

A History of Monitoring Marine Birds at Sea in Eastern and Arctic Canada

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Abstract

Systematic surveys of marine birds from ships were first conducted by the Canadian Wildlife Service (CWS) in Atlantic Canada in 1965, and then expanded to the Canadian Arctic in 1969 under PIROP (Programme intégré de recherches sur les oiseaux pélagiques). PIROP surveys ended in 1992, then resumed in 2006 under the Eastern Canada Seabirds at Sea (ECSAS) program with an updated survey protocol. Surveys under both monitoring programs were conducted from a variety of ship types engaged in scientific, transport, and supply activities, totalling over 120,000 km within sub-Arctic and Arctic Canada waters and over a million marine birds observed, primarily northern fulmar (*Fulmarus glacialis*), black-legged kittiwake (*Rissa tridactyla*), thick-billed murre (*Uria lomvia*), and dovekie (*Alle alle*). The data collected inform offshore ecological inquiries, environmental impact reviews, mortality estimates from accidental oil releases, and define areas in need of protection. Although surveys were designed to quantify seabird distribution within the waters of eastern Canada, the data also include sightings of non-avian taxa that are made publicly available. Long-term and large-scale monitoring programs will remain essential for assessing the status and health of Canada's marine birds, including surveys that take place at sea where these species spend most of their time.

Key words: seabird, ships-of-opportunity, surveys at sea, marine mammal

Introduction

For much of their lives, seabirds live beyond their colonies, adapted for life in the marine environment. Although monitoring seabirds at their colonies plays a crucial role in understanding population trends and the surrounding ecosystem health (Gaston et al. 2009; Wilhelm et al. 2015), surveys at sea identify important foraging areas in need of protection (Smith et al. 2014; Zipkin et al. 2015), areas of high marine productivity for multiple species (Yurkowski et al. 2019), and areas where the birds may be vulnerable to hazards from human activities (e.g., Hedd et al. 2011; Lieske et al. 2020). Seabirds are considered sentinels of ecosystem health (Piatt et al. 2007; Moore and Kuletz 2019) whereby changes in distribution, abundance, and diversity at sea may be linked to major ecosystem perturbations (Romano et al. 2020; Kuletz et al. 2024). As such, seabird surveys are often included in long-term ecosystem monitoring programs (Ballance 2007, Ainley et al. 2012; Kuletz et al. 2019; Mueter et al. 2021; Kuletz et al. 2024). In Canada, ship-based surveys that quantify abundance and distribution of birds have been led primarily by the Canadian Wildlife Service (CWS) and form the basis of what we know of seabird marine habitat use in Canada (Brown 1986; Morgan et al. 1991; Bolduc et al. 2016). The data have been supplemented in some nearshore areas by aerial surveys (Prach and Smith 1985; Fifield et al. 2016; Wong et al. 2018b), and more recently by data collected from miniaturized instruments attached to individual birds from a selection of colonies (e.g., Frederiksen et al. 2016; Lavoie et al. 2022; Ronconi et al. 2022; d'Entremont et al. 2023). Collectively, these various data sources inform conservation and management of marine birds in Canada and provide the baseline against which future changes can be measured.

Canada's Arctic and sub-Arctic waters support over ten million breeding seabirds, in addition to nonbreeding individuals and migrants that also number in the tens of millions (Mallory and

Fontaine 2004; Gaston et al. 2012; Fort et al. 2013), that include globally significant numbers of some species (Gaston et al. 2012; Maftei et al. 2012; Spencer et al. 2015; Wilhelm et al. 2015; Hedd et al. 2018). In this paper, we describe two long-term (> 10 years) monitoring programs for birds at sea in eastern and Arctic Canada, conducted from mobile monitoring stations (i.e., vessels) where CWS has led seabird surveys for almost 60 years. This is a relatively shallow, continental-shelf-dominated area, parts of which are ice-covered during much of the year (Michel et al. 2015), and encompasses most of the Canadian Arctic Archipelago, including the waters of Hudson Bay and the Canadian territorial waters of Baffin Bay (Fig. 1). Specifically, we examine the history of the long-term at-sea monitoring programs and survey methods, summarize the main findings and their significance for conservation and policy, and discuss the importance of continued monitoring in an era of disappearing ice cover and increased human activities (Pizzolato et al. 2016).

