to commercial fisheries relative to more abundant pinnipeds in the region, e.g. grey seals (Benoĭt et al., 2011) and harp seals (*Pagophilus groenlandicus*) (Hammill et al., 2021), their low commercial value and their more dispersed distribution, compared to grey and harp seals which aggregate at a small number of breeding colonies (den Heyer et al., 2021; Hammill et al. 2021). Of the surveys that have been conducted, trends in abundance are difficult to evaluate due to multiple methods being used across different time periods and regions (Hammill et al., 2010). Areas of the GSL and the St. Lawrence Estuary (SLE) have been surveyed, albeit infrequently, since the mid-1990s (Robillard et al., 2005). Recent counts suggest the population in these areas has greatly increased in size since the early 2000s, with 2,140 harbour seals counted in the SLE and 3,574 in the GSL in 2019 (Mosnier et al., 2023) compared to 530 in the SLE and 423 in the GSL in 2000 and 2001, respectively.

Harbour seal abundance in Nova Scotia (NS) and New Brunswick (NB) waters has been assessed far less frequently compared with population assessments for the coast of Maine and the GSL. An early population assessment used interviews, bounty records and questionnaires to estimate the abundance of harbour seals in Eastern Canada (Boulva & McLaren, 1979) and reported a population size in 1973 of 5,250 and 980, for NS and NB, respectively. The first aerial surveys were conducted across five years between May and August 1985 and 1992, although restricted to the Bay of Fundy and Southwest NS (SWNS; see Fig. 1a) (Stobo & Fowler, 1994). Although there was a broad trend of an increase in counts from 1,575 in 1987 to 3,534 in 1992, weather conditions, timing, regions surveyed and potential disturbance to haul-out sites make it difficult to compare counts among years. Stronger support for population growth during this period comes from Sable Island (Lucas & Stobo, 2000; Bowen et al., 2003). Using a series of annual counts of pups born as an index of abundance, it was shown that pup production increased from 350 in the early 1970's to 600 in 1989. However, during the 1990s the population declined dramatically to fewer than 12 pups counted in 2002. The cause of the decline is thought to be due to resource competition with the grey seal and heavy predation from sharks (Bowen et al., 2003; Lucas & Natanson, 2010; Lucas & Stobo, 2000).

Monthly to bi-monthly aerial surveys from Saint John (Bay of Fundy) to the border with Maine were conducted in 1987 to assess seasonal abundance of harbour seals and determine whether seasonal trends were driven by the availability of Atlantic herring (*Clupea harengus harengus*) (Colbourne & Terhune, 1991). The study showed counts of hauled-out individuals increased from January to September reaching a peak of 1,041 and then declined through to December. Neither the distribution of seals nor the changes in counts were related to trends in herring abundance. Subsequent bi-monthly aerial and ship surveys were conducted in the same area from September to December in 1998 and recorded similar counts and trends with a peak of ~1,000 seals at haul-outs in September and a decline through to December (Jacobs & Terhune, 2000). It has been suggested the decline is a consequence of individuals moving south during the winter to the Northeastern US (Colbourne & Terhune, 1991; NOAA, 1998 (and references therein)), although there are no telemetry or flipper tag data available to support this.

In contrast to the harbour seal, the grey seal has a more limited distribution being restricted to the Northeastern and Northwestern Atlantic regions with a small population in the Baltic Sea (Hall & Thompson, 2009). In the Northwest Atlantic, grey seals breed during the months of December to February and go through an annual moult in May and June. Given that individuals aggregate on land during the breeding period and pups are visible from the air, population abundance is estimated from pup counts taken either directly during aerial surveys (for small colonies) or from a series of aerial images. Surveys in the GSL and on Sable Island have been conducted regularly since the 1960s (Hammill et al., 2017). On Sable Island, where approximately 80% of the Northwest Atlantic grey seal population breeds, the population has increased in abundance since the 1960s (den Heyer et al., 2021). Including the coastal NS colonies (see Fig. 1b and 1c for geographical locations of breeding areas), the most recent population estimate for the Scotian Shelf is 310,700 as of 2021 (DFO, 2022). The remaining population breeds in the GSL with a 2021 estimate of 56,000. Although there are estimates of pup production for all of the major colonies in Atlantic Canada, knowledge of the non-breeding abundance and distribution of grey seals is limited since individuals disperse widely post-breeding and spend more time at sea (Breed et al., 2009). Stobo and Fowler (1994) counted grey seals during their 5-year aerial summer survey in the mid-1980s and early 1990s and showed considerable variability in counts among sites and years (NB: 72 – 346 individuals; NS: 2 – 486 individuals), with the majority of counts lower than those for harbour seals. However, given the increase in abundance of grey seals in the Northwest Atlantic and the re-establishment of breeding colonies throughout the range (Wood et al., 2022, den Heyer et al., 2021), the non-breeding abundance and distribution of grey seals along the NS and NB coastlines has very likely changed since the early 1990s (Stobo & Fowler, 1994).

It is quite clear that updated estimates of the summer abundance and distribution of both harbour and grey seals is urgently needed. Given that harbour seals are a coastal dwelling species and that most commercial fisheries are also coastal, harbour seals are likely vulnerable to the threats of bycatch and local depletion of their prey populations (Read, 2008). Although the non-breeding abundance of grey seals on the Scotian Shelf is likely to be larger than that of harbour seals and the population is assessed as healthy and growing (DFO 2022), without recent estimates of grey seal non-breeding abundance and distribution, the potential magnitude of human induced threats is difficult to evaluate.

An aerial survey for grey and harbour seals was conducted along the Atlantic coast and major rivers of NS and NB, and within the Bras D'Or Lake in the summer of 2020. Estimates of the summer population size of grey and harbour seals can be based on a count of the number of adults hauled-out during the low tide period (Gilbert et al., 2005; Mosnier et al., 2023). To provide an all-inclusive count of harbour and grey seals for the Scotian Shelf, counts were collected from Sable Island based on either onshore counts (harbour seals) or existing digital imagery (grey seals). This report provides the first estimates of harbour and grey seal haul-out counts and their distribution during the summer along the NS and southern NB coastlines. It is one in a series of three reports (Mosnier et al., 2023, Hamilton et al. in preparation) for estimating the summer abundance and distribution of harbour and grey seals in Eastern Canada.

2. METHODS

2.1 SURVEY AREA

The aerial survey was conducted during June and July 2020 along the coastline and major rivers of NS and NB with all inshore and offshore islands circumnavigated. Given the sparse data available on the distribution of seals, the entire coastline (other than the extensive mudflats in the Bay of Fundy) and islands were surveyed with close attention given to areas where seals had been reported previously. The western coastline of Cape Breton Island and the North Shore of NS were surveyed in 2019 by DFO Quebec and thus were excluded from this survey. Sable Island was not included in the aerial survey due to its distance offshore (~300 km from Halifax, NS) and other logistical constraints. Rather, an onshore count of harbour seals present on Sable Island was conducted during June 2021, and imagery from an aerial survey completed by Parks Canada in August 2019 was used to complete a count of grey seals hauled-out.

For comparison with previous abundance estimates, the surveyed area was divided into five areas (Fig. 1a).

2.1.1. The Bay of Fundy

The Bay of Fundy (see Fig. 1b) is a 155 km long embayment that tapers to 48 km at the northeastern end where it splits into the Chignecto Bay and Minas Basin. The area is well known for its extreme tidal range which during the survey period was between 5.1 m (Saint John) and 15.1 m (St. Andrews). The topography is quite varied with several large islands, including Grand Manan at the entrance to the Bay, extensive mudflats, steep volcanic terrain along Digby Neck and Long Island, and the Saint John River. The areas of extensive mudflats at the northeastern and northwestern parts of the Bay were not surveyed due to being unsuitable habitat. The Saint John River was surveyed up to south of Hog Island. Grey and harbour seals are known to use the coastline and inshore islands from Quaco Head to Machias Seal Island, New Brunswick, including Grand Manan (Boulva and McLaren, 1979; Colbourne and Terhune, 1991; Stobo and Fowler, 1994; Jacobs & Terhune, 2000; Fowler and Stobo, 2005).

2.1.2. Southwest Nova Scotia

Southwest Nova Scotia (SWNS) (see Fig. 1b) extends from the southern tip of Long Island to the northwestern corner of St. Margaret's Bay. The coastline, particularly in the southwestern and southern regions, is deeply indented with numerous inshore and offshore islands. The terrain is varied from steep cliffs to sandy and rocky beaches. In 2001, the southern counties of SWNS (i.e., Annapolis, Digby, Yarmouth, Shelburne and Queens) were designated as a UNESCO Biosphere Reserve based on its unique natural and cultural heritage (https://swnovabiosphere.ca/). Grey and harbour seals are known to use the coastline and islands of Yarmouth and Shelburne Counties for breeding and non-breeding haul-out (Boulva & McLaren, 1979; Stobo & Fowler, 1994; Hammill et al., 2008; den Heyer et al. 2021).

2.1.3. Eastern Shore

The Eastern Shore (see Fig. 1c) extends from the northwest corner of St. Margaret's Bay to the causeway connecting mainland NS with Cape Breton Island. Similar to SWNS, the coastline is highly indented with numerous inshore islands. This area of NS includes the Eastern Shore Islands ecosystem (ESI), a complex archipelago system comprised of more than 200 inshore islands (1.4 islands per km) and designated as an Area of Interest (an initial designation for a proposed Marine Protected Area) (DFO, 2019). Both harbour and grey seals are known to use the ESI for haul-out and/or breeding (Mansfield & Beck, 1977; Gray & Beck, 1978; den Heyer et al., 2017; Jeffery et al., 2020; den Heyer et al. 2021). Historically, the Eastern Shore was an important breeding area for harbour and grey seals and also a target for hunts and culls from the 1920s through to 1970s, with grey seals being targeted more in the later decades (Boulva, 1974; Mansfield & Beck, 1977; Gray & Beck, 1978).

2.1.4. Cape Breton Island

Cape Breton Island (see Fig. 1c) sits north-east of mainland NS, separated by the Strait of Canso, approximately 3 km wide. The coastline is bounded by different water bodies: the southeastern and eastern regions flank the Atlantic Ocean, the northern region forms the southern boundary of the Cabot Strait, the northwestern and western region is bounded by the GSL and the southwestern region is bounded by the Northumberland Strait. A large proportion of the southern region of the Island is comprised of a large lake, the Bras d'Or Lake. The lake is 1,099 km^2 and brackish due to freshwater input from rivers and being open to the Atlantic Ocean through two channels to the northeast, on either side of Boularderie Island, and a man-made canal, Saint Peter's canal, to the south. Two inshore islands, Isle Madame and Scatarie Island, are located on the southern and eastern coastlines of Cape Breton, respectively, and St. Paul Island sits offshore from the northern tip of Cape Breton. The coastline topography varies from tall cliffs to rocky and sandy beaches, and small rocky inshore islands. Only the southeastern to northeastern coastline (from Port Hastings to Cape North, including St. Paul Island) was surveyed since the western coastline was surveyed in the previous year by DFO Quebec (Mosnier et al., 2023). Harbour seals are known to occur along the eastern coastline of Cape Breton (Boulva & McLaren, 1979; Bowen & Harrison, 1996), while grey seals use Scatarie Island and more recently Red Island (Bras d'Or Lake) for breeding (den Heyer et al., 2017). Historically, grey and harbour seals used the southern regions of Cape Breton (Basque Islands and Fourchu, respectively) for breeding and were also culled here (Boulva, 1974; Mansfield & Beck, 1977).

2.1.5. Sable Island

Sable island (see Fig. 1c) is a ~40 km long, 1.5km at its widest, crescent shaped sand island approximately 300 km from Halifax, and was designated as a National Park Reserve in 2013. This offshore island is home to the largest single breeding colony of grey seals in the world (Hammill et al., 2017) and a feral horse population. It also has a harbour seal colony that experienced a rapid and dramatic decline in size during the 1990s from 625 pups in 1989 to less than 12 in 2002 (Bowen et al., 2003).

2.2. COASTAL AERIAL SURVEY DESIGN AND METHODS

The survey was designed to occur during the breeding season for harbour seals (May to July), a period of their lifecycle when they are known to spend more time on land and are thus more visible for counting (Bowen et al., 1992). Surveys were also timed to occur during two hours on either side of peak low tide since the highest numbers of grey and harbour seals are known to haul-out on land during this period (Olesiuk et al., 1990; Gilbert et al., 2005; Robillard et al., 2005; Lonergan et al., 2011; Mosnier et al., 2023) . To further maximize the probability of sighting seals, surveys were restricted to days with good visibility (i.e, no rain or fog) and low winds (<20 km/h).

Aerial surveys were conducted in a Bell Textron 429 helicopter with one pilot and two observers. One observer was placed in the front of the aircraft and the second in the rear; both observers were facing forward on the left-hand side. The pilot maintained the position of the helicopter such that the two observers were always facing the coastline or haul-out. The observer in the front of the helicopter had the advantage of seeing and photographing seal haul-outs before they were disturbed by our approach, while the observer in the rear also took photographs, monitored the path of the survey and gave directions to the pilot. During the last day of the survey (17th July 2020) only one observer was present although no seals were observed hauled-out. Both observers were experienced in conducting aerial surveys and in pinniped identification. The survey was flown at an altitude of 150 to 200 m, 300 m from the shoreline and at a speed of 150 km/h (~80 knots); to maximize the use of the short daily survey window, the speed was increased when flying over areas of unsuitable habitat (e.g., bathing beaches, tall and steep terrain, etc).

Single seal sightings and general observations were recorded using a hand-held Sony ICDUX560BLK Digital Voice Recorder (https://www.sony.ca). For haul-outs with multiple seals, it was not possible to accurately count individuals due to seals moving quickly toward the water, being dispersed across the haul-out area or being present in large numbers. In these cases, a series of digital photographs of each haul-out were taken. Photographs were taken using a handheld digital Nikon D850 (45.7 MP, full-frame CMOS sensor) with a Nikon 55-300 mm 4.5-5.6G ED lens and a handheld digital Canon EOS 6D (20.2 MP, full-frame CMOS sensor) with a Canon EF 70 – 300 mm/f4.5-5.6 IS II USM lens. Images were recorded at the highest possible resolution and in JPEG format.

The path of the survey was monitored and recorded in real time using a Bluetooth link between a Bad Elf GPS Pro (https://bad-elf.com) and QGIS (https://www.qgis.org/) operating on a standard PC laptop. This allowed the rear observer to ensure that all areas had been covered which was particularly useful when surveying multiple islands. GPS waypoints were recorded for each sighting or haul-out. At the start of each survey a photograph was taken of the time displayed by the Bad Elf GPS to ensure the GPS and camera were synchronized in time.

2.2.1. Counting seals

In addition to the sightings mentioned on the voice recorders, the two observers also counted grey and harbour seals on the photographs they had taken during the survey. Separate counts were made for harbour seal pups and juveniles and adults with pups being distinguished by their small size and light colouration. In most cases the observer at the front of the helicopter was able to acquire photographs of the haul-outs before seals began to depart while the observer at the back of the helicopter often captured images of partially disturbed haul-outs. Harbour seals showed less of a tendency than grey seals to leave the haul-out upon our approach. Minimum estimates of the number of seals at a haul-out were based on the maximum counts taken by the two observers, which was often achieved by the front observer. Seals observed in the water close to haul-outs were also counted since they were likely hauled-out prior to our approach. Uncertainty over the identity of species or harbour seal pups vs. juveniles was resolved by conferring with the other observer and comparing images. To assess differences in counting accuracy between the two observers, approximately 10% (n = 38) of the photographs taken by observer one were randomly chosen and counted by observer two. Double-counting was avoided by basing counts on the photographs that showed haul-outs when least disturbed, which were often recorded by observer one.

2.2.2. Sable Island harbour and grey seal survey

The harbour seal survey on Sable Island was conducted by Zoe Lucas (Sable Island Institute) on 2 June 2021. The survey involved circumnavigating the island using an All-Terrain Vehicle two hours on either side of peak low tide (09:20). The survey started at 07:45 on the South Beach at the Parks Canada Main Station and included both the South and North Beaches between the East and West Spits. The survey was completed by 11:20.

The topography and land cover of Sable Island have been surveyed by various groups since 1959 (Canadian Air Force, Nova Scotia Community College (Applied Geomatics Research Group), Environment and Climate Change Canada, Sable Island Preservation Trust and Parks Canada (Colville et al., 2016; Eamer et al., 2022) using aerial imagery and Light Detection And Ranging (LiDAR). In 2019, the digital aerial imagery and LiDAR survey was completed by Leading Edge Geomatics (New Brunswick) on behalf of the Parks Canada Agency (PCA) (Eamer et al., 2022). On Aug 8, 2019, within 2.5 hours of low tide, 12 lines were flown at a height of between 829m to 882m and 592 overlapping photographs were taken (Fig. 2). The imagery was orthorectified in ESRI's ArcMap, using the 2014 orthophoto mosaic and associated previous survey LiDAR data as a reference. Pixel error was 0.1m, digitizing error was 0.25m and the total error was 0.27m (Eamer et al., 2022).

QGIS Desktop version 3.14.16 was used to count grey seals from the orthorectified image. Due to the resolution, grey seals could not be distinguished from harbour seals. However, given the relatively small number of harbour seals expected on the island (< 12), this was not a concern. A polygon layer of 50m by 50m cells was created over the extent of the image and four point layers were created to track the counts of live seals in water and on land, dead seals and objects that required additional review before they were marked as a seal. Dead seals were distinguished from live seals by the presence of a gull or gulls and/or lying away from other seals typically further up the beach. For each layer, points were used to mark individual seals within each cell to avoid double counting, and a larger point was used to mark completed cells to track progress (Fig. 3). Once all of the cells were counted, a 0.25m buffer was created around each point to identify and remove accidental double counts. To validate the initial count, two different counters conducted a count of 30 randomly selected vertical transects (Appendix C1) and among the three readers, a reference consensus pup count was generated (Appendix C2). The per cent difference between the consensus and initial count was used to adjust the all-island pup count.

Images were also counted using the citizen science online platform, Zooniverse (Appendix C3). Zooniverse (https://www.zooniverse.org/) is an online platform for employing volunteers, irrespective of experience, to assist with research projects through data processing and sharing ideas. Aerial imagery from the 2019 Sable Island LiDAR survey was broken up into 1,012 tiles and volunteers, or citizen scientists, were asked to count seals hauled out or in the water (see Appendix C3 for details). Here, we use the experienced reader count rather than the counts acquired through the Zooniverse platform.

3. RESULTS

3.1 SURVEY DESIGN AND EFFORT

The total distance travelled was 16,004 km and total flying time was 105 hours, with 6,992 km (44%) as survey effort and the remaining being travel to and from the survey areas and for refueling (Figs 2a & b; Table 1). The first survey was flown on 14 June 2020 at Gannet Rock (Bay of Fundy; Fig. 4a) and the last on 17 July 2020 between Canso and Port Hawkesbury (Eastern Shore) (Fig. 4b; see Appendix A). Of the 34 days between the start and end of the survey period, 22 days were suitable for counting. The initial intention was to travel in an easterly and then northerly direction from the Bay of Fundy, along the SWNS coastline and Eastern Shore and completing the survey on Cape Breton Island. However, due to COVID restrictions all flights originated from the Canadian Coastguard (CCG) hangar at CFB Shearwater, other than those on the 9th and 10th July which originated from Sydney Airport (Figs. 2a & b). As a result of the restrictions, sections of the survey were completed opportunistically as weather and tides permitted (Table 1).

3.2 SEAL DISTRIBUTION AND COUNTS FROM AERIAL SURVEY AND SABLE ISLAND LAND SURVEY

Observer one was positioned in the front of the helicopter and collected 366 photographs while observer two sitting directly behind observer one, collected 368 photographs; each observer counted seals on the photographs they had taken. Only two species of seal were reported, namely the harbour and grey seal. For those photographs counted by both observers to assess count accuracy (n = 38), no bias in counting was found (harbour seal adults: total count = 171 vs 163, median difference in counts between observers

= 0; harbour seal pups: total count 18 vs 16, median difference in counts between observers = 0; grey seals: total count = 323 vs 339, median difference in counts between observers = 0). Eight adult seals could not be identified to species due to a blurred photograph and, given the low count, were excluded from the total count.

During the coastal survey, harbour seals were mostly found close to shore, often in small groups and mostly distributed in the northwestern region of the Bay of Fundy and along the coastline of SWNS (Table 2; Fig. 5a). Grand Manan, Machias Seal Island and Musquash Ledges in the Bay of Fundy (Fig. 5a), inshore rocky shoals near Lunenburg, SWNS (Fig. 5a) and Fourchu Black Rocks in Cape Breton (Fig. 5b) were areas with the highest counts of harbour seals. The maximum haul-out size was 180 at Twin Rocks, SWNS. Very few adult harbour seals (4 adults) were counted on Sable Island on 2 June 2021. The total number of adult harbour seals counted for the coastal survey and Sable Island combined was 2,161. Harbour seal pups were mostly sighted in the Bay of Fundy (Grand Manan, Machias Seal Island and Musquash Ledges) and SWNS, e.g., near Lunenburg (Table 2, Fig. 6a) with only 6 counted in Cape Breton and 2 on Sable Island (Fig. 6b). The total number of harbour seal pups counted for the coastal survey and Sable Island combined was 165. This gives a total count for harbour seals on the Scotian Shelf of 2,326.

Grey seals tended to be found further from shore compared with harbour seals, with a preference for exposed rocky ledges. For the NS and NB coastal survey they were relatively abundant in SWNS (Table 2, Fig. 7a) but also equally abundant along the Eastern Shore, particularly in the Canso region (Table 2, Fig. 7b). There were only a few grey seal haul-outs in Cape Breton with the largest at Cape Dauphin and Hay Island. The maximum haul-out size along the coast of NS and NB was 427 at Gannet Rock in the Bay of Fundy (Fig. 7a).

The per cent difference between the initial and consensus counts for the 30 random transects on Sable Island was 0.8 (Appendix C2), thus we considered it unnecessary to adjust the total count. In the water around Sable Island, 11,087 seals were counted while 10,731 were counted on land giving a total of 21,818 grey seals on Sable Island. This gives a total count for grey seals on the Scotian Shelf of 25,784 (Table 2).

4. DISCUSSION

Harbour and grey seals were found to be distributed throughout the Atlantic coast of NS and NB from Grand Manan, Bay of Fundy to northeastern Cape Breton and on Sable Island. The count and distribution of the two species differed. The total count of grey seals across the survey area was 25,784 while the count of harbour seals was 2,326 (including 165 pups), less than 10% of the grey seal count. The count of harbour seals was highest in the Bay of Fundy, and on the SWNS and Cape Breton coastline where they were typically found close to shore. In contrast, the greatest proportion of grey seals was found on Sable Island with the remaining population (~ 15%, 3,966) favouring SWNS and the Eastern Shore; the least number of grey seals was found on Cape Breton Island. The maximum size of a coastal haul-out was greater for grey seals with a few sites reaching more than 400 individuals, compared with a maximum haul-out count for harbour seals of 180.

Counts of harbour and grey seals at haul-outs from the current study should be considered as minimum estimates. On several occasions, seals departed the haul-out upon our approach with grey seals tending to do so more than harbour seals. This limitation was mitigated through having an observer in the front of the helicopter and able to record or photograph haul-outs before seals began to disperse and to count those already present in the water near the haul-out. Nevertheless, it is quite likely that some individuals were missed due to leaving their haul-out prior to our approach. Further, our count of harbour seal pups as a proportion of the total count (7.1%) is lower than counts from previous studies

(14.2% to 40%; Calambokidis et al., 1987; Olesiuk et al., 1990 and references therein; Mathews and Pendleton, 2006; Merkel et al., 2013). Given that the pupping season starts in May in NS and NB (Boulva and McLaren, 1979), it is likely that a proportion of pups had departed the breeding colonies and may have moved outside of the survey area, e.g. toward New England, or were spending more time at sea (Harvey and Goley, 2011). Pups may also have been missed in counts from photographs due to being obscured by their mother (Mathews and Pendleton, 2006) or mistakenly classified as juveniles.

Counts from an aerial survey also represent a single point index of abundance. Several factors are known to govern haul-out behaviour of harbour and grey seals including age and sex (Huber et al., 2001; Cunningham et al., 2009), tidal state (Thompson & Harwood, 1990; Frost et al., 1999; Sigourney et al., 2021), time of day (Thompson & Harwood, 1990; Frost et al., 1999; Cunningham et al., 2009; Russell et al., 2015; Sigourney et al., 2021), meteorological conditions (Pauli & Terhune, 1987; Sjoberg et al., 1999), resource availability (Härkönen, 1987; Sjoberg et al., 1999) and inter-species competition (Russell et al., 2015). Thus, one may expect considerable variability in haul-out counts with time. To minimize variability, counts occurred during the breeding period (and possibly the start of the moulting period) for harbour seals (a period of time when one may expect adults to spend more time onshore; Thompson et al., 2006), within two hours of peak low tide, during days with low wind (<20 km/h), no rain and good visibility, and within a relatively short survey period (~ 3 weeks). Nevertheless, one should assess the counts obtained with caution (Frost et al., 1999). For example, the number of seals hauled-out was very much dependent upon the state of the tide. Along the coastline of SWNS, Eastern Shore and Cape Breton the availability of seals hauled-out was spread over a 3 to 4 hour time window centered on peak low tide, providing sufficient opportunity for the survey team to record representative counts. However, in the Bay of Fundy the window appeared to be much narrower, perhaps within an hour or so centered around peak low tide. Thus, the number of seals recorded in the Bay of Fundy was very likely unrepresentative of what is present, both in terms of counts and distribution. As an example, on the 15th

of June at Musquash Ledges west of Saint John, 10 harbour seals were counted at 2 hours past peak low tide. On the 16th of June at peak low tide, 70 harbour seals were counted at the same location. Arguably, it is not known whether the haul-out on the 15th of June had been disturbed prior to our arrival.

Further, to achieve a count that is representative of the population size, a species-specific correction factor is needed to account for those individuals at sea during the survey (Hammond et al., 2021). Harbour and grey seals haul-out for a limited period of time, thus counts from aerial surveys of haul-out areas need to be corrected to account for those individuals at sea. It is advisable to obtain records of haul-out behaviour in the same region and during the same period of time as the population survey (Hammond et al., 2021). Time spent on land can be recorded using VHF or satellite transmitters deployed on a sub-sample of the population, or obtained from haul-out counts collected at the same location over an extended period of time (Huber et al., 2001; Vincent et al., 2005; Harvey & Goley, 2011; Russell et al., 2015) .

4.1. COMPARISON WITH PREVIOUS HARBOUR AND GREY SEAL SURVEYS

The number of harbour and grey seal haul-out surveys which have been conducted along the NS and NB coastline is limited. Further, comparisons between data from these historical surveys with those from the current survey are difficult due to differences in survey coverage, timing and methodology and issues with species identification. We compared counts from the current survey with those from Stobo and Fowler (1994) which were collected in 1985 during an aerial survey of a section of the same survey area and during a similar time period, i.e., the harbour seal breeding season. Counts from the 1985 survey and the current study were summed for five broad regions: NB – Inner Bay of Fundy, Passamaquoddy Bay and Grand Manan; and NS – Bay of Fundy and the southwest coast (Table 3). Stobo and Fowler (1994) recorded higher counts of harbour seals along the coastline of Grand Manan and the NS section of the Bay of Fundy (Digby Neck to Brier Island), while the present study recorded higher counts of harbour seals along the coastline of the Inner Bay of Fundy (Quaco Head to Point LePreau), Passamaquoddy Bay (Point LePreau to Campobello Island) and the SWNS coastline (St. Mary's Bay east to Cape Sable Island) (Table 3; Fig. 8a). Although counts of harbour seals from both studies were not corrected for the proportion of individuals at sea, it is interesting to note these changes in distribution and the similarity in the total counts between the two studies (May 1985 (Stobo and Fowler, 1994): 731 vs. this study: 737). It is also noteworthy to mention the greater presence of grey seals in all areas in the present study compared with the 1985 survey (Fig. 8b). Other than two grey seals recorded on the SWNS coast, the only other location where Stobo and Fowler (1994) recorded grey seals in 1985 was at Grand Manan (n = 78). In the present study, 437 grey seals were recorded at Grand Manan with a total of 982 individuals across all five regions previously surveyed by Stobo and Fowler (1994) which represents a more than 10-fold increase compared with the 1985 count. Although the growth of the Northwest Atlantic grey seal population since the 1980s has been well documented (Bowen et al., 2003; Hammill et al., 2017; Rossi et al., 2021; DFO, 2022), the present study is the first to show an increase in the size of summer grey seal haul-outs on the Scotian Shelf.

The differences in harbour seal counts and distribution between the two studies might be partly due to the variability incurred with the use of single point estimates, changes in the proportion of time individuals are hauled-out, the short haul-out window in the Bay of Fundy and/or differences in methodology. In the present study, seals that were in the water but close to haul-outs were included in the count while it is not clear whether that was done in the Stobo and Fowler (1994) study. The present study counted seals from photographs of the haul-outs while Stobo and Fowler made direct counts while in the field. Lastly, Stobo and Fowler noted difficulties in distinguishing between harbour and grey seals while taking counts; such difficulties were minimized in the present study through the use of photographs, thus providing the opportunity for the two observers to confer over species identification.

In contrast to these comparative findings, Mosnier et al. (2023) have shown that the current counts of harbour seals in the SLE (2,140) and GSL (3,574) were much higher than those recorded in 1996 (467 and 467, respectively; Robillard et al., 2005) or the early 2000s (530 and 423, respectively; Robillard et al., 2005). However, similar to the present study, Mosnier et al. (2023) recorded a much larger count of grey seals in the same regions (Estuary: 839; Gulf: 13,852) than those recorded by Robillard et al. (2005) (SLE (1996): 354; GSL (1996): 2,449).

Divergent trends in counts of harbour and grey seals have been documented on Sable Island and in Northeastern USA. Lucas and Stobo (2000) and Bowen et al. (2003) have shown a rather dramatic decline in harbour seal abundance on Sable Island during the 1990s and early 2000s from 600 in 1989 to 12 in 2002, with a concurrent rapid increase in the grey seal population (den Heyer et al., 2021). Inter-species competition and shark predation have been suggested as the causes for the harbour seal decline. Using a Bayesian hierarchical approach to model changes in harbour seal abundance in Maine based on five aerial survey counts, Sigourney et al. (2021) showed that harbour seal abundance increased from a low in 1993 to a high in 2001, declined through to 2012 and remained relatively stable through to 2018. In contrast, there has been a continual increase in grey seal pup production throughout Northeastern USA since the late 1980s with Muskeget Island, MA now being the third largest grey seal pupping colony in the Northwest Atlantic after Sable Island and Pictou Island (GSL) (Wood et al., 2020; den Heyer et al., 2021). Inter-species competition with a large and growing population of grey seals is likely one cause for the less abundant and lower rates of increase observed for harbour seals in the Northeastern US and on the Scotian Shelf. There are now several reports of grey seals predating on harbour seals in Germany (Van Neer et al., 2015; Westphal et al., 2023) and on young grey seals in the UK (Bishop et al., 2016; Brownlow et al., 2016). Notably, the same wound patterns observed in the UK have been observed on grey seal pups during the breeding season on Sable Island (Bowen et al., 2003; Lucas & Stobo, 2000). Thus, given the size and distribution of the grey seal population in Eastern Canada and its spatial overlap with harbour seals, it is quite possible that grey seals are having a direct impact on the harbour seal population. Given their coastal and resident habits relative to grey seals, harbour seals may also be more vulnerable to local depletions of their prey, habitat loss, disease and human disturbance (Blanchet et al., 2021).

In the Northwest Atlantic, tagging and telemetry studies on grey seals and sightings of permanently marked breeding adults have revealed movements among the numerous breeding colonies such that grey seals within this large area are considered part of a metapopulation (den Heyer et al., 2021). Pup production appears to be relatively stable in the GSL and on the Eastern Shore of NS with no new breeding colonies observed since 2016. However, although at a slower rate than the 13% rate of increase observed between 1976 and 1997 (Bowen et al., 2003; Bowen et al., 2007), pup production on Sable Island has continued to increase until the last survey in 2021 (den Heyer et al., 2021; DFO, 2022). As observed in other grey seal metapopulations (Gaggiotti et al., 2002), emigration from Sable Island is likely subsidizing the growth of the breeding colonies in SWNS and the northeastern states of Maine and Massachusetts (den Heyer et al., 2021). The rapid increase in coastal breeding colonies could contribute to the increase in the summer haul-out counts of grey seals along the NS and NB coast documented in this study.

There is less information available on the movements of harbour seals in the Northwest Atlantic to evaluate population structure. Opposing seasonal changes in abundance of harbour seals along the NB Bay of Fundy and that of the northeastern States coastline (Rosenfeld et al., 1988; Colbourne & Terhune, 1991; Jacobs & Terhune, 2000) have been used to suggest the existence of a single population of harbour seals encompassing the northeastern States and Eastern Canada. A single harbour seal population has also been proposed based on the similarity in the timing of pupping (Temte et al., 1991). Although there are no telemetry or flipper tag data available to support this hypothesis (Waring et al., 2006, 2015), telemetry studies from other regions and resights of permanently marked individuals suggest harbour seals exhibit a coastal habit, strong site fidelity and engage in short distant trips (Härkönen & Harding, 2001; Waring et al., 2006; Cunningham et al., 2009; Cordes & Thompson, 2015) suggesting the occurrence of subpopulations with a degree of connectivity. Using tissue samples collected from harbour seals from various locations in North America and Europe, Liu et al. (2022) demonstarted that harbour seals from the Northwest Atlantic, i.e. northeastern States and Eastern Canada, formed a distinct genetic cluster differentiated from samples collected from the Atlantic Arctic (i.e. Greenland, Iceland and Svalbard) and the Northeast Atlantic. Population genetic studies of harbour seals in Europe provide evidence of strong philopatry and suggest geographical barriers, including bodies of water, limit dispersal and contribute to population differentiation (Goodman, 1998; Olsen et al., 2014; Steinmetz et al., 2023). Given the distribution and proximity of haul-outs along the NB Bay of Fundy and Maine coastline and the absence of geographical barriers, it is reasonable to propose the existence of a single population (Stanley et al., 1996). However, telemetry and more detailed genetic studies of harbour seals in NS and NB are needed to evaluate these propositions.

4.2. LIMITATIONS OF THE SURVEY

4.2.1 Photographs of undisturbed haul-outs

The second observer sitting behind the observer in the front of the helicopter was often limited to photographing partially disturbed haul-outs. Thus, it is recommended to have a skilled observer in the front of the helicopter to capture photographs of the haul-out before seals begin to depart.

4.2.2 Tidal cycle in the Bay of Fundy

The extreme tidal range and narrower observed duration of the haul-out period in the Bay of Fundy limited our ability to capture photographs of haul-out sites in use for each tidal cycle. To overcome this issue, it is recommended that either this region is surveyed by more than one survey team or the survey is extended to two years with the Bay of Fundy surveyed in one year (with the duration of the survey extended to accommodate the greater effort required), and the remaining regions that have similar tidal ranges (i.e., SWNS, Eastern Shore and Cape Breton) surveyed in the year prior to or following the Bay of Fundy survey.

<u>4.3.3. An assessment of time spent hauled-out</u>

As noted earlier, very little research on harbour seal population ecology has been done in NS or NB nor has there been a NS and NB survey of the size and distribution of summer grey seal haul-outs . Although the current survey on the size and distribution of harbour and grey seal haul-outs is a significant achievement, an understanding of the timing of haul-out and the factors that influence it are needed to correct haul-out counts for those individuals at-sea during the survey period. Given the large tidal amplitude, these data would be of most value for the Bay of Fundy for improving the survey design to obtain improved estimates of abundance and distribution. As discussed earlier, data on the timing of haul-out can be obtained from satellite or VHF transmitter deployments on a representative proportion of the population (i.e., adult male and females, juveniles and pups) in different regions of the survey area, or from serial haul-out counts. Ideally, deployments and haul-out counts should occur in the same region and within the same time period as the aerial survey.

4.3. RECOMMENDATIONS FOR FUTURE SURVEYS

<u>4.3.1. Weather concerns</u>

The original timing for the aerial survey was during May, the start of the harbour seal breeding season. However, due to delays related to the COVID-19 pandemic, the survey did not begin until mid-June. As the survey approached the end of June, the frequency of daytime fog, particularly in the early morning at CFB Shearwater, increased resulting in the loss of survey days. The frequent occurrence of fog continued through July to the end of the survey. This was a re-occurring problem given that the majority of flights were required to start from CFB Shearwater due to COVID restrictions. It is expected that in future years, these restrictions will not be in place and flights will originate close to the last area surveyed. Nevertheless, it is strongly recommended that the survey occurs in May and/or early- to mid-June.

4.3.2. Areas that should not be included in future surveys

During the low tidal period in the Bay of Fundy extensive mudflat areas in the upper regions of the Bay are exposed (see Fig. 4a). These areas are unsuitable as seal haul-outs and need not be included in future surveys.

4.3.3. Sable Island aerial photographic and ground survey

Due to timing and other logistics, we were unable to conduct an aerial and ground survey of Sable Island in 2020. Fortunately, PCA were able to provide aerial imagery from their 2019 Sable Island LiDAR Survey and Zoe Lucas was able to conduct a land count for harbour seals in 2021. As there are a large number of seals on Sable, future summer seal surveys should include a one sortie aerial survey of Sable Island to generate a series of digital images that can be orthorectified to produce a single orthomosaic from which to count seals, either done independently or in collaboration with Parks. If there is not sufficient resolution in the aerial imagery, harbour seal counts will have to be completed from the ground.

4.3.4. Hand-held vs. mounted pod camera

Taking photographs of each haul-out using a hand-held digital SLR camera provides a record for future reference and more accurate counts of individuals hauled-out by species than counting directly from the helicopter. Photographs also provide the opportunity for observers to confer over species identification post-survey. However, achieving sharp focused images is difficult due to the speed and vibration of the helicopter, resolution of images is quickly compromised with altitude and images are not geo-referenced thus increasing data handling time post-survey. For future surveys, the recently acquired Canadian Coastguard external mounted camera system, Wescam MX-10 (https://www.l3harris.com) would improve image quality. This camera system provides high definition, auto-focused, four-axis-stabilized imagery with the opportunity to record still or video at an altitude that will minimize or avoid disturbing seals. The system offers low light colour-sensitive and short-wave infra-red imaging for identifying seals when visibility is compromised or when contrast between the haul-out substrate and body pelage is low. The system is fully operational from inside the survey craft.