Early history of at-sea surveys in eastern Canada

In 1969, R.G.B. Brown (CWS) with P. Germain (l'Université de Moncton) initiated PIROP (Programme intégré de recherches sur les oiseaux pélagiques), which is considered one of the first programs to systematically study the distributions of birds at sea, based on a standardized counting technique and a computer database. It was recognized at the time that information on the distribution and numbers of seabirds in eastern Canada was needed for environmental impact assessments of an emerging oil and gas industry, and to "... provide a basis for further research into the neglected field of pelagic ornithology..." (Brown et al. 1975). PIROP surveys (Fig. 2A) started in Atlantic Canada in 1965 (preceding the formalization of the program in

1969), and within five years had expanded to include the Gulf of St. Lawrence, eastern Canadian Arctic as high as 77°N, multiple trans-Atlantic voyages (Hyrenbach et al. 2012), and in 1970, were conducted during the first circumnavigation of the Americas (Wadhams 2009). In the Pacific Ocean, the PIROP methods were followed by CWS during pelagic bird surveys off the coast of British Columbia that began in 1981 (Morgan et al. 1991). In eastern Canada, PIROP surveys were conducted from ships engaged in a variety of scientific, transport, and supply activities (also known as ships-of-opportunity), primarily based out of the Bedford Institute of Oceanography in Nova Scotia (NS), Canada. Most of the early data were collected by CWS, but a significant number of surveys were also done by consulting companies working for the oil industry (Brown 1986). Data collection under PIROP continued until 1992 when R.G.B. Brown retired from CWS, although the bulk of the data were collected during the 1970s (Fig. 2A).

By the 1990s, PIROP survey data covered much of the waters of eastern Canada (Fig. 2A) and were relied upon for defining seabird vulnerability to oil spills and other environmental emergencies involving marine pollutants (Lock et al. 1994), as well as risks to seabirds from hydrocarbon exploration activities that peaked offshore of Atlantic Canada in the 1970s. However, as offshore oil and gas production activities expanded through the 2000s, and marine ecosystems were undergoing significant changes (Nagelkerken and Connell 2015), CWS could no longer reliably use PIROP data to represent current seabird distributions to assess and mitigate risks to this growing offshore industry (e.g., Burke et al. 2012). In addition, chronic oil pollution from ships travelling through Canadian waters, particularly in Newfoundland and Labrador, was killing hundreds of thousands of seabirds every year (Wiese and Ryan 2003). As a result, the Government of Canada increased surveillance to monitor oil pollution, introduced

105 legislation to better enforce marine pollution regulations, and in 2005, increased capacity at
106 CWS and revitalized the pelagic seabird monitoring program using survey methods
107 standardized with those used by the European Seabirds at Sea (ESAS) group (Gjerdrum et al.
108 2012a).

109 CWS conducted the first surveys under the new Eastern Canada Seabirds at Sea (ECSAS)
110 program (Gjerdrum et al. 2012a) in the spring of 2006 within Atlantic Canada and the Gulf of St.
111 Lawrence. Support from the Environmental Studies Research Funds (ESRF;
112 <https://www.esrfunds.org/>) added significant survey effort from 2006-2009 to specifically
113 assess seabird abundance and distribution on the northern Grand Bank (Fig. 1) and other areas
114 of oil industry activity in eastern Canada, including the Labrador Shelf (Fifield et al. 2009b). In
115 2007, CWS in collaboration with the US Fish and Wildlife Service (USFWS) – Alaska Region,
116 initiated seabird surveys through the Northwest Passage, between the Pacific and Atlantic
117 Oceans, as part of “Canada’s Three Oceans” (C3O) project (Carmack et al. 2008), a contribution
118 to International Polar Year (IPY) that continued through 2012 (Wong et al. 2014). The ECSAS
119 monitoring program relied primarily on oceanographic research vessels and collaborations that
120 integrated multidisciplinary observational programs (i.e., Davis Strait Arctic Gateway Observing
121 System, University of Washington, WA; Atlantic Zone Monitoring Program, Department of
122 Fisheries and Oceans, Canada; and Amundsen Science, Université Laval, QC. However,
123 beginning in 2008, a significant number of ECSAS surveys were also conducted from cruise and
124 expedition-style passenger ships in coastal areas of the Arctic through collaborations with
125 Acadia University (NS), Adventure Canada (Scientist-in-Residence program), and Students on Ice
126 expeditions. The ECSAS surveys are ongoing, and although focused in western North Atlantic