Given the size of the colony, an estimate of the summer abundance of grey seals on Sable Island is only possible with a helicopter or fixed-wing aerial survey. If the resolution of the imagery is sufficiently high, an assessment of harbour seal abundance would also be possible from the imagery otherwise a land count would be required.

4.3.4. Transect survey design for areas with multiple islands

In SWNS and along the Eastern Shore there are sections of the coastline that comprise multiple small islands, e.g. between Clam Harbour and Marie Joseph, a distance of ~ 75 km, on the Eastern Shore there are 400 islands. During the current study, each island was circumnavigated or flown over depending upon its size. Although the survey route was tracked in real-time allowing observers to note which islands had been surveyed, it is challenging to ensure no islands are missed and to achieve a time efficient route. An alternative survey design is to conduct a series of transects either perpendicular or in parallel to the coastline. The CCG Bell Textron 429 helicopter can be automated to run a transect survey design, thus removing pilot and observer-error.

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7. TABLES

Table 1. The area surveyed, dates and number of survey days and the distance travelled by helicopter for the five regions of the Atlantic seal survey, 2019-2021.

Area Surveyed	Survey year			Number of survey days	Distance travelled, km	
	2019	2020	2021		Transit	Survey
Bay of Fundy		14 to 18 June		5	2,483	2,081
Southwest Nova Scotia		18, 20, 25 June; 5, 7 July		5	2,556	1,823
Eastern Shore		19 June; 2 to 4, 7, 14, 17 July		7	1,637	1,588
Cape Breton		26 June; 4, 8, 10, 16 July		5	2,335	1,500
Sable Island	8 August		2 June	2	-	-

Table 2. Counts of harbour seal adults, pups (with per cent of total count) and total count (with per cent of total count), adult grey seals (with per cent of total count), and unidentified seals for the five regions of the survey (June – July 2020: Bay of Fundy, Southwest Nova Scotia (SWNS), Eastern Shore, Cape Breton Island; June 2021 (harbour seal) and August 2019 (grey seal): Sable Island)

Region	Survey distance km	Harbour Seal					Grey Seal		Unidentified
		Adult n	Pup n	% of Pup	Total n	% of Total	Total n	% of Total	Total n
Bay of Fundy	2,080	574	64	11.1	638	27.4	952	3.69	0
SWNS	1,823	980	63	6.4	1,043	44.8	1,345	5.22	0
Eastern Shore	1,703	290	18	6.2	308	13.2	1,349	5.23	0
Cape Breton Island	1,500	313	18	5.8	331	14.2	320	1.24	8
Total for Atlantic coast of NS and NB	7,106	2,157	163	7.6	2,320	99.7	3,966	15.4	8
Sable Island	NA	4	2	0.5	6	0.3	21,818	84.6	0
Total for Scotian Shelf		2,161	165	7.6	2,326	100	25,784	100	8

Table 3. Comparison of historic (Stobo and Fowler, 1994; Colbourne and Terhune, 1991) and current (this study) harbour seal (adult and pup) and grey seal counts for five regions in the Bay of Fundy and southwest coast of Nova Scotia recorded during aerial surveys. Details of areas covered within the five regions are given below. Pv - *Phoca vitulina*, Hg - *Halichoeurs gryp*us

	Reference	Stobo & Fowler 1994		Colbourne & Terhune 1991	This study	
		May 1985		May 1987	June – July 2020	
Province	Region	Pv	Hg	Pv	Pv	Hg
NB	Inner Bay of Fundy[2]	78	0	176[1]	173	19
	Passamaquoddy Bay[3]	52	0	89	191	65
	Grand Manan[4]	398	73	-	140	437
NS	Bay of Fundy[5]	111	0	-	23	287
	Southwest coast[6]	92	2	-	210	174
Total		731	75		737	982

[1] Survey excluded coastline east of Saint John

[2] Inner Bay of Fundy - Quaco Head to Point to Point Lepreau including the Wolf Islands

[3] Passamaquoddy Bay - Point Lepreau to Liberty Point, Campobello Island

[4] Grand Manan - Grand Manan, Gannet Rock and Machias Seal Island

[5] Bay of Fundy – Digby Neck to Brier Island

[6] Southwest coast - St. Mary's Bay to Cape Sable Island

8. FIGURES

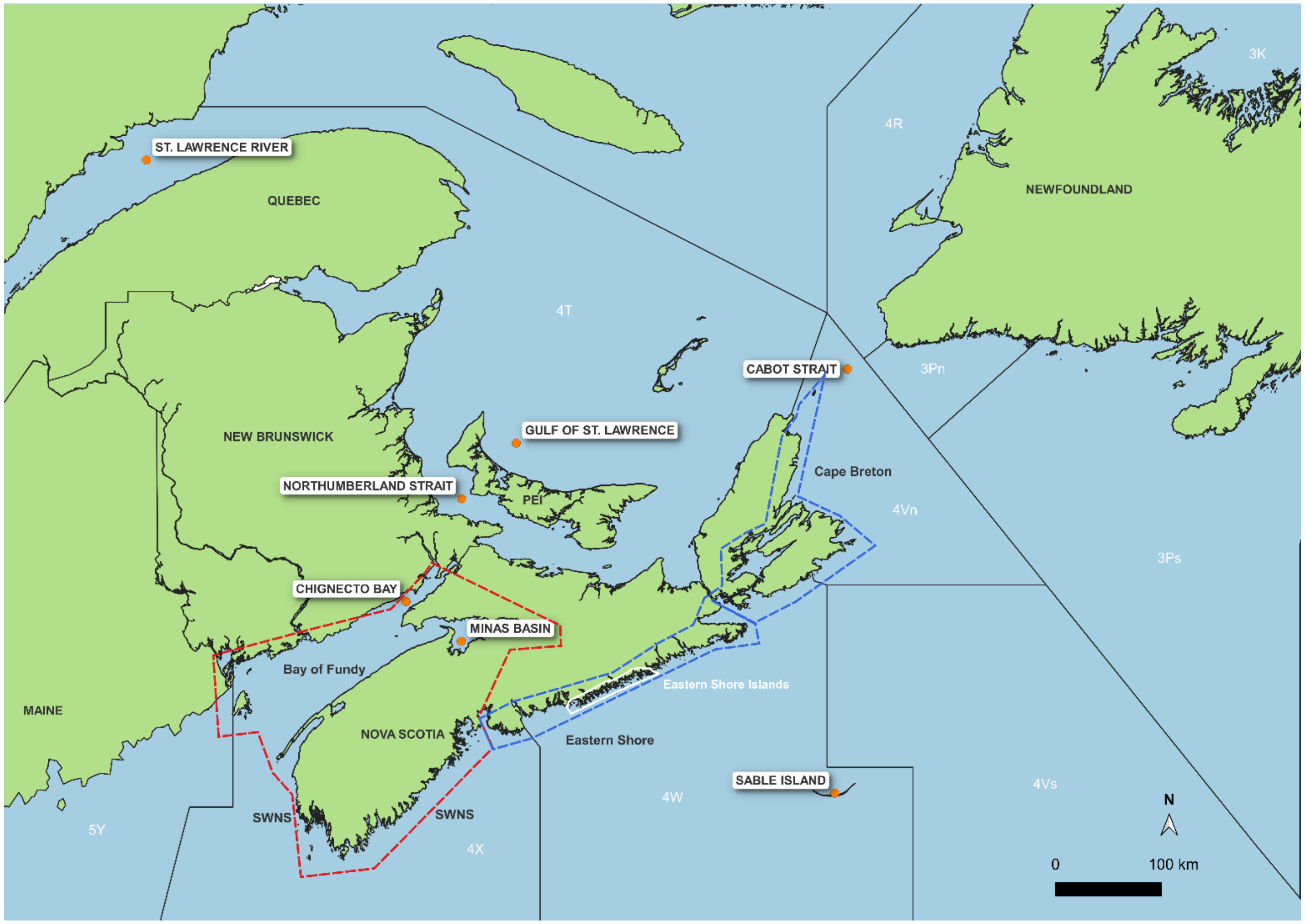


Figure 1a. The study area of Nova Scotia and New Brunswick showing the regions of Bay of Fundy, SWNS, Eastern Shore, Cape Breton and Sable Island, and NAFO Divisions and key water bodies. The red and blue dashed lines refer to the geographical extent of the detailed maps, Fig 1b and Fig 1c, respectively.

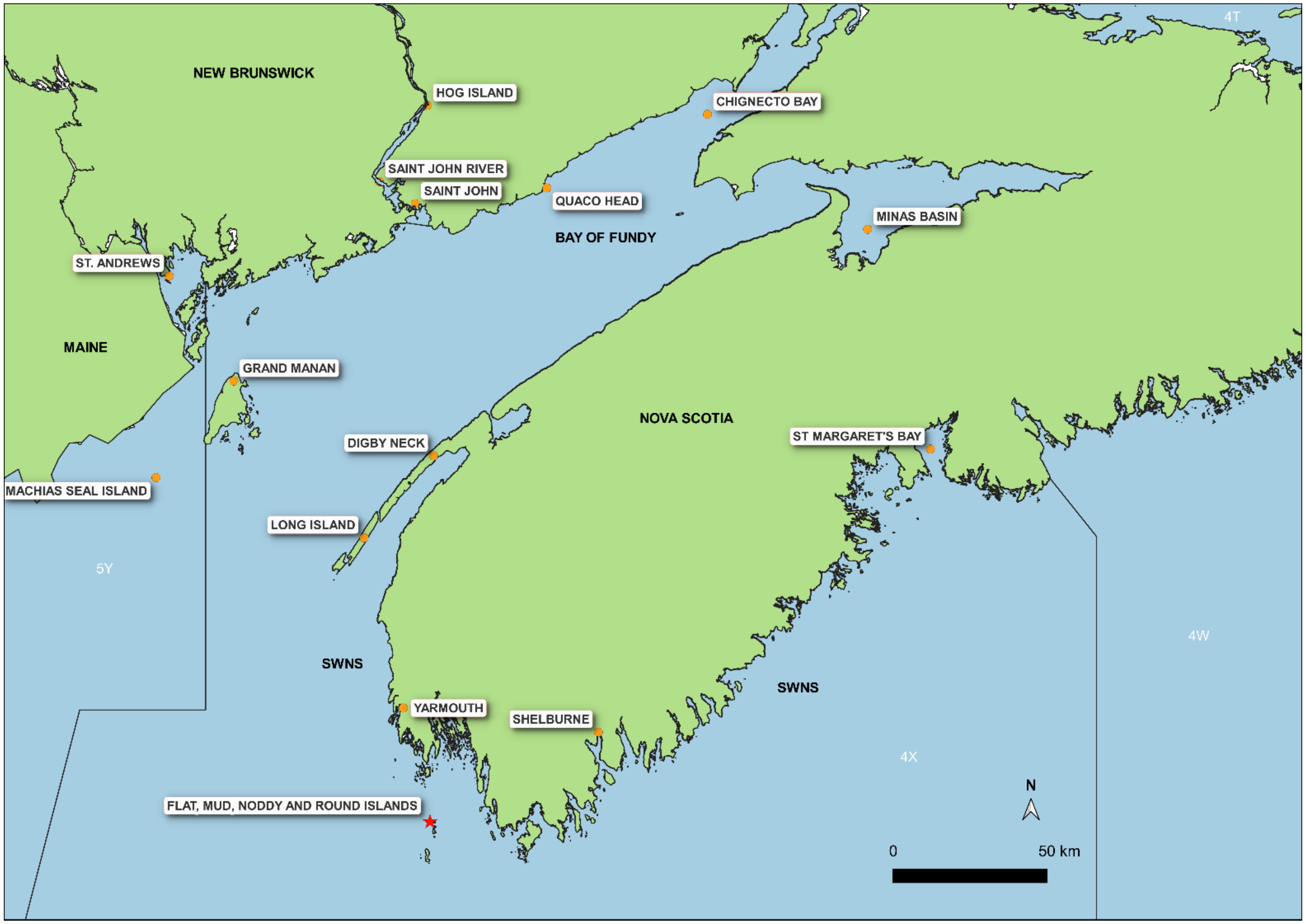


Figure 1b. The Bay of Fundy and SWNS study area (as referred to in Fig. 1a by the red dashed line) showing key place names (●) and grey seal breeding areas (★).

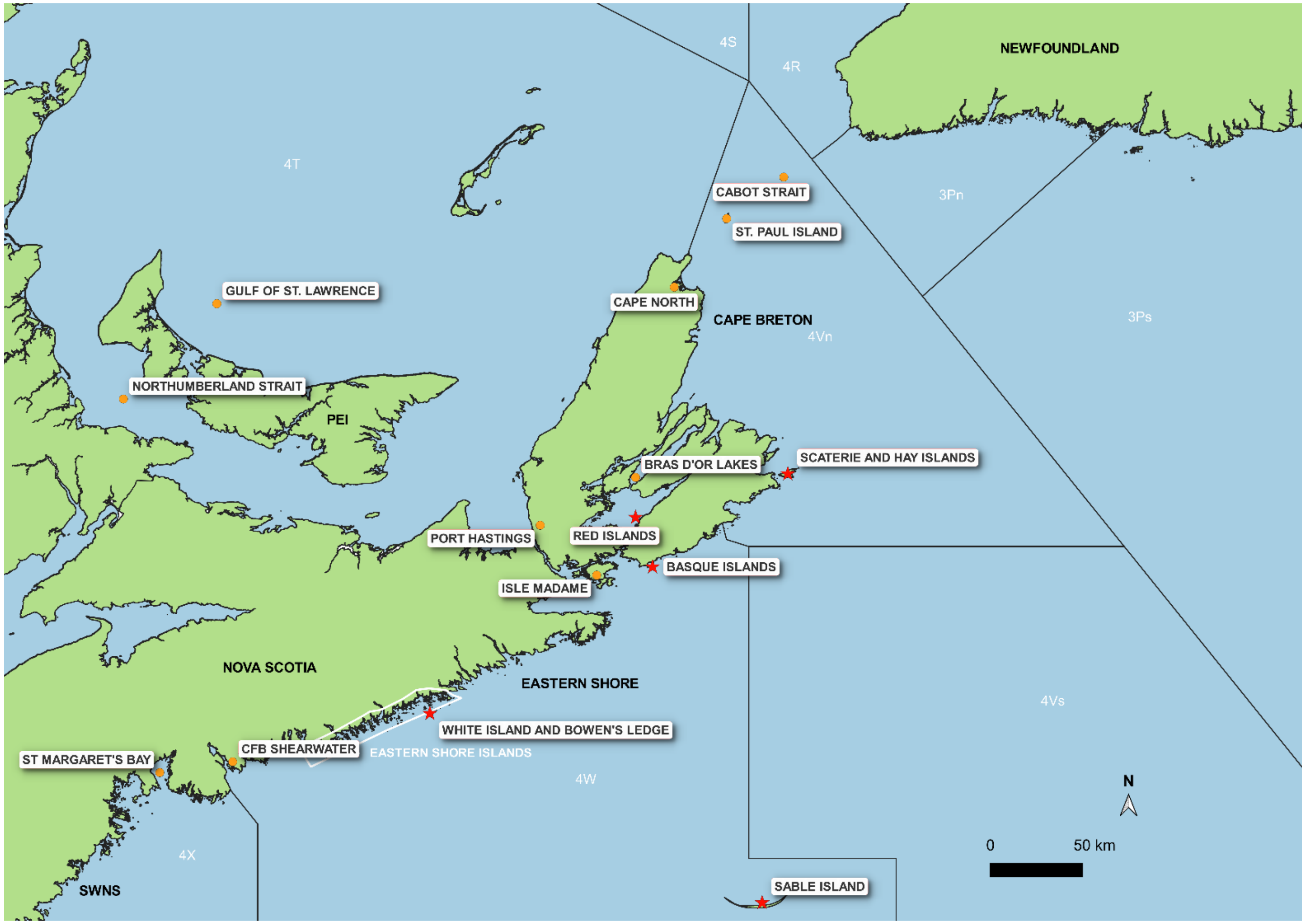


Figure 1c. The Eastern Shore and Cape Breton study area (as referred to in Fig. 1a by the blue dashed line) showing key place names (●) and grey seal breeding areas (★).

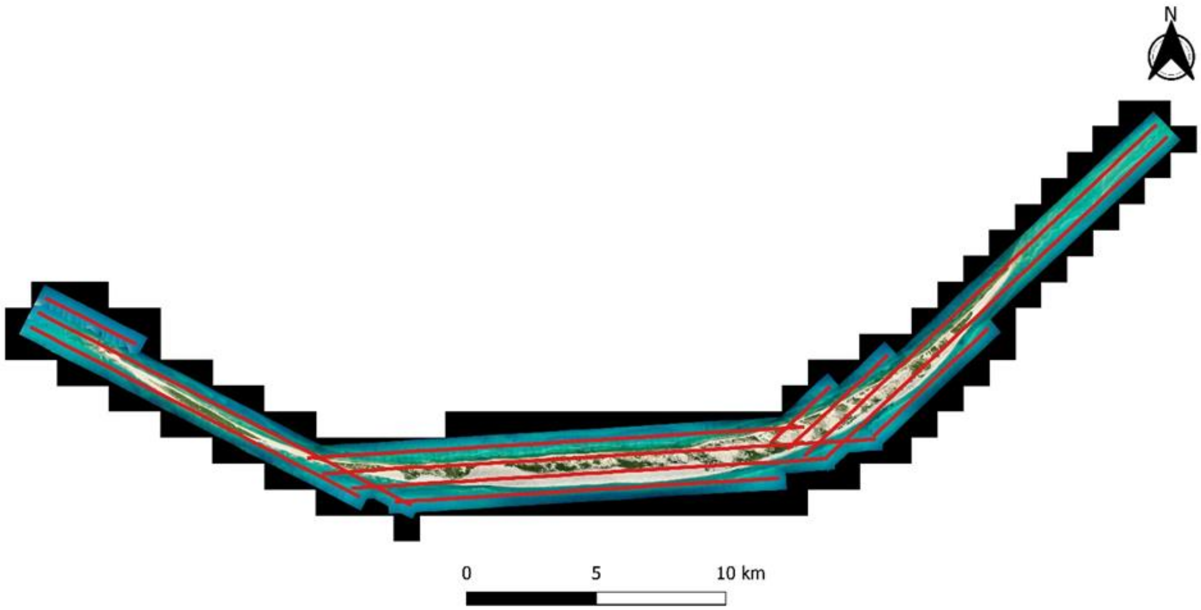


Figure 2. Flight transects for light detection and ranging (LiDAR) survey on Sable Island, 8 August 2019. The LiDAR survey was completed by Applied Geomatics Research Group, Leading Edge Geomatics (New Brunswick) and Parks Canada Agency (Eamer et al., 2022).

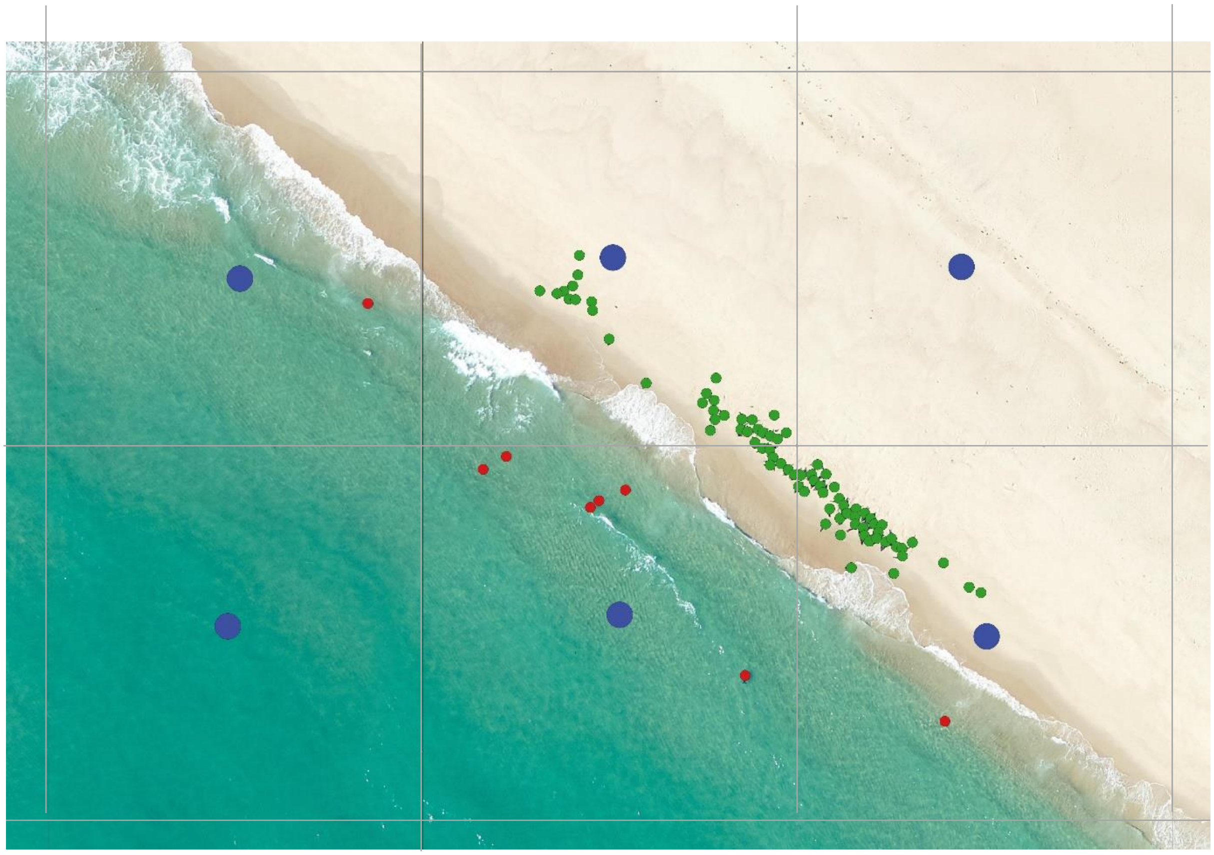


Figure 3**.** A screenshot of six 50m x 50m cells from the orthorectified aerial photographic survey. The blue dots indicate cells with a completed count, red dots indicate seals in the water and green dots indicate seals on land.

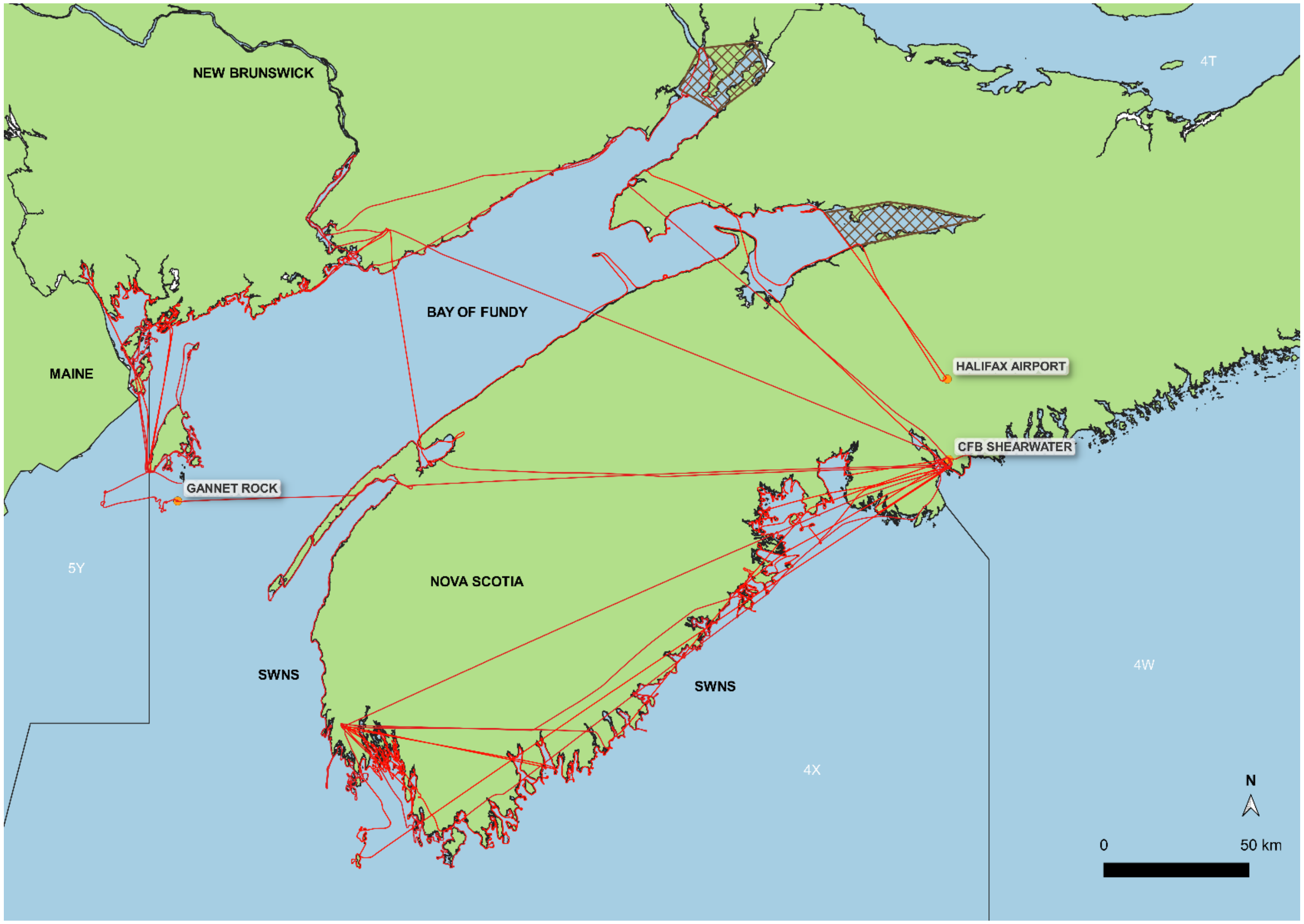


Figure 4a. Survey routes (red) for the 2020 seal aerial survey for the Bay of Fundy and SWNS. Direct travel flights between airports/fuel stations have been removed for clarity. Brown hatching highlights extensive mudflat areas that were not surveyed.

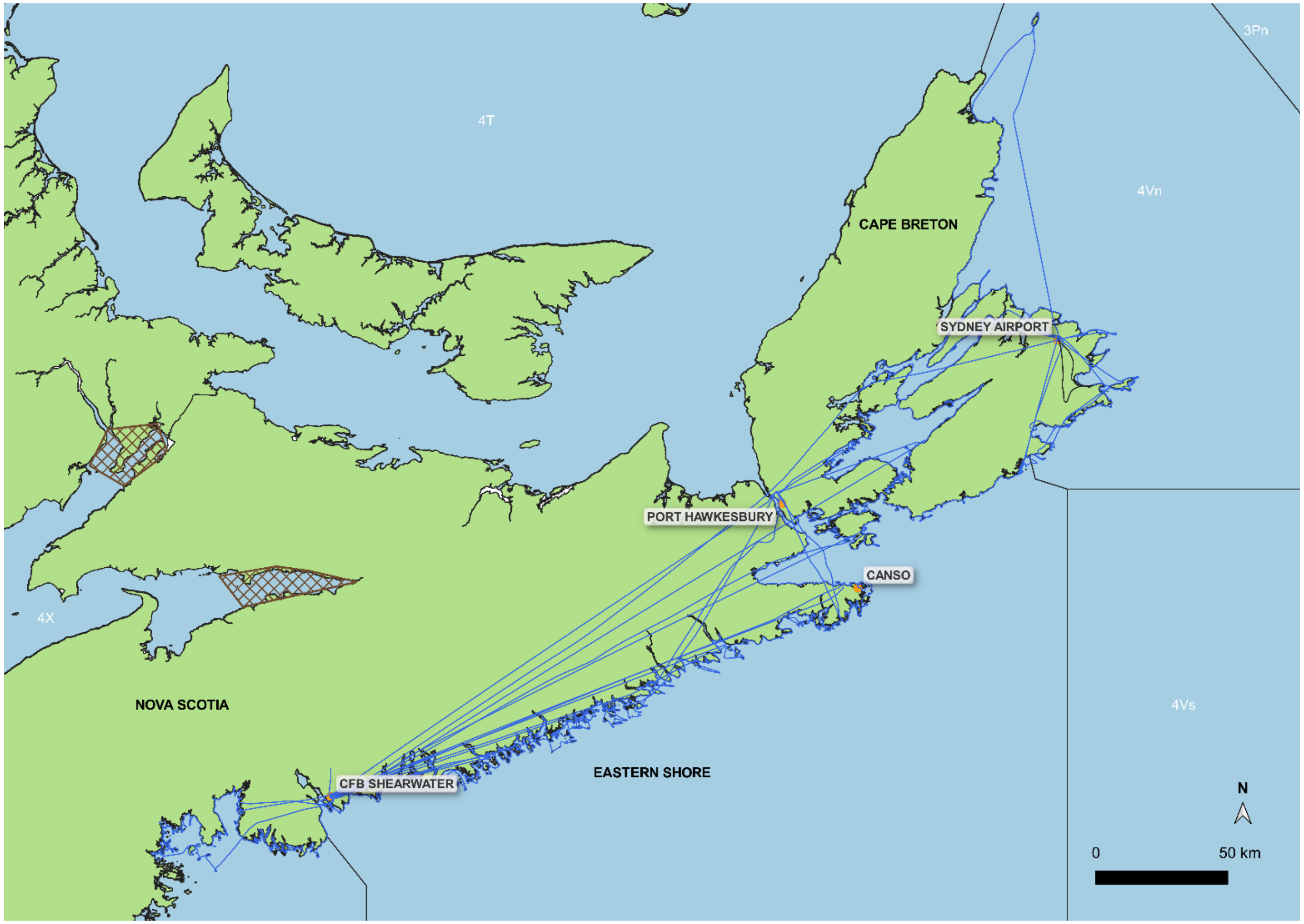


Figure 4b. Survey routes (blue) for the 2020 seal aerial survey for the Eastern Shore and Cape Breton. Direct travel flights between airports/fuel stations have been removed for clarity.

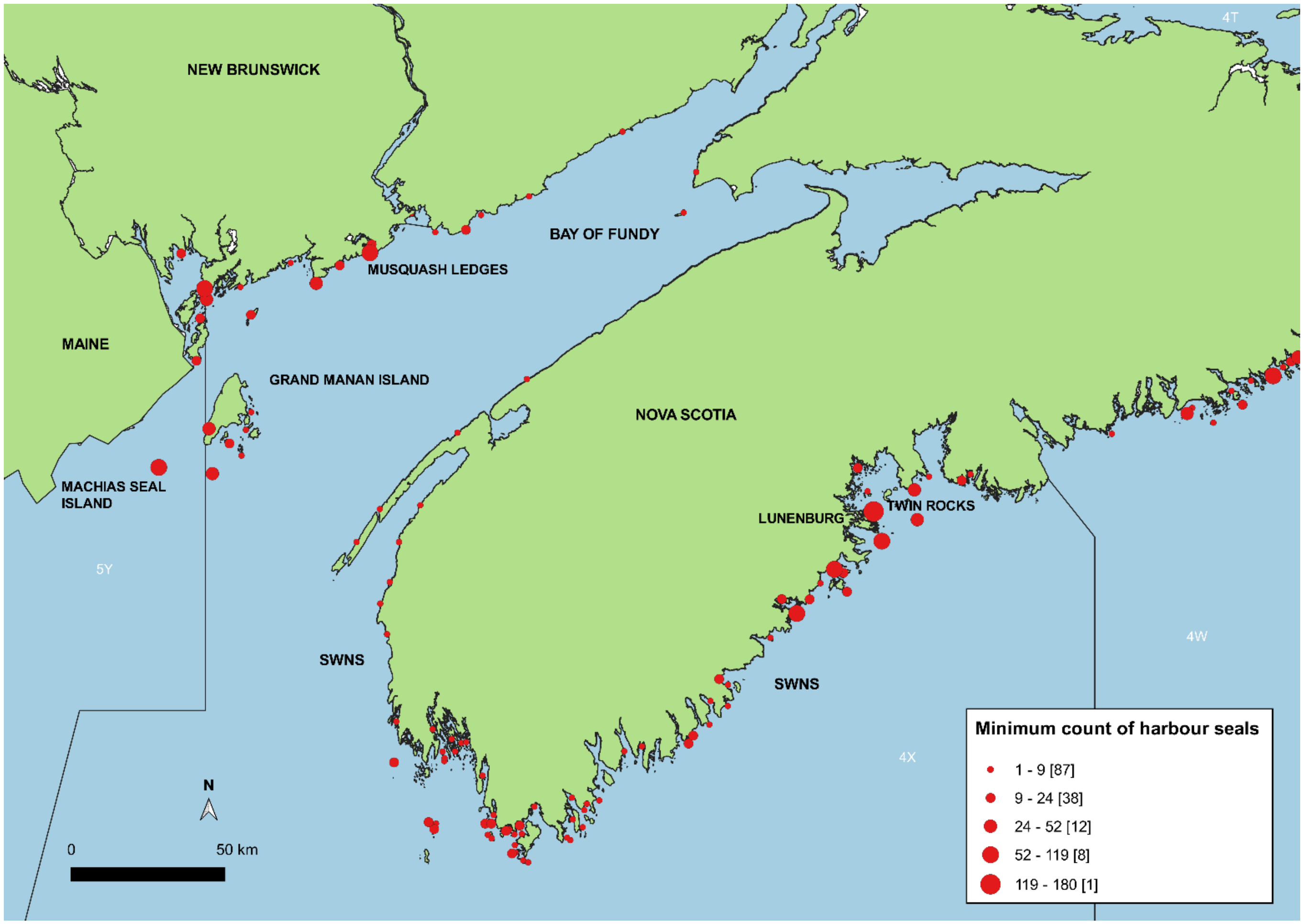


Figure 5a. Minimum estimate of harbour seals (all ages) at haul-out sites in the Bay of Fundy and along the SWNS coastline, 14 June to 17 July 2020. The black solid lines indicate the NAFO Divisions (5Y, 4T, 4X, 4W).

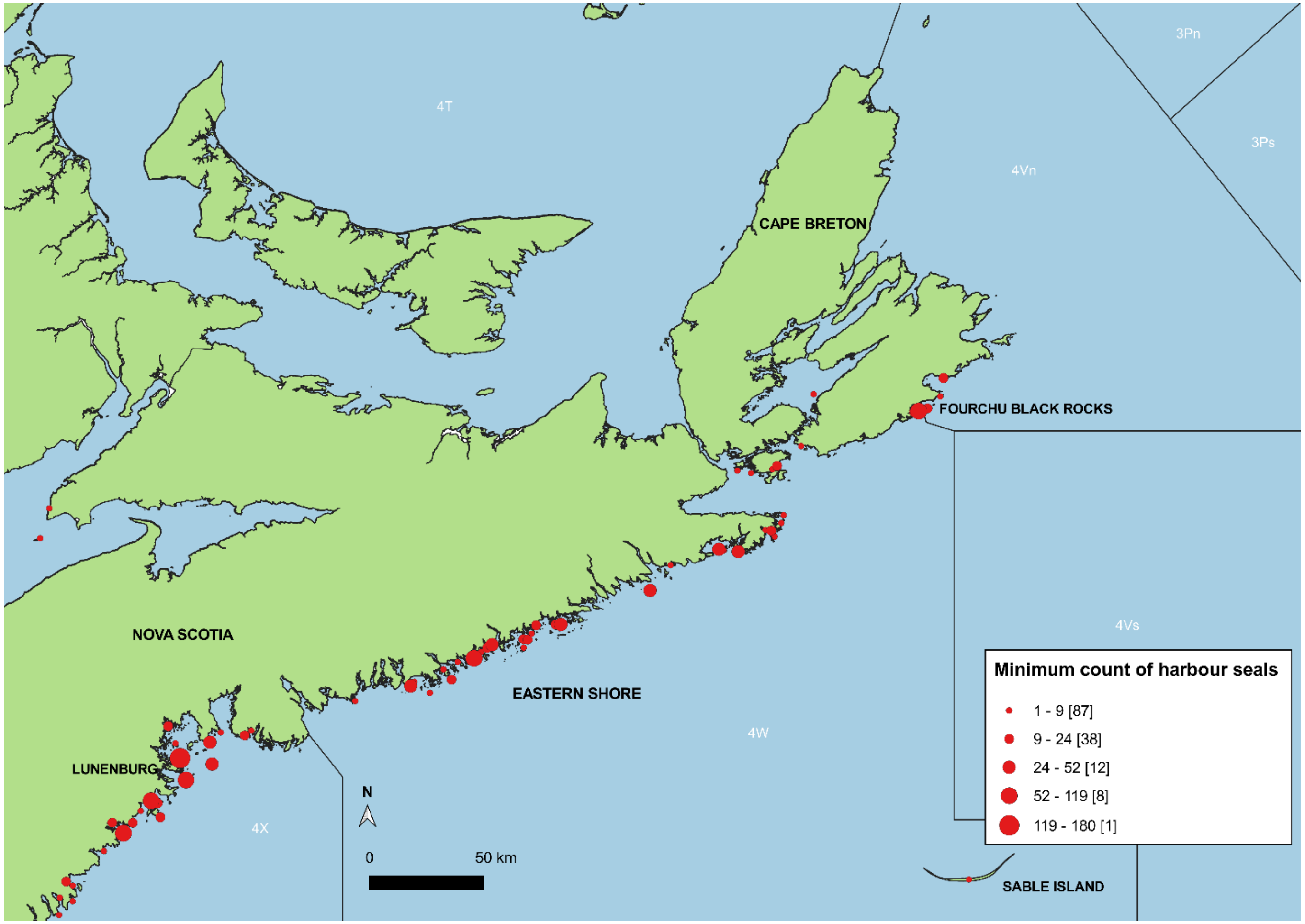


Figure 5b. Minimum estimate of harbour seals (all ages) at haul-out sites on the Eastern Shore and along the Cape Breton coastline, 14 June to 17 July 2020. The black solid lines indicate the NAFO Divisions (3Pn, 3Ps, 4Vn, 4T, 4Vs, 4W, 4X). The count of harbour seal adults on Sable Island was conducted by Zoe Lucas on 2 June 2021.