and eastern Arctic waters, some effort extends east across the North Atlantic, south into US waters, as well as into the western Canadian Arctic and Pacific Oceans (Fig. 2B).

Aerial surveys of seabirds in coastal areas (Prach and Smith 1985; Fifield et al. 2016) and platform-based stationary surveys in oil production areas in Atlantic Canada (Baillie et al. 2005) have been used to supplement boat-based information, but to-date have not been part of any systematic, long-term (> 10 years) monitoring program and are thus not included in this summary. Similarly, we do not include aerial survey data nor opportunistic seabird surveys that have taken place in western Arctic waters (e.g., Searing et al. 1975), nor do we include industry-led survey data collected in support of regional scale environmental assessments. Seabird survey data from long-term monitoring in Alaska waters (Renner et al. 2013; Kuletz et al. 2019; Kuletz et al. 2020) are also not included as these surveys took place outside of Canadian jurisdiction (although survey data collected within our study area, in eastern Arctic waters, in collaboration with USFWS – Alaska Region, are included). Pelagic seabird surveys led by CWS in Pacific waters (Morgan et al. 1991) are also outside the geographic scope of this paper. These data, however, are publicly available from the North Pacific Pelagic Seabird Database (Drew et al. 2005).

Development of the monitoring programs

Survey methods

Early PIROP surveys (1965-1984) were aboard ships-of-opportunity (Table 1) and used 10-min observation periods (i.e., watches) during which all birds observed were recorded,

149 regardless of their distance from the vessel. Following a review of survey methods by Tasker et
150 al. (1984), PIROP surveys after 1984 recorded birds observed within a 300 m strip transect to
151 allow the estimation of densities (i.e., number of birds per km²), although the new protocol did
152 not adopt the recommended snapshot approach for flying birds (Tasker et al. 1984, Gaston et
153 al. 1987). At the beginning of each 10-min watch, observers recorded the ship's position, speed,
154 and direction, and various characteristics of the survey conditions (e.g., visibility, weather, sea
155 state). The bird-related data included, species, number, age, plumage, moult, sex, behaviour,
156 and any biotic or abiotic associations (Brown 1971).

157 ECSAS surveys (2006-present; Fig. 2B) have also been conducted from ships-of-
158 opportunity, primarily those with regular routes and/or oceanographic sampling stations. In
159 general, the survey protocol (Gjerdrum et al. 2012a) was modelled after Tasker et al. (1984)
160 with a 300 m wide transect to one side of the vessel and a 90° scan angle. All birds on the water
161 within the transect are recorded. Birds typically fly faster than the ship and therefore, during an
162 observation period, more birds will fly through the survey area than are present at any one
163 instant of time (Tasker et al. 1984). To avoid overestimating abundance of flying birds, ECSAS
164 surveys record flying birds within transect and 300 m forward of the vessel during
165 instantaneous counts (i.e., snapshots), the frequency of which is determined by the speed of
166 the vessel. Distance sampling techniques are used to account for varying seabird detectability
167 (Buckland et al. 2001). At the beginning of each observation period (10-min duration from
168 March 2006 to June 2007, and 5-min thereafter), observers record the ship's position, speed,
169 and direction, in addition to a number of environmental conditions (e.g., visibility, sea state,
170 swell height, wind speed; Gjerdrum et al. 2012a). Each sighting is identified to species (where