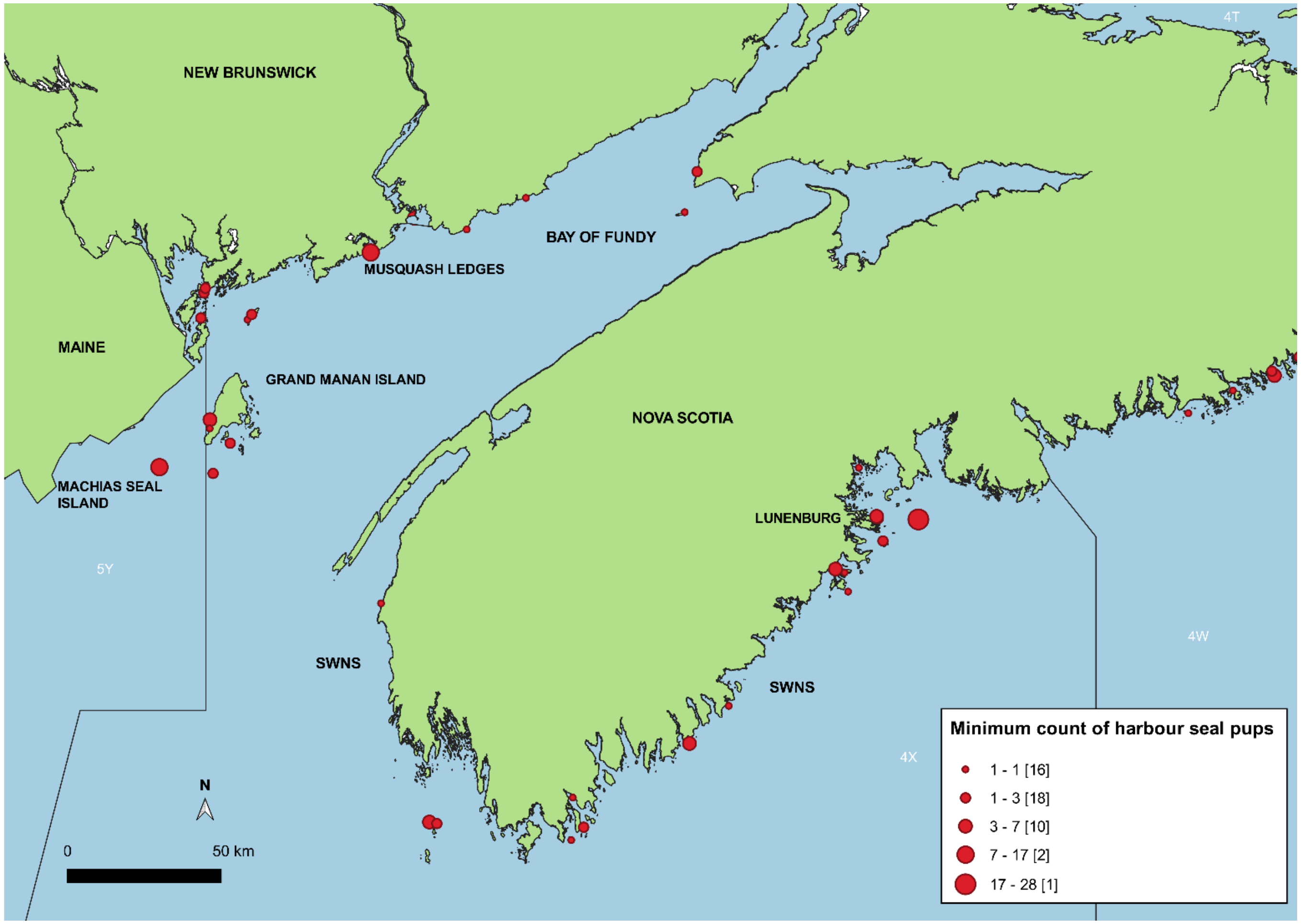


Figure 6a. Minimum estimates of harbour seal pups at haul-out sites in the Bay of Fundy and along the SWNS coastline, 14 June to 17 July 2020.

The black solid lines indicate the NAFO Divisions (5Y, 4T, 4X, 4W).

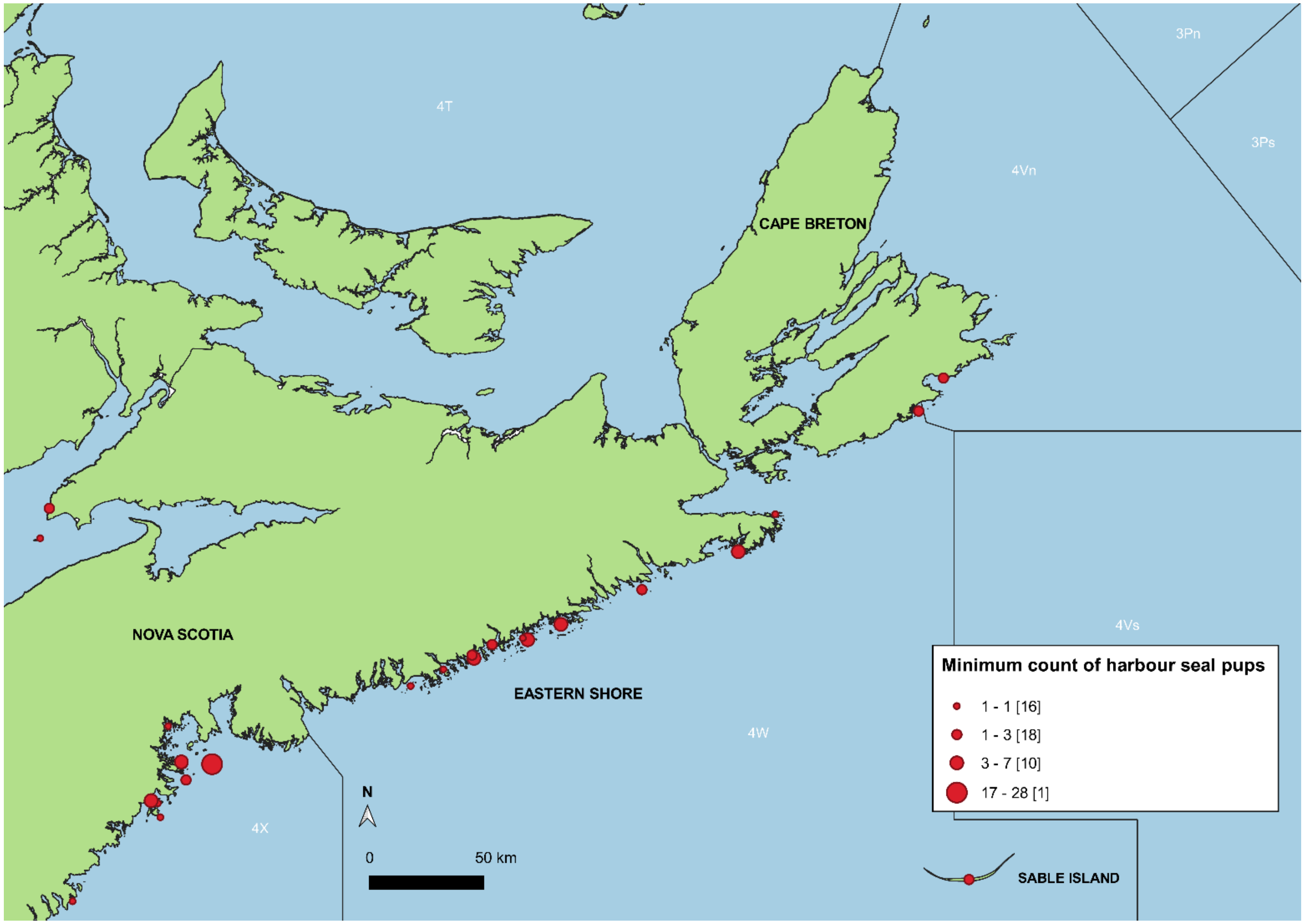


Figure 6b. Minimum estimate of harbour seal pups at haul-out sites on the Eastern Shore and along the Cape Breton coastline, 14 June to 17 July 2020. The black solid lines indicate the NAFO Divisions (3Pn, 3Ps, 4Vn, 4T, 4Vs, 4W, 4X). The count of harbour seals pups on Sable Island was conducted by Zoe Lucas on 2 June 2021.

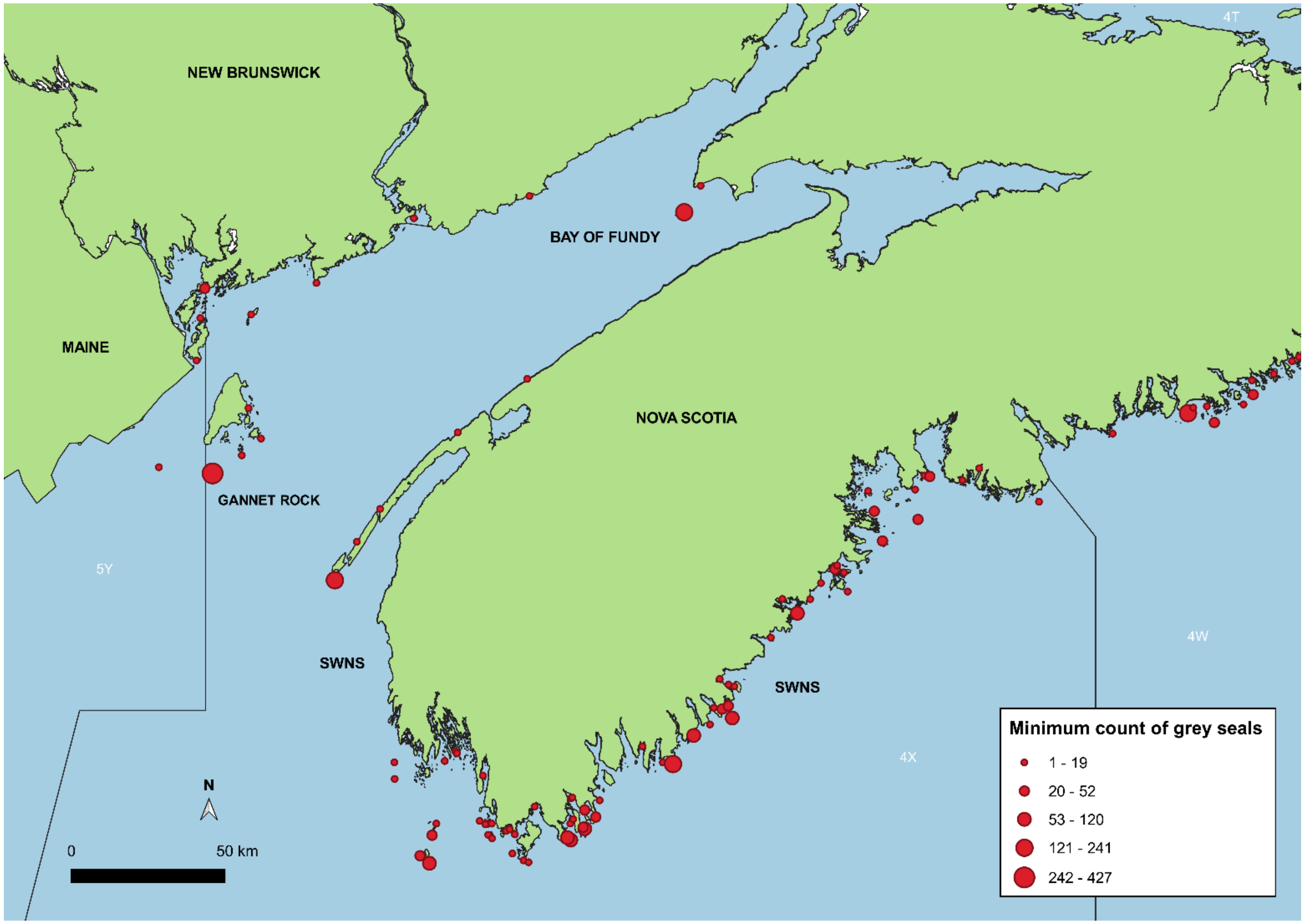


Figure 7a. Minimum estimates of grey seals at haul-out sites in the Bay of Fundy and along the SWNS coastline, 14 June to 17 July 2020. The black solid lines indicate the NAFO Divisions (5Y, 4T, 4X, 4W).

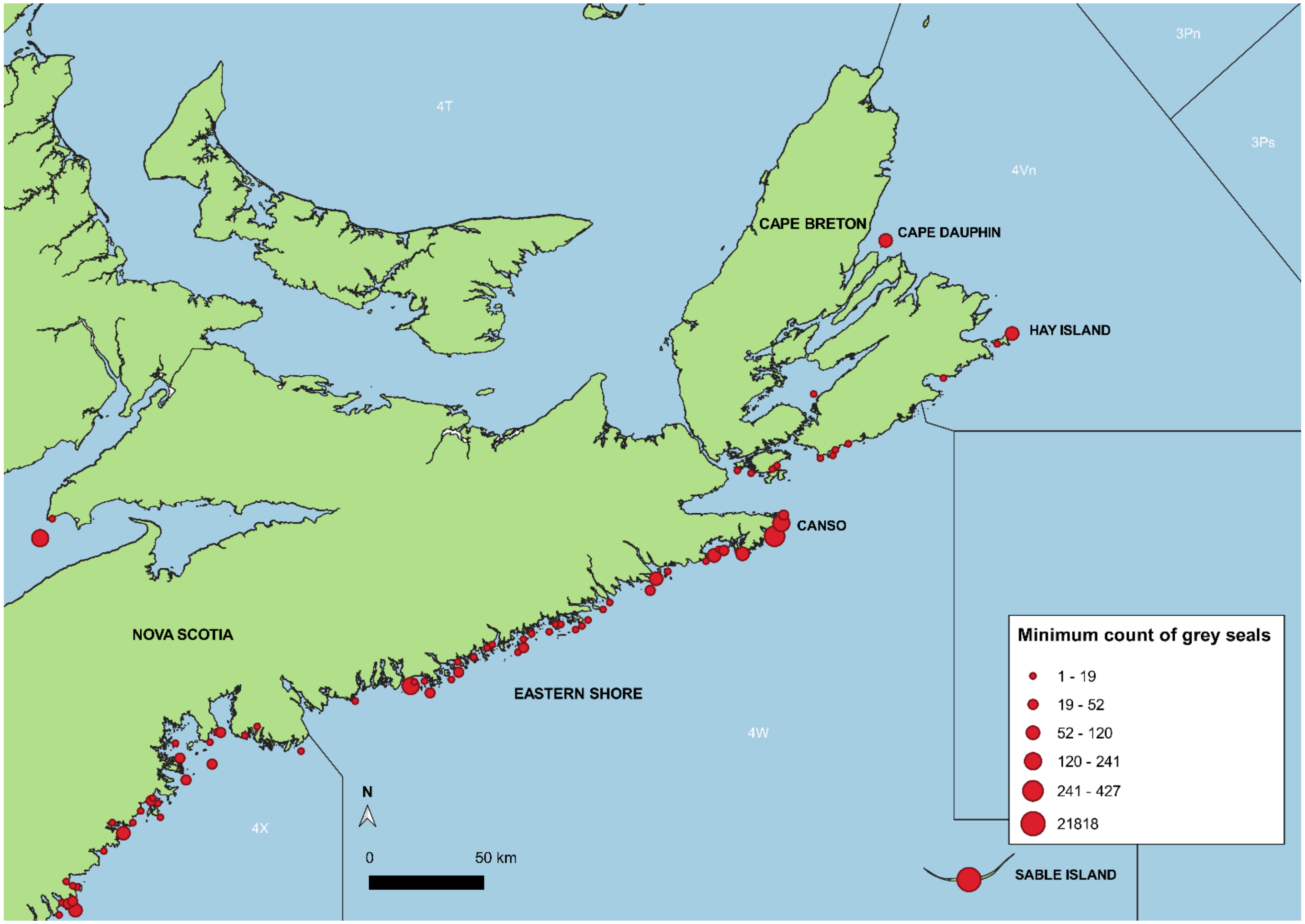


Figure 7b. Minimum estimate of grey seals at haul-out sites on the Eastern Shore and along the Cape Breton coastline, 14 June to 17 July 2020. The black solid lines indicate the NAFO Divisions (3Pn, 3Ps, 4Vn, 4T, 4Vs, 4W, 4X). The count of grey seals on Sable Island was derived from aerial LiDAR survey imagery completed by Parks Canada on 8 August 2019.

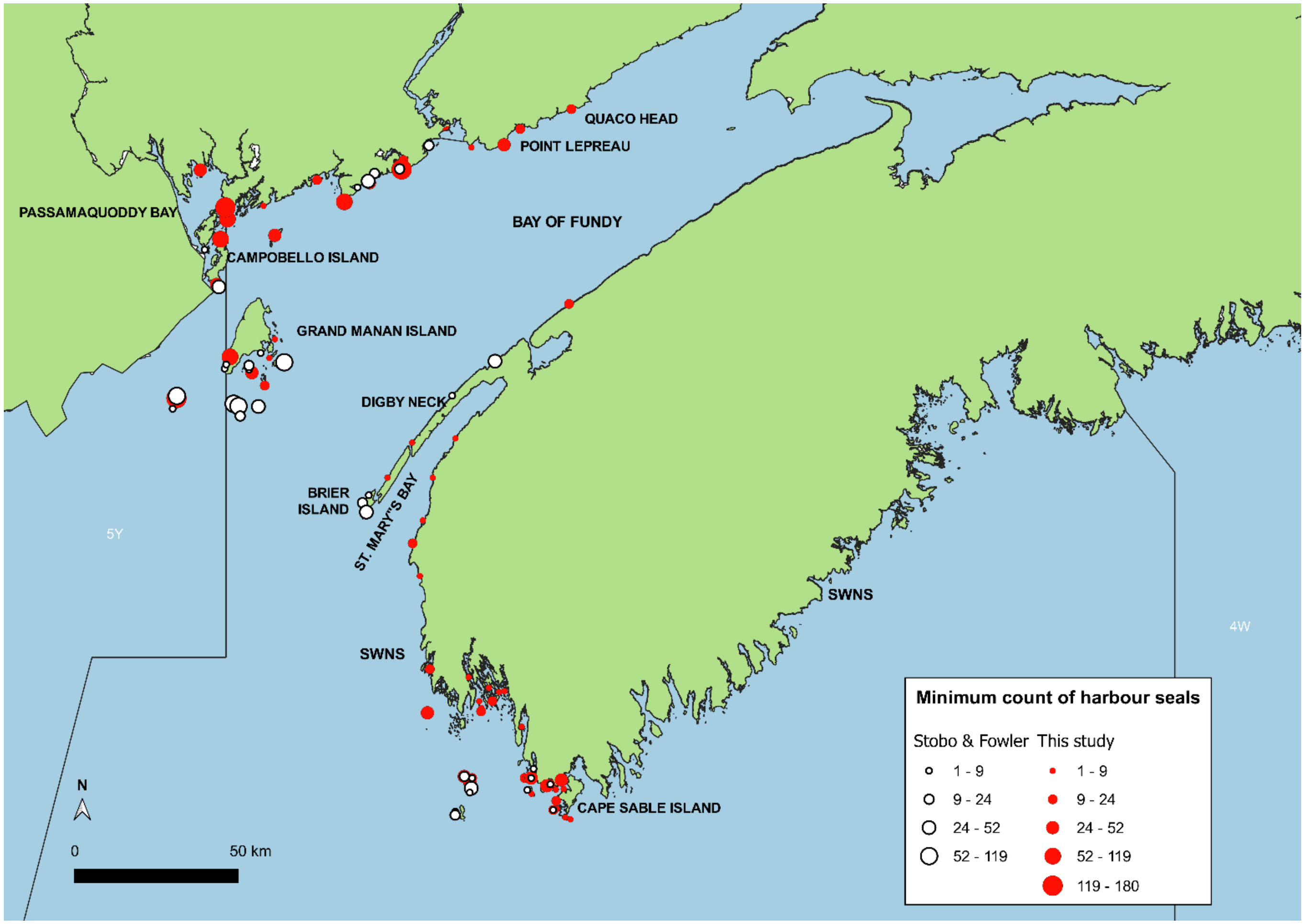


Figure 8a. Counts of harbour seals (all ages) at haul-out sites in the Bay of Fundy and along the SWNS coast according to Stobo and Fowler 1994 (○ ; data collected May 1985) and the current study (● ; data collected June-July 2020). The black solid lines indicate the NAFO Divisions (5Y, 4X, 4W).

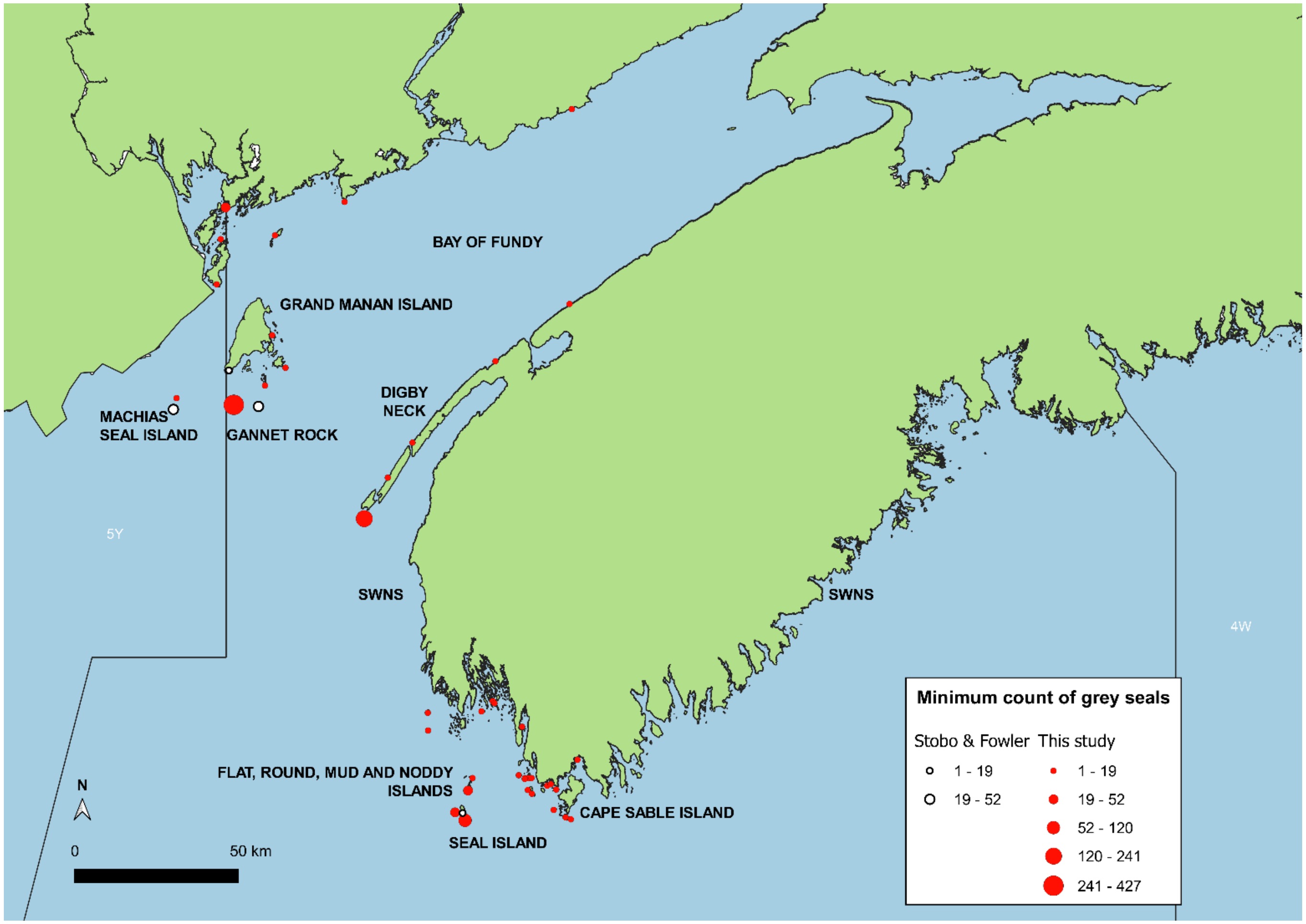


Figure 8b. Counts of grey seals (all ages) at haul-out sites in the Bay of Fundy and along the SWNS coast according to Stobo and Fowler 1994 (○; data collected May 1985) and the current study (●; data collected June-July 2020). The black solid lines indicate the NAFO Divisions (5Y, 4X, 4W).

9. APPENDICES

A: SUMMARY OF AERIAL SURVEY COVERAGE, PEAK LOW TIDE, SURVEY START AND END TIME, AND DISTANCE (KM) AND TIME TRAVELLED (HR)

Date	Survey coverage[1]	Peak Low Tide (ADT)	Survey Start-End Time (ADT)	Total distance[1] (km)	Total time[1] (hr)
14 June 2020	Machias Seal Island, Wolf Islands, Campobello Island and Deer Island	13:25 Machias Is.	11:04 - 15:48	1138	8.1
15 June 2020	Grand Manan to Bliss Island	14:50 Grand Manan	12:30 – 17:02	1043	7.7
16 June 2020	Saint John River to Fundy National Park; Saint John Harbour to Musquash Ledges, Sea Dog Cove to Apple River	15:29 Saint John	13:18 – 17:30	1023	6.5
17 June 2020	Apple River to Digby	16:09 Advocate	13:53 – 17:52	987.0	6.4
18 June 2020	Digby to Comeau Hill/Tusket	16:34 Digby 14:25 Wedgeport	14:03 - 17:50	844.5	6.3
19 June 2020	McNabs Island to Ship Harbour	13:48 Halifax	13:01 – 15:28	351.5	2.5
20 June 2020	Seal Island to Johns Island	16:41 Tusket	15:03[3] – 18:10	966	4.5

		15:49 Lower East Pubnico			
21 June 2020	Aborted due to weather				
24 June 2020	Aborted due to weather				
25 June 2020	Cape Sable to Port l'Herbert	18:24 Lockeport 19:09 Clarks Harbour	16:26 – 20:21	944.5	5.4
26 June 2020	Bras D'Or Lake to Isle Madame	19:42 Port Hawkesbury	12:41 – 18:46	1112	6.9
2 July 2020	Spry Harbour to Harrigan Cove	12:46 Spry Harbour	12:17 – 13:40	398.7	2.7
3 July 2020	Sober Island to Seal Harbour	13:49 Ecum Secum	11:22 – 16:15	840.7	5.5
4 July 2020	Seal Harbour to Canso	14:42 Canso	13:27 – 16:28	759.9	5
5 July 2020	Port l'Hebert to La Have; Lower East Pubnico to Barrington Passage	16:09 Clarks Harbour 15:25 Port Mouton	13:45 – 17:54	1080	7
7 July 2020	La Have to St. Margaret's Bay	16:52 Lunenburg	14:48 – 19:15	753.3	5.7
8 July 2020	Little Narrows, Bras D'Or Lake to Sydney and St. Paul's Island	17:55 Dingwall	12:34 – 20:30	1076	7.5
9 July 2020	Aborted due to weather				
10 July 2020	Forchu to Scatarie Island	19:19 Louisburg	16:30 – 17:07 [4]	583.0	3.5
14 July 2020	St. Margaret's Bay to Halifax	08:57 Halifax	09:00 – 10:30	225	1.5

16 July 2020	Isle Madame to Forchu; Scatarie Island to Donkin	11:46 Canso 11:51 Louisburg	10:01 – 14:00	1015	6.6
17 July 2020	Canso to Port Hawkesbury	12:40 Canso	10:15 - 11:24	503	2.5

[1] includes travel to and from fueling stations[2]

[2] Fueling stations: Grand Manan CCG, Saint John Airport, Shearwater CCG, Stanfield International Airport, Digby Airport, Yarmouth Airport, Sydney Airport and Port Hawkesbury Airport

[3] Late departure from Shearwater due to mechanical issue

[4] Poor visibility shortened survey time

B1: MINIMUM COUNTS OF HARBOUR SEAL ADULTS IN THE BAY OF FUNDY AND ALONG THE NOVA SCOTIA COASTLINE, 14 JUNE TO 17 JULY 2020

Date	Location	Region	Latitude	Longitude	Count
June 14, 2020	Gannet Rock	Bay of Fundy	44.5147800	-66.8745490	47
June 14, 2020	Machias Seal Island	Bay of Fundy	44.5326670	-67.0898060	84
June 14, 2020	Kent Island	Bay of Fundy	44.5664130	-66.7574970	6
June 14, 2020	Cheney Island	Bay of Fundy	44.6400400	-66.7401260	2
June 14, 2020	Nantucket Island	Bay of Fundy	44.6905150	-66.7189860	1
June 14, 2020	Wolf Islands	Bay of Fundy	44.9676250	-66.7197790	21
June 14, 2020	West Grand Manan	Bay of Fundy	44.6432470	-66.8880720	27
June 14, 2020	Outer Wood Island	Bay of Fundy	44.6010800	-66.8058610	20
June 14, 2020	Gooseberry Ledges	Bay of Fundy	44.837005	-66.938771	13
June 14, 2020	Deer Island	Bay of Fundy	45.0111400	-66.8978890	26
June 14, 2020	Campobello Island	Bay of Fundy	44.9575370	-66.9239010	24
June 14, 2020	Parker Island	Bay of Fundy	45.0285770	-66.9113160	12
June 15, 2020	Dick's Island	Bay of Fundy	45.1413350	-66.9999860	17
June 15, 2020	Mohawk Island	Bay of Fundy	45.0418280	-66.9055110	65
June 15, 2020	Moose Island	Bay of Fundy	45.0463400	-66.7623010	4
June 15, 2020	Pocologan Island	Bay of Fundy	45.1147600	-66.5606440	9
June 15, 2020	Point Lepreu	Bay of Fundy	45.0567570	-66.4580240	28
June 15, 2020	Lobster Cove	Bay of Fundy	45.107587	-66.363589	14
June 16, 2020	Mispec	Bay of Fundy	45.2013370	-65.9800520	1

June 16, 2020	West Beach	Bay of Fundy	45.2082400	-65.8571070	14
June 16, 2020	Tynemouth Creek	Bay of Fundy	45.3026570	-65.6039970	9
June 16, 2020	Little Salmon	Bay of Fundy	45.4851630	-65.2289310	2
June 16, 2020	Black river	Bay of Fundy	45.2500620	-65.7963860	6
June 16, 2020	Saint John Harbour	Bay of Fundy	45.2400630	-66.0674190	21
June 16, 2020	Musquash Ledges	Bay of Fundy	45.1430350	-66.2423840	70
June 16, 2020	Partridge Island	Bay of Fundy	45.235218	-66.056106	8
June 17, 2020	Cape Chignecto	Bay of Fundy	45.371367	-64.933079	6
June 17, 2020	Isle Haut	Bay of Fundy	45.2568750	-64.9831070	5
June 17, 2020	Annapolis	Bay of Fundy	44.7847730	-65.6123920	8
June 18, 2020	Culloden	Bay of Fundy	44.6317880	-65.8911020	1
June 18, 2020	Digby Neck	Bay of Fundy	44.4132520	-66.2027460	1
June 18, 2020	Long Island	Bay of Fundy	44.3189170	-66.2959070	2
June 18, 2020	Sissiboo River, St Mary's Bay	SWNS	44.4247070	-66.0399290	1
June 18, 2020	Church Point, St Mary's Bay	SWNS	44.318887	-66.125727	1
June 18, 2020	Meteghan, St Mary's Bay	SWNS	44.2040230	-66.1626740	2
June 18, 2020	Bear Cove, St Mary's Bay	SWNS	44.1419720	-66.2009970	6
June 18, 2020	Salmon River	SWNS	44.0536900	-66.1738720	1
June 18, 2020	Yarmouth Harbour	SWNS	43.8013680	-66.1365370	9
June 18, 2020	Green Island	SWNS	43.6827720	-66.1454340	18
June 20, 2020	Mud Island	SWNS	43.4892120	-65.9845060	16
June 20, 2020	Flat Island	SWNS	43.5093270	-66.0068410	20

June 20, 2020	Round Island	SWNS	43.5049680	-65.9770960	7
June 20, 2020	Gooseberry Island	SWNS	43.6866050	-65.9435190	8
June 20, 2020	Outer Sheep Island	SWNS	43.7145950	-65.9011260	9
June 20, 2020	Inner Fish Island	SWNS	43.6954580	-65.9428570	4
June 20, 2020	Tucker Island	SWNS	43.7142830	-65.9507070	1
June 20, 2020	Squires Island	SWNS	43.7792800	-65.9907690	1
June 20, 2020	Morris Island	SWNS	43.750623	-65.914319	2
June 20, 2020	Hay Islands	SWNS	43.73949	-65.875809	2
June 20, 2020	Rankins Island	SWNS	43.741613	-65.855756	1
June 20, 2020	Ile Ferre	SWNS	43.644653	-65.790672	3
June 25, 2020	Thrum Cap	SWNS	43.554623	-65.582396	2
June 25, 2020	Baccaro	SWNS	43.456888	-65.437972	2
June 25, 2020	Taylors Rocks	SWNS	43.463982	-65.451254	1
June 25, 2020	Ram Island	SWNS	43.517452	-65.428434	1
June 25, 2020	The Old Hen	SWNS	43.49438	-65.388311	3
June 25, 2020	Round Island	SWNS	43.58042	-65.431732	8
June 25, 2020	North East Harbour	SWNS	43.544272	-65.382226	2
June 25, 2020	Ingomar	SWNS	43.562605	-65.372336	2
June 25, 2020	Gull Rock	SWNS	43.572497	-65.322166	1
June 25, 2020	Jordan Bay	SWNS	43.71534	-65.222036	1
June 25, 2020	Stephens Island	SWNS	43.72929	-65.150624	1
June 25, 2020	Harding’s Island	SWNS	43.73736	-64.963864	11

July 5, 2020	Little Port L'Hebert	SWNS	43.760625	-64.945052	13
July 5, 2020	Lesser Hope Rock	SWNS	43.7924	-64.880004	2
July 5, 2020	Bijou Rocks	SWNS	43.860907	-64.875732	3
July 5, 2020	Moose Rock	SWNS	43.846225	-64.806374	8
July 5, 2020	Big Ledges	SWNS	43.907477	-64.805449	5
July 5, 2020	Charley Island	SWNS	43.924027	-64.840896	22
July 5, 2020	Coffin Island	SWNS	44.043477	-64.635724	1
July 5, 2020	Toby Island	SWNS	44.11345	-64.529289	104
July 5, 2020	Northwest Bay	SWNS	44.154657	-64.589552	23
July 5, 2020	Apple Cove	SWNS	44.154183	-64.477937	10
July 5, 2020	Green Bay	SWNS	44.200363	-64.434737	2
July 5, 2020	Goodwin's Island	SWNS	43.504863	-65.779454	11
July 5, 2020	The Ball	SWNS	43.50454	-65.768897	6
July 5, 2020	Sunken Ledge	SWNS	43.504908	-65.755142	20
July 5, 2020	Duck Island	SWNS	43.472255	-65.769279	2
July 5, 2020	Outer Island	SWNS	43.462057	-65.753976	1
July 5, 2020	Western Way Ledges	SWNS	43.530017	-65.746306	2
July 5, 2020	Green Ledge	SWNS	43.483863	-65.696572	14
July 5, 2020	Shag Harbour	SWNS	43.48796	-65.683084	9
July 5, 2020	Sloop Rock	SWNS	43.473462	-65.662189	2
July 5, 2020	Murray Cove	SWNS	43.499553	-65.641391	18
July 5, 2020	Newellton	SWNS	43.475268	-65.632771	2

July 5, 2020	Clark's Harbour	SWNS	43.442592	-65.660829	8
July 5, 2020	Green Island	SWNS	43.417827	-65.672017	11
July 5, 2020	Pork Ledge	SWNS	43.421087	-65.658187	1
July 5, 2020	Cape Sable Island	SWNS	43.397743	-65.627216	1
July 5, 2020	Black Rock	SWNS	43.392265	-65.607459	1
July 7, 2020	Black Rock, La Have	SWNS	44.175925	-64.327771	14
July 7, 2020	Moshers Island	SWNS	44.230478	-64.342087	14
July 7, 2020	Rabbit Island	SWNS	44.240647	-64.378312	80
July 7, 2020	Coveys Island	SWNS	44.2508730	-64.3699660	6
July 7, 2020	Hounds Ledges	SWNS	44.321408	-64.187961	119
July 7, 2020	Twin Rocks	SWNS	44.406545	-64.220857	180
July 7, 2020	Pearl Island	SWNS	44.382945	-64.045824	28
July 7, 2020	Little Rafuse Island	SWNS	44.46424	-64.245667	9
July 7, 2020	Warrens Ledge	SWNS	44.530912	-64.284741	14
July 7, 2020	Seal Ledge, New Harbour	SWNS	44.46842	-64.057117	52
July 7, 2020	Owls Head	SWNS	44.506205	-63.998519	1
July 14, 2020	Bakers Island	SWNS	44.495082	-63.867496	12
July 14, 2020	Flat Island, Blind Bay	SWNS	44.513055	-63.831991	2
June 19, 2020	Three Fathom Harbour	Eastern Shore	44.6285230	-63.2649520	4
June 19, 2020	Jeddore	Eastern Shore	44.6867020	-62.9628220	38
June 19, 2020	Ship Ledges	Eastern Shore	44.6601820	-62.8573390	1
June 19, 2020	Duck Island Ledges	Eastern Shore	44.7025320	-62.9419270	2

June 19, 2020	Passage Islands	Eastern Shore	44.7513280	-62.7845720	4
June 19, 2020	Gunning Rock	Eastern Shore	44.7117150	-62.7404470	10
July 2, 2020	Inner Baltee Island	Eastern Shore	44.779975	-62.706601	7
July 2, 2020	Phoenix Island	Eastern Shore	44.793947	-62.617551	65
July 2, 2020	Mink Island	Eastern Shore	44.806577	-62.628167	8
July 2, 2020	Wendell’s Island	Eastern Shore	44.803997	-62.637927	2
July 2, 2020	Green Island	Eastern Shore	44.818813	-62.578384	1
July 2, 2020	South Mud Hole	Eastern Shore	44.834858	-62.545907	12
July 2, 2020	Horse Island	Eastern Shore	44.847152	-62.518321	40
July 2, 2020	Horse Island Ledge	Eastern Shore	44.835193	-62.347261	2
July 2, 2020	Bald Harbour Islands	Eastern Shore	44.867945	-62.347972	16
July 2, 2020	Macdonald Island	Eastern Shore	44.921812	-62.278947	10
July 3, 2020	Outer Eastern Harbour Island	Eastern Shore	44.865847	-62.324726	13
July 3, 2020	Long Island	Eastern Shore	44.889357	-62.302897	2
July 3, 2020	Little Goose Island	Eastern Shore	44.924852	-62.171834	17
July 3, 2020	Ragged Islands	Eastern Shore	44.925328	-62.143554	29
July 3, 2020	Holland Harbour, offshore ledges	Eastern Shore	45.056108	-61.656676	34
July 4, 2020	Coddles Island	Eastern Shore	45.152888	-61.546186	1
July 4, 2020	Topstone Ledge	Eastern Shore	45.214213	-61.282244	50
July 4, 2020	Net Ledge	Eastern Shore	45.209543	-61.255462	1
July 4, 2020	Outer Gull Ledge	Eastern Shore	45.205268	-61.176584	39
July 4, 2020	Dover Harbour	Eastern Shore	45.288687	-61.028692	1