possible or else to lowest taxonomic group), and flock size and behaviour (e.g., flying, swimming, feeding) are noted. The perpendicular distance of the sighting from the trackline is also recorded in one of four distance bins (with limits 50, 100, 200, and 300 m). If fog or rain limit the visibility of the survey area, those conditions are noted and the transect width is adjusted accordingly. Surveys from late-2008 to 2011 recorded the radial distance to birds in flight (i.e., point-transect method) in the same four distance bins but reverted back to perpendicular distances when a comparison of methods showed the line-transect method provided superior results (Bolduc and Fifield 2017). Notes on species' associations (e.g., birds associated with other marine species, marine debris, oil slicks, fishing vessels, etc.), flight direction, age, plumage, and sex are also recorded when possible (Gjerdrum et al. 2012a). Birds observed outside the transect are also recorded if this does not affect observations within the transect.

Data entry, storage and accessibility

PIROP survey data were initially transcribed into notebooks or log sheets in the field, then numerically coded and punched into standard 80-column computer cards (Brown et al. 1975) from which they could be analysed and mapped using specialized FORTRAN routines (Lock et al. 1997). In 1997, CWS built the PIROP relational database (FoxPro v. 2.6) designed to store and analyze the PIROP data (Huettmann and Lock 1997; Lock et al. 1997), which was then extended to include seabird survey data collected from the Gulf of Maine by Manomet Bird Observatory (Powers et al. 1979).

In 2006, CWS constructed the ECSAS relational database (Microsoft Access) to store the at-sea data collected under the new ECSAS protocol, but also to archive the older PIROP data, resulting in one database for all at-sea survey data collected in eastern Canada (Fifield et al. 2009b). Early ECSAS surveys (2006) used datasheets for recording data, then later (2007-2009) adopted a voice recognition facility (Dragon, Nuance Communications Inc.) to allow observers to dictate their sightings directly into the database (Fifield et al. 2009b; Robertson et al. 2012), with the ship's position, speed and heading recorded via an integrated GPS. From 2007-2009, this system recorded the ship's position at the beginning and end of each watch, and thereafter also recorded the ship's position at each sighting. This data entry system allows observers to focus on the bird sightings, and greatly reduces post-processing time and transcription errors (Robertson et al. 2012). To ensure proficiency and consistency among observers, CWS also developed an observer training program that is delivered periodically when there is a need for additional observers (Gjerdrum et al. 2012b). In 2022, the ECSAS database was expanded to include aerial survey data collected in Atlantic Canada, including the Labrador Shelf (e.g., Fifield et al. 2016).

Seabird sightings from both the PIROP and ECSAS databases are publicly available for download from OBIS-Seamap (<https://obis.org>), as are marine mammal sightings collected incidentally during the seabird surveys. ECSAS sightings are also available through the BioTIME database (<https://biotime.st-andrews.ac.uk>), recently updated to include ECSAS sightings from 2006-2020. In addition, the Atlas of Seabirds at Sea in Eastern Canada is available from the Government of Canada open data web site (Bolduc et al. 2016), which was also recently updated to include survey data through 2020 (<https://open.canada.ca/data>). The Atlas

represents seabird densities computed by species, group (family or subfamily), and periods of the year, and provides printable maps, web services, and downloadable data files.

Summary of at-sea survey effort within the Canadian Arctic and sub-Arctic waters

Within our defined study area, from the southern Labrador Sea at 52°N and 50°W to the western extent of Canadian Arctic waters at 141°W (Fig. 1), a total of 100 PIROP survey trips were conducted between 1969 and 1987 by 33 different observers (Table 2, Fig. 2A), although R.G.B. Brown himself was responsible for 27% of the survey effort. It is unclear from the existing documentation the level of observer experience and training, although industry and volunteer observers were certainly involved in the data collection (Brown 1986; Diamond et al. 1986). However, more than half of the survey effort (51.9%) was completed by just four observers. The surveys were done from 26 different vessels and covered a total of 36,357 km, primarily (77%) from Jul through Sep (Fig. 3A). The surveys were conducted from a vast array of vessel types, including hydrographic and oceanographic research vessels (46% of the total survey effort), fishing boats (17%), cargo ships (10%), Canadian Coast Guard icebreaker and supply ships (8%), Canadian Navy ships (6%), passenger vessels and ferries (5%), offshore support vessels (4%), and cruise ships (4%) (Fig. 4A).

In comparison, under the ECSAS program, a total of 132 survey trips were conducted in the study area, between 2006 and 2023 (Fig. 2B), by 56 different observers aboard 30 different vessels (Table 2; Fig. 3B-D). Observers for ECSAS surveys first participated in a training course prior to data collection or had equivalent experience that met CWS standards (Gjerdrum et al.

2012b). Similar to PIROP, just four observers were responsible for more than half (51.6%) of the ECSAS survey effort. The total distance surveyed within the study area was 88,215 km, which was restricted to the months between Apr and Dec (Fig. 3A). The vessel types used for ECSAS surveys were less diverse than those used during PIROP surveys (Fig. 4B), primarily consisting of oceanographic research vessels (81%), followed by cruise ships (12%), fishing boats (5%), and Canadian Coast Guard icebreaker and supply ships (2%). Research vessels have been targeted for ECSAS surveys as they are led by large research institutions or governments that have the means to support a wildlife observer. In addition, their research is typically focused on collecting chemical and biological oceanographic data, and coupled with seabird surveys, provide an opportunity to explore the underlying mechanisms of observed seabird distributions (Joiris et al. 2013; Renner et al. 2013; Kuletz et al. 2019). Conversely, fishing boats have largely been avoided as a survey platform during ECSAS efforts due to their proclivity to attract seabirds (Hyrenbach 2001). The increased level of support since 2010 from cruise and expedition-style passenger ships reflects company itineraries that are seeking opportunities to support science (Mallory et al. 2021), and a general pattern of increasing cruise ship numbers in Arctic waters (Dawson et al. 2018).

In general, survey coverage is good on the Labrador Shelf, Hudson Strait, and through Lancaster Sound within both PIROP and ECSAS programs (Fig. 2), although coverage in those areas varies through the year with the bulk of effort (60.4%) occurring from Jun-Oct (Fig. 3). Survey coverage is lacking through much of Hudson Bay, Foxe Basin, and throughout the western Canadian archipelago. ECSAS surveys extended farther west than PIROP surveys (ECSAS surveys reached 140.8°W compared to PIROP at 94.9°W) and farther north (81.7°N compared

to 79.7°N; Fig. 2), perhaps as a result of increased access to these waters over time (i.e., diminished ice cover). The distribution of survey effort with respect to distance from shore is similar between the survey programs within the study area, with 23.9% (PIROP) and 30.0% (ECSAS) of the surveys occurring within 25 km of the coastline (Fig. 5).

Vertebrate Biodiversity

Over a million individual marine birds (1,030,448) were recorded during PIROP and ECSAS surveys within our study area, with records for 64 species across 9 families (Table 3). The vast majority of the birds sighted (78.2%) included the common Arctic-breeding species such as the northern fulmar (*Fulmarus glacialis*; 38.7% of the total individuals), black-legged kittiwake (*Rissa tridactyla*; 13.7%), dovekie (*Alle alle*; 13.7%), and thick-billed murre (*Uria lomvia*; 12.1%) (Table 1, 3). Individual sightings also included five species of conservation concern listed under the federal Species at Risk Act (SARA) or Canada's Committee on the Status of Endangered Wildlife in Canada (COSEWIC), including Leach's storm-petrel (*Hydrobates leucorhous*), red-necked phalarope (*Phalaropus lobatus*), ivory gull (*Pagophila eburnean*), Ross's gull (*Rhodostethia rosea*), and ancient murrelet (*Synthliboramphus antiquus*) (Table 3). Species richness was lower for PIROP compared to ECSAS surveys (47 and 59 species, respectively; Table 3), which may in part be a result of survey coverage during the latter period extending farther west where some species are restricted in their range to Western Arctic waters (n=7; Table 3).