July 4, 2020	Shag Cove	Eastern Shore	45.28598	-60.996886	11
July 4, 2020	Little Dover Island	Eastern Shore	45.263727	-60.977494	1
July 4, 2020	Black Rocks	Eastern Shore	45.314968	-60.941792	1
July 4, 2020	Park Ledge	Eastern Shore	45.345543	-60.929411	5
June 26, 2020	Red Island	Bras D'Or Lake	45.807168	-60.765566	2
June 26, 2020	Janvrin Island	Cape Breton	45.516138	-61.181599	2
June 26, 2020	Crichton Island	Cape Breton	45.506188	-61.107197	8
June 26, 2020	Pondville	Cape Breton	45.521345	-60.991091	4
July 10, 2020	Myers Rock, Gabarus	Cape Breton	45.753018	-60.144802	21
July 10, 2020	Fourchu Black Rocks	Cape Breton	45.742637	-60.192812	74
July 10, 2020	Yellow Rock	Cape Breton	45.739387	-60.218639	24
July 16, 2020	Les Rochers	Cape Breton	45.534335	-60.964962	12
July 16, 2020	Black Rock	Cape Breton	45.609652	-60.834269	4
July 16, 2020	Flat Ledge	Cape Breton	45.798463	-60.075449	2
July 16, 2020	Kennington Rocks	Cape Breton	45.868408	-60.057557	23

B2: MINIMUM COUNTS OF HARBOUR SEAL PUPS IN THE BAY OF FUNDY AND ALONG THE NOVA SCOTIA COASTLINE, 14 JUNE TO 17 JULY 2020

Date	Location	Region	Latitude	Longitude	Coun
June 14, 2020	Gannet Rock	Bay of Fundy	44.514780	-66.8745490	2
June 14, 2020	Machias Seal Island	Bay of Fundy	44.532667	-67.0898060	15
June 14, 2020	Wolf Islands	Bay of Fundy	44.952845	-66.7367560	4
June 14, 2020	West Grand Manan	Bay of Fundy	44.668323	-66.8870590	5
June 14, 2020	Outer Wood Island	Bay of Fundy	44.601080	-66.8058610	2
June 14, 2020	Campobello Island	Bay of Fundy	44.957537	-66.9239010	2
June 14, 2020	Parker Island	Bay of Fundy	45.028577	-66.9113160	2
June 15, 2020	Mohawk Island	Bay of Fundy	45.041828	-66.9055110	2
June 16, 2020	West Beach	Bay of Fundy	45.208240	-65.8571070	1
June 16, 2020	Tynemouth Creek	Bay of Fundy	45.297182	-65.6200260	1
June 16, 2020	Saint John Harbour	Bay of Fundy	45.240063	-66.0674190	5
June 16, 2020	Musquash Ledges	Bay of Fundy	45.143035	-66.2423840	17
June 16, 2020	Partridge Island	Bay of Fundy	45.235218	-66.0561060	3
June 17, 2020	Cape Chignecto	Bay of Fundy	45.371367	-64.933079	2
June 17, 2020	Isle Haut	Bay of Fundy	45.256875	-64.9831070	1
June 18, 2020	Bear Cove, St Mary's Bay	SWNS	44.141972	-66.2009970	1
June 20, 2020	Flat Island	SWNS	43.509327	-66.0068410	4
June 20, 2020	Round Island	SWNS	43.504968	-65.9770960	2
June 25, 2020	Baccaro	SWNS	43.456888	-65.437972	1

June 25, 2020	The Old Hen	SWNS	43.49438	-65.388311	2
June 25, 2020	Round Island	SWNS	43.58042	-65.431732	1
June 25, 2020	Hardings Island	SWNS	43.73736	-64.963864	4
July 2, 2020	Phoenix Island	Eastern Shore	44.793947	-62.617551	7
July 2, 2020	Gerard Island	Eastern Shore	44.806577	-62.628167	2
July 2, 2020	Horse Island	Eastern Shore	44.847152	-62.518321	3
July 5, 2020	Moose Rock	SWNS	43.846225	-64.806374	1
July 7, 2020	Black Rock, La Have	SWNS	44.175925	-64.327771	1
July 7, 2020	Moshers Island	SWNS	44.230478	-64.342087	1
July 7, 2020	Rabbit Island	SWNS	44.240647	-64.378312	6
July 7, 2020	Hounds Ledges	SWNS	44.321408	-64.187961	2
July 7, 2020	Twin Rocks	SWNS	44.385582	-64.206396	3
July 7, 2020	Twin Rocks	SWNS	44.39186	-64.213221	5
July 7, 2020	Pearl Island	SWNS	44.382945	-64.045824	28
July 7, 2020	Warrens Ledge	SWNS	44.530912	-64.284741	1
June 19, 2020	Jeddore	Eastern Shore	44.686702	-62.9628220	1
June 19, 2020	Passage Islands	Eastern Shore	44.751328	-62.7845720	1
July 3, 2020	Outer Eastern Harbour Island	Eastern Shore	44.865847	-62.324726	4
July 3, 2020	Bald Harbour Islands	Eastern Shore	44.872065	-62.351334	1
July 3, 2020	Ragged Islands	Eastern Shore	44.925328	-62.143554	4
July 3, 2020	Holland Harbour, offshore	Eastern Shore	45.059033	-61.701902	2
July 4, 2020	Outer Gull Ledge	Eastern Shore	45.205268	-61.176584	4

July 4, 2020	Barrys Rock	Eastern Shore	45.348852	-60.974859	1
July 10, 2020	Fourchu Black Rocks	Cape Breton	45.742637	-60.192812	3
July 16, 2020	Kennington Rocks	Cape Breton	45.868408	-60.057557	3

B3: MINIMUM COUNTS OF GREY SEALS IN THE BAY OF FUNDY AND ALONG THE NOVA SCOTIA COASTLINE, 14 JUNE TO 17 JULY 2020

Date	Location	Region	Latitude	Longitude	Count
June 14, 2020	Gannet Rock	Bay of Fundy	44.5147800	-66.8745490	427
June 14, 2020	Machias Seal Island	Bay of Fundy	44.5326670	-67.0898060	7
June 14, 2020	Kent Island	Bay of Fundy	44.5664130	-66.7574970	1
June 14, 2020	Nantucket Island	Bay of Fundy	44.7012670	-66.7303320	1
June 14, 2020	White Head, GM	Bay of Fundy	44.6141920	-66.6802190	1
June 14, 2020	Wolf Islands	Bay of Fundy	44.9676250	-66.7197790	1
June 14, 2020	Gooseberry Ledges	Bay of Fundy	44.837005	-66.938771	6
June 14, 2020	Campobello Island	Bay of Fundy	44.9575370	-66.9239010	10
June 15, 2020	Mohawk Island	Bay of Fundy	45.0418280	-66.9055110	48
June 15, 2020	Point Lepreu	Bay of Fundy	45.0567570	-66.4580240	3
June 16, 2020	Tynemouth Creek	Bay of Fundy	45.3026570	-65.6039970	2
June 16, 2020	Saint John Harbour	Bay of Fundy	45.2400630	-66.0674190	14
June 17, 2020	Cape Chignecto	Bay of Fundy	45.3316000	-64.9175210	6
June 17, 2020	Isle Haut	Bay of Fundy	45.2568750	-64.9831070	138
June 17, 2020	Annapolis, BoF	Bay of Fundy	44.7847730	-65.6123920	14
June 18, 2020	Culloden, BoF	Bay of Fundy	44.6317880	-65.8911020	12
June 18, 2020	Digby Neck	Bay of Fundy	44.4132520	-66.2027460	7
June 18, 2020	Long Island	Bay of Fundy	44.3189170	-66.2959070	13
June 18, 2020	Brier Island	Bay of Fundy	44.2084870	-66.3841770	241

June 18, 2020	Green Island	SWNS	43.6827720	-66.1454340	11
June 18, 2020	Gannet Rock	SWNS	43.6345370	-66.1442140	3
June 20, 2020	Limbs Limb, Seal Island	SWNS	43.4113300	-66.0426340	40
June 20, 2020	Mother Owens Rocks	SWNS	43.3893450	-66.0050110	67
June 20, 2020	Mud Island	SWNS	43.4709020	-65.9941970	42
June 20, 2020	Round Island	SWNS	43.5049680	-65.9770960	1
June 20, 2020	Gooseberry Island	SWNS	43.6866050	-65.9435190	4
June 20, 2020	Outer Sheep Island	SWNS	43.7145950	-65.9011260	2
June 20, 2020	Étoile Island	SWNS	43.70866	-65.894702	2
June 20, 2020	Ile Ferre	SWNS	43.644653	-65.790672	2
June 25, 2020	Thrum Cap	SWNS	43.554623	-65.582396	18
June 25, 2020	Baccaro	SWNS	43.456888	-65.437972	69
June 25, 2020	Taylors Rocks	SWNS	43.463982	-65.451254	71
June 25, 2020	Johns Island Rock	SWNS	43.505023	-65.440104	1
June 25, 2020	Ram Island	SWNS	43.517452	-65.428434	18
June 25, 2020	Wine Ledge	SWNS	43.489967	-65.382007	71
June 25, 2020	The Old Hen	SWNS	43.49438	-65.388311	21
June 25, 2020	Big Island	SWNS	43.578383	-65.437447	3
June 25, 2020	Round Island	SWNS	43.58042	-65.431732	2
June 25, 2020	North East Harbour	SWNS	43.544272	-65.382226	27
June 25, 2020	Grey Rocks	SWNS	43.523935	-65.337786	45
June 25, 2020	Gull Rock	SWNS	43.572497	-65.322166	2

June 25, 2020	Stephens Island	SWNS	43.72929	-65.150624	3
June 25, 2020	Black Point Ledges	SWNS	43.682383	-65.068827	12
June 25, 2020	Ram Island	SWNS	43.677802	-65.028177	159
June 25, 2020	Green Rock	SWNS	43.75798	-64.944131	1
June 19, 2020	Three Fathom Harbour	Eastern Shore	44.6285230	-63.2649520	9
June 19, 2020	Jeddore	Eastern Shore	44.6867020	-62.9628220	207
June 19, 2020	Black Rock	Eastern Shore	44.7061830	-62.8874660	1
June 19, 2020	Ship Ledges	Eastern Shore	44.6601820	-62.8573390	46
June 19, 2020	Duck Island Ledges	Eastern Shore	44.7025320	-62.9419270	7
June 19, 2020	Gunning Rock	Eastern Shore	44.7117150	-62.7404470	17
June 19, 2020	Charles Ledges	Eastern Shore	44.7398420	-62.7012170	32
July 2, 2020	Bald Harbour Islands	Eastern Shore	44.867945	-62.347972	3
July 2, 2020	Inner Baltee Island	Eastern Shore	44.779975	-62.706601	1
July 2, 2020	Phoenix Island	Eastern Shore	44.798687	-62.618951	5
July 2, 2020	South Mud Hole	Eastern Shore	44.834858	-62.545907	2
July 2, 2020	Horse Island	Eastern Shore	44.847152	-62.518321	3
July 2, 2020	Pumpkin Island	Eastern Shore	44.81699	-62.377966	19
July 2, 2020	Horse Island Ledge	Eastern Shore	44.835193	-62.347261	52
July 3, 2020	Long Island	Eastern Shore	44.889357	-62.302897	2
July 3, 2020	Middle Halibut Island	Eastern Shore	44.896687	-62.207264	3
July 3, 2020	Little Goose Island	Eastern Shore	44.924852	-62.171834	1
July 3, 2020	Ragged Islands	Eastern Shore	44.925328	-62.143554	1

July 3, 2020	East Black Ledge	Eastern Shore	44.904513	-62.063987	2
July 3, 2020	The Nightcap	Eastern Shore	44.919233	-62.028736	2
July 3, 2020	Seal Ledges	Eastern Shore	44.942143	-61.995726	6
July 3, 2020	Crook Shoals	Eastern Shore	44.982792	-61.914429	15
July 3, 2020	Wedge Island	Eastern Shore	45.010007	-61.877437	2
July 3, 2020	Holland Harbour, offshore	Eastern Shore	45.056108	-61.656676	32
July 4, 2020	Black Ledge	Eastern Shore	45.101198	-61.624302	86
July 4, 2020	Inside Annies Shoal	Eastern Shore	45.12925	-61.560527	2
July 4, 2020	Shag Rock	Eastern Shore	45.16845	-61.353027	14
July 4, 2020	Berry Head Lighthouse	Eastern Shore	45.190597	-61.308226	95
July 4, 2020	Topstone Ledge	Eastern Shore	45.214213	-61.282244	2
July 4, 2020	Net Ledge	Eastern Shore	45.209543	-61.255462	30
July 4, 2020	Outer Gull Ledge	Eastern Shore	45.205268	-61.176584	11
July 4, 2020	Shag Ledge	Eastern Shore	45.196953	-61.153176	120
July 4, 2020	White Point Ledges	Eastern Shore	45.247798	-60.981957	3
July 4, 2020	Thrumcap Island	Eastern Shore	45.264527	-60.978747	403
July 4, 2020	Black Rocks	Eastern Shore	45.314968	-60.941792	159
July 4, 2020	Park Ledge	Eastern Shore	45.345543	-60.929411	36
July 5, 2020	Little Port L'Hebert	SWNS	43.760625	-64.945052	108
July 5, 2020	Lesser Hope Rock	SWNS	43.7924	-64.880004	6
July 5, 2020	St. Catherines	SWNS	43.84085	-64.864247	1
July 5, 2020	Little Hope Island	SWNS	43.811177	-64.790551	87

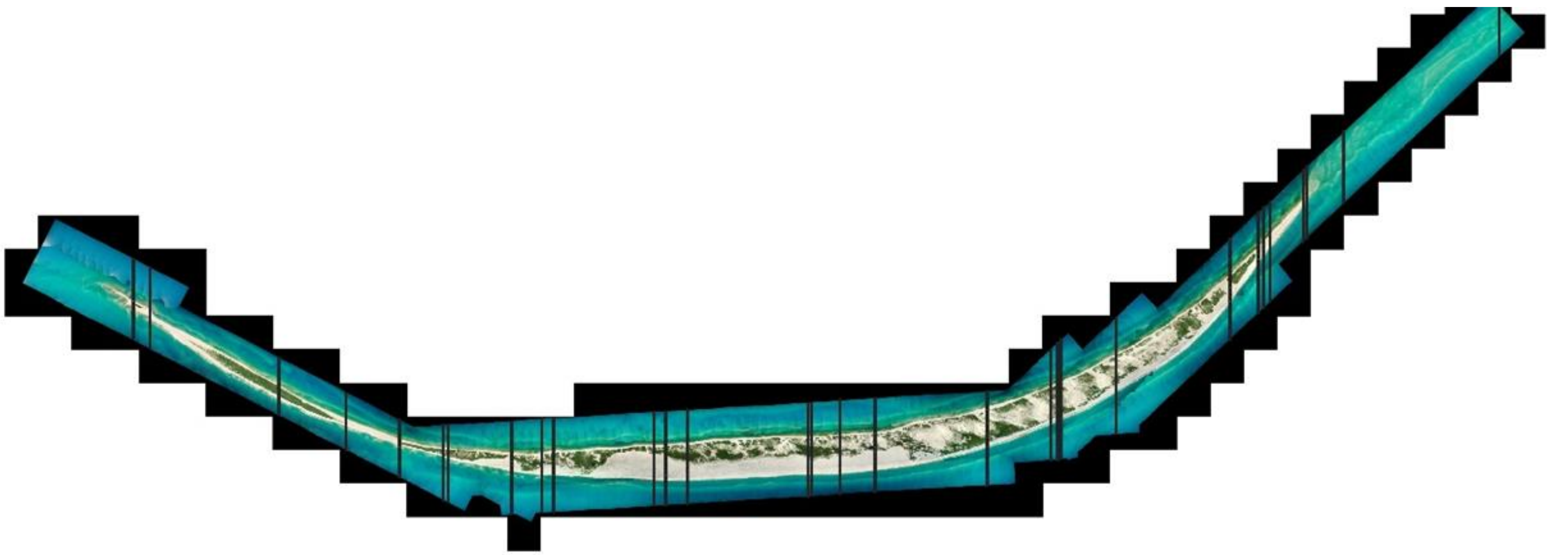
July 5, 2020	MacLeods Cove	SWNS	43.837012	-64.831184	37
July 5, 2020	Moose Rock	SWNS	43.846225	-64.806374	37
July 5, 2020	Jackies island	SWNS	43.902265	-64.781626	3
July 5, 2020	Big Ledges	SWNS	43.907477	-64.805449	16
July 5, 2020	Charley Island	SWNS	43.924027	-64.840896	11
July 5, 2020	Coffin Island	SWNS	44.043477	-64.635724	2
July 5, 2020	Toby Island	SWNS	44.11345	-64.529289	83
July 5, 2020	Northwest Bay	SWNS	44.154657	-64.589552	2
July 5, 2020	Apple Cove	SWNS	44.154183	-64.477937	1
July 5, 2020	Green Bay	SWNS	44.200363	-64.434737	6
July 5, 2020	John Islands Ledge	SWNS	43.512543	-65.803261	10
July 5, 2020	Goodwins Island	SWNS	43.504863	-65.779454	4
July 5, 2020	The Ball	SWNS	43.50454	-65.768897	2
July 5, 2020	Sunken Ledge	SWNS	43.504908	-65.755142	3
July 5, 2020	Goodwins Island	SWNS	43.502785	-65.780866	2
July 5, 2020	Duck Island	SWNS	43.472255	-65.769279	13
July 5, 2020	Outer Island	SWNS	43.462057	-65.753976	1
July 5, 2020	Green Ledge	SWNS	43.483863	-65.696572	5
July 5, 2020	Shag Harbour	SWNS	43.48796	-65.683084	6
July 5, 2020	Sloop Rock	SWNS	43.473462	-65.662189	2
July 5, 2020	Green Island	SWNS	43.417827	-65.672017	2
July 5, 2020	Cape Sable Island	SWNS	43.397743	-65.627216	2

July 5, 2020	Black Rock	SWNS	43.392265	-65.607459	1
July 7, 2020	Black Rock, La Have	SWNS	44.175925	-64.327771	7
July 7, 2020	Moshers Island	SWNS	44.230478	-64.342087	2
July 7, 2020	Rabbit Island	SWNS	44.240647	-64.378312	36
July 7, 2020	Coveys Island	SWNS	44.250873	-64.369966	2
July 7, 2020	Hounds Ledges	SWNS	44.321408	-64.187961	41
July 7, 2020	Twin Rocks	SWNS	44.406545	-64.220857	41
July 7, 2020	Pearl Island	SWNS	44.382945	-64.045824	21
July 7, 2020	Little Rafuse Island	SWNS	44.46424	-64.245667	2
July 7, 2020	Seal Ledge, New Harbour	SWNS	44.46842	-64.057117	1
July 7, 2020	Dry Rock, Aspotogan	SWNS	44.508813	-64.019684	6
July 7, 2020	Owls Head	SWNS	44.506205	-63.998519	25
July 14, 2020	Bakers Island	SWNS	44.495082	-63.867496	1
July 14, 2020	Turf Island	SWNS	44.529172	-63.800476	1
July 14, 2020	Gull Rock, Sambro	SWNS	44.433725	-63.560536	9
June 26, 2020	Red Island	Bras D'Or Lake	45.807168	-60.765566	4
June 26, 2020	Janvrin Island	Cape Breton	45.516138	-61.181599	1
June 26, 2020	Crichton Island	Cape Breton	45.506188	-61.107197	8
June 26, 2020	Pondville	Cape Breton	45.521345	-60.991091	13
July 8, 2020	Spectacle Island	Bras D'Or Lake	46.07914	60.7349	5
July 8, 2020	Cape Dauphin	Cape Breton	46.388135	-60.372829	79
July 16, 2020	Les Rochers	Cape Breton	45.534335	-60.964962	9

July 16, 2020	Michaud Ledges	Cape Breton	45.563305	-60.728931	5
July 16, 2020	Basque Islands	Cape Breton	45.573895	-60.661137	1
July 16, 2020	Shag Ledge	Cape Breton	45.595245	-60.647442	12
July 16, 2020	L'Archeveque Cove	Cape Breton	45.618398	-60.576411	1
July 16, 2020	Flukes Head Cove	Cape Breton	45.997725	-59.765122	9
July 16, 2020	Hay Islands	Cape Breton	46.037097	-59.683454	90
July 16, 2020	Kennington Rocks	Cape Breton	45.868408	-60.057557	1

C1: AERIAL PHOTOGRAPHIC SURVEY IMAGES INDICATING THE LOCATIONS (BLACK LINES) OF THE 30 RANDOMLY SELECTED TRANSECTS USED FOR VALIDATION COUNTS

The aerial photographic survey was completed by Leading Edge Geomatics (New Brunswick) on behalf of the Parks Canada Agency (Eamer et al., 2022).



C2: INITIAL, VALIDATION AND CONSENSUS COUNTS FOR ASSESSING THE ACCURACY OF GREY SEAL COUNTS OBTAINED FROM LIDAR AERIAL IMAGERY

To evaluate the accuracy of grey seal counts obtained from the aerial imagery, 30 randomly selected vertical transects were defined across the island (see Appendix C1). An initial count of grey seals within the 30 transects was carried out by the counter who conducted the count of grey seals from the complete series of aerial images. Subsequently, to validate the initial count, two other counters conducted a count across the same transects. Among the three readers, a reference consensus pup counts was generated. The per cent difference between the total consensus (1821) and the total initial (1836) count was used to adjust the all-island pup count.

Validation Transect	Counts	
	Initial	Consensus
1	60	59
2	116	117
3	1	1
4	33	33
5	61	59
6	2	1
7	12	11
8	32	32
9	4	4
10	4	4
11	19	19
12	16	16

13	18	18
14	4	4
15	5	4
16	55	50
17	3	1
18	22	22
19	14	14
20	10	10
21	8	8
22	99	97
23	2	2
24	23	23
25	3	3
26	7	7
27	435	435
28	88	87
29	487	487
30	193	193
Total	**1836**	**1821**

C3: ZOONIVERSE SEAL COUNT DATA SUMMARY

Zooniverse (https://www.zooniverse.org/) is an online platform for employing volunteers to assist with research projects through data processing and sharing ideas. Here we used Zooniverse to count the number of seals on Sable Island through viewing a series of digital images collected during the 2019 Sable Island LiDAR Survey (Eamer et al., 2022). The orthomosaic was broken into non-overlapping images (n = 1,012) to be counted by volunteers. Volunteers, herein referred to as citizen scientists, were asked to count seals hauled out or in the water by following basic instruction: "Click on each seal you see in the photo with the marker tool. The seal can be on land, in the water, or under the water. If the seal is cutoff at the image edge, mark it if it is on the upper or right-hand side, otherwise ignore it." The expectation was that every image would be counted by multiple citizen scientists. An image was scheduled to be retired once 25 counts had been achieved.

Between 6 February and 30 March 2021, 510 citizen scientists participated in the project and recorded 23,655 counts (Fig. C3i). Most people counted multiple images (median = 8, max = 961) and all images were counted 10 or more times (median = 23, max = 54). There were several peaks in counting during the study period, likely due to the involvement of school classes of children and young adults (Fig. C3i).

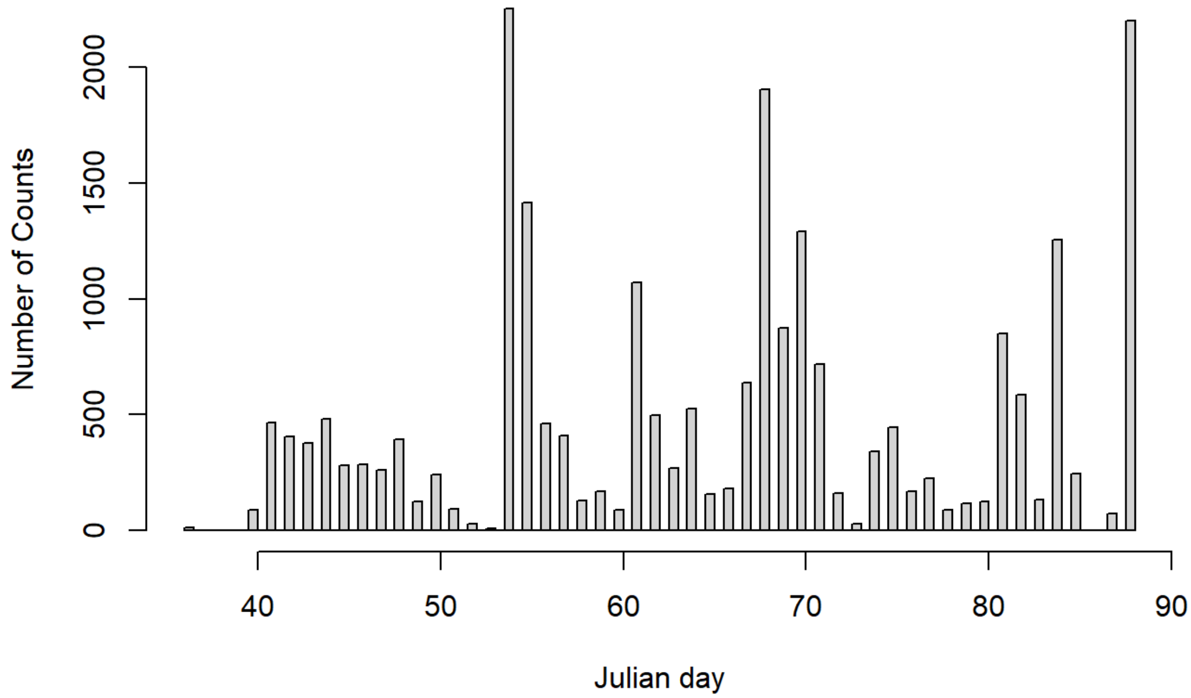


Figure C3i. Number of counts of images from the 2019 Sable Island LiDAR survey completed by citizen scientists on the Zooniverse platform between 6 February and 30 March 2021.

There were some issues with the citizen scientist counts. First, a small number of citizen scientists counted the same image more than once and some did not have the same count each time. For each image counted more than once by the same citizen scientist, we retained the maximum count for that image by that citizen scientist (2,541 counts were discarded). Second, a review of the frequency distribution of counts for an image found that there were more zero counts than one would expect. This pattern was likely caused, in part, by a few inexperienced citizen scientists providing high counts when in fact there were no seals on the image by mis-identifying birds as seals. There may also have been some underestimating of the number of seals in the water or underwater. It is also possible that some citizen scientist may have been overwhelmed with the number of seals in a particular image and decided not to count that image. Crowdsourcing projects may also be subject to bad actors (Marcus et al., 2012), although this is less likely in volunteer situations where there is no reward for participants. Work to better understand the unexpectedly high number of low and zero counts is ongoing.

After dropping the repeat counts by a citizen scientist there were 21,114 counts of seals on 1,012 images. The median number of images that were counted by the citizen scientist was 8 (max = 917) and the median number of counts for each image was 21 (max = 39), with all images counted 10 or more times (Fig. C3ii).

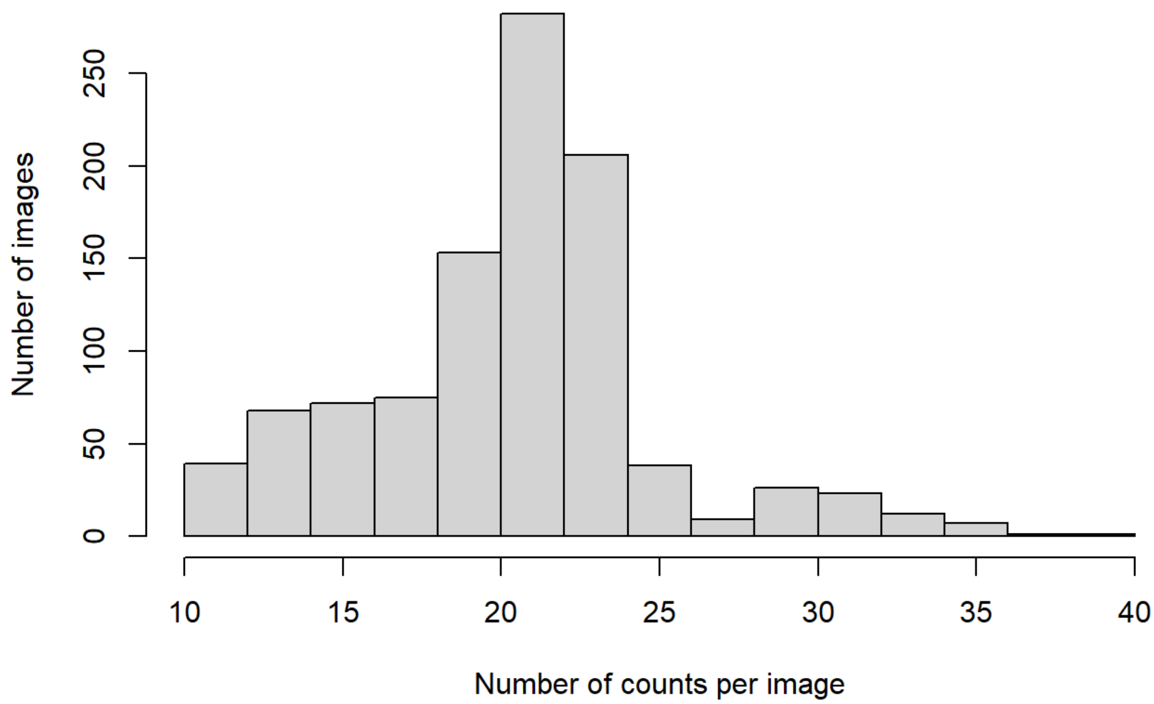


Figure C3ii. The number of images from the 2019 Sable Island LiDAR Survey counted by citizen scientists (n=510). All images had 10 or more counts.

To get a total count of seals on the island, the mean, median and maximum Zooniverse counts from each image were summed. We also had an experienced counter count seals from the orthomosaic in QGIS (https://www.qgis.org/). The sum of the median counts from the images is the closest estimate of the expert count, with the maximum count being an overestimate and the mean an underestimate.

Here we explored zero-truncation, where all zero counts were dropped (Fig. C3iii; Table C3i). Other methods of filtering high and low counts have been used in the literature (Wood et al., 2021) but here the filter application is arbitrary. As there were many images where all counts were zero this resulted in a reduced number of images with counts, but the images that were dropped did not contribute to the total number of seals. Both the mean and median counts from the zero-truncated data was closer to the expert count than using all the counts.

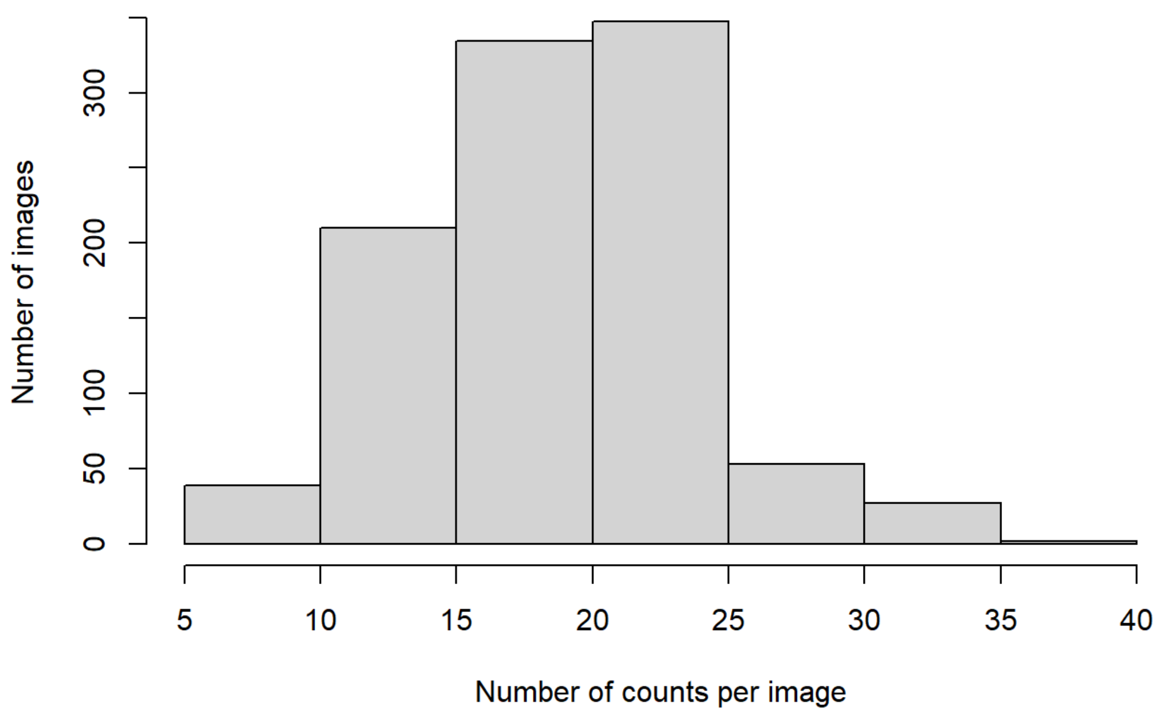


Figure C3iii. The number of images form digital aerial imagery from the 2019 Sable Island LiDAR Survey with 5 or more than counts completed by citizen scientists that had counted at least five images.

Table C3i. Estimated number of seals from the citizen scientist counts of the digital aerial imagery from the 2019 Sable Island LiDAR Survey. The number of counts of images (N counts) is reported for all counts, and for all non-zero counts (Zero-truncated counts). The totals from the mean, median and max count per image can be compared to the expert count from the orthomosaic that was used to produce the images counted on the Zooniverse platform.

Data	N counts	Mean Total	Median Total	Max Total
All counts	21114	16348.6	19595	26728
Zero-truncated counts	17771	20236.9	22121.5	26728
Expert count		21818		

Crowdsourcing has been used to evaluate large volumes of high resolution imagery on several platforms. There is a general consensus that investment in training is essential for successful crowdsourcing, particularly when there are multiple species involved (Swanson et al., 2016; Wood et al., 2021). Here, we believe there may have been overcounts with the misidentification of birds as seals or counting of dead seals, and undercounts of seals in the water that were assumed to be birds, seaweed, or other species. To alleviate these issues in the future, and reduce the number of false positives and negatives, examples of birds and dead seals should be provided. A scale or measuring tool would also be helpful to identify objects. Although no experience was required to join this Zooniverse project, in the future requesting users with some expertise in image recognition and motivation to contribute to the estimate of seals on Sable Island might be helpful. Further, providing several images with a known count of seals from different parts of the island (e.g. beach only, beach and water, water only) would be useful for training. At this time, because of the accessibility of an experienced counter to provide counts from all of the images, we have opted to use the experienced reader count rather than that acquired through the Zooniverse platform. If there was a larger number of images to process, either because of acquiring images from multiple surveys or from a larger survey area, the investment in crowdsource or machine learning methods to count the images might be a time efficient method to get counts.

As a public engagement tool, 'Sable Island National Parks Reserve grey seal count on Zooniverse' was highly successful. Sable Island is a remote and difficult to access National Park Reserve (NPR) and holds a strong interest by the public and schools in Nova Scotia and adjacent Provinces. The number of citizen scientists that participated provided a virtual experience of the island to roughly the same number of tourists that visit the island each year. Projects on platforms such as this have the potential to process large volumes of high resolution imagery and improve our understanding of the ecology of the Sable Island NPR.

D1: COUNTS OF HARBOUR SEALS IN NOVA SCOTIA AND NEW BRUNSWICK FROM PREVIOUS SURVEYS, 1973 TO 1998.

Data collected in 1973 were from questionnaires, interviews and bounty kills, between 1984 and 1992 counts were recorded during aerial surveys and in 1998 counts were recorded during aerial and ship surveys

Year	1973	1984	1985	1986	1987					1991	1992	1998	
Month	-	10	05	08	05	08	09	10	12	07	08	09	12
Bay of Fundy (NB)[7]	778[2]	979[3]			439[1,4]	709[1,4]	934[1,4]	768[1,4]	404[4]			1032[6]	254[6]
Bay of Fundy[8]			639[5]	1428[5]		776[5]				2254[5]	2918[5]		
SWNS[9]	1366[2]		92[5]	147[5]		146[5]				227[5]	516[5]		
Eastern Shore	1573[2]												
Cape Breton	995[2]												

[1]Mean of a bi-monthly count

[2]Boulva and McLaren (1979), [3](Terhune (1985), [4]Colbourne and Terhune (1991), [5]Stobo and Fowler (1994), [6]Jacobs and Terhune (2000)

[7]Survey extended from Saint John to Campobello Island and excluded offshore islands including Grand Manan and the Wolf Islands; [8]Survey extended from Campobello to Brier Islands, [9]Survey extended from St Mary's Bay to Cape Sable Island

D2: COUNTS OF HARBOUR SEALS ON SABLE ISLAND, NOVA SCOTIA, 1970 TO 2002

All counts are land-based. [1] (Boulva, 1971), [2] Counts 1971 - 1973, Boulva and McLaren (1979), [3]Counts 1980 - 1997, Lucas and Stobo (2000); [4]Counts 1998 – 2002, Bowen et al. (2003)

Year	Adults	Pups
1970[1]	1223	262
1971[2]	1329	331
1972	1147	359
1973	1302	334
1980[3]	-	333
1981	-	391
1982	-	403
1983	-	482
1984	-	487
1985	-	526
1986	-	531
1987	-	577
1988	-	585
1989	-	625
1990	-	591
1991	-	570
1992	-	470
1993	-	380
1994	-	270
1995	-	180
1996	-	91
1997	-	40
1998[4]	-	23
1999	-	
2000	-	29
2001	-	12
2002	-	8