Although we present numbers of birds sighted by species from both PIROP and ECSAS surveys separately, the numbers are not meant to be directly compared given the differences between survey methods and spatiotemporal coverage of the programs (Figs. 2, 3). However, it is notable that seabird families were observed in similar proportions across the survey periods, dominated (>95% of all birds sighted) by three families: Procellariidae, Alcidae, and Laridae (Table 3). A few differences are also worth noting. For example, almost 4000 ivory gull were observed during PIROP surveys compared to just 113 during ECSAS surveys, which is likely a reflection of the significant population declines known from colony counts conducted since the 1970s (Gilchrist and Mallory 2005; Gaston et al. 2012). Similarly, far fewer phalaropes were sighted during the more recent ECSAS surveys compared to PIROP, which again may reflect population declines that have been documented for this group during migration counts (Nisbet and Veit 2015; Wong et al. 2018b). More great (*Ardenna gravis*) and sooty shearwaters (*A. grisea*) observed from southern Labrador north to 65°N, were counted during PIROP compared to ECSAS surveys, although only the sooty shearwater is thought to be declining globally (BirdLife International 2024). It is unclear why PIROP surveys sighted no king eider (*Somateria spectabilis*) compared to ECSAS surveys that recorded over 1700 (Table 3); although PIROP surveys did not collect data as far west as ECSAS surveys, we would have expected PIROP surveys to have encountered eastern populations of king eider, particularly in migration and on non-breeding grounds that are well documented from aerial surveys (Abraham and Finney 1986). In general, new analytical techniques have improved the use of at-sea survey data to address issues with unequal survey coverage (Miller et al. 2021b; Arimitsu et al. 2023) and may eventually be used to estimate population trends for species not well-monitored at colonies.

Major scientific findings from monitoring seabirds at sea

Basic information on the ecology and pelagic distributions of seabirds of the eastern Canadian Arctic from early PIROP surveys were first published in the form of an Atlas in 1975 (Brown et al. 1975), with supplements focused on Baffin Bay and Hudson Strait (Brown 1978; 1979), followed by an update in 1986 (Brown 1986). Although descriptive, these maps were the first to summarize quantitative seabird distribution data collected at sea throughout the region and formed the basis of ecological inquiries and management initiatives for decades to come. Some of the first published descriptions of seabird communities at sea, foraging guilds, and foraging ranges came from early PIROP survey data, which recognized the importance of oceanographic and bathymetric factors that concentrate prey and drive seabird distributions (Brown 1966; 1976; 1980; 1988). Later, the data were converted to absolute densities (Diamond et al. 1986), which were used to estimate the year-round energy requirements of seabirds in eastern and Arctic Canada (Diamond et al. 1993), significantly advancing our understanding of the role seabirds play in large-scale marine ecosystems. The PIROP survey data were also used to describe moulting locations, timing and migration routes of immature birds in the western North Atlantic and Canadian Arctic, with implications for marine conservation (Huettmann and Diamond 2000). Analytical advancements led to the use of spatially-explicit predictive models to examine the environmental determinants of seabird distribution and help overcome gaps where PIROP data were limited (Huettmann and Diamond 2001; Huettmann et al. 2011).

More recently, PIROP data now form the baseline conditions against which present (i.e., ECSAS) seabird distribution and abundance can be compared, and have shown shifts in both distribution and abundance (Gjerdrum and Bolduc 2016; Gjerdrum et al. 2018). The ECSAS survey data documented for the first time the marine distribution of seabirds across the entire North American Arctic within the summer season (Wong et al. 2014), detailed the first record of red-footed booby (*Sula sula*) for Canada (Abbott and Gjerdrum 2015), identified areas with significant concentrations of birds in need of protection (Guse et al. 2013; Allard et al. 2014; Wakefield et al. 2021), highlighted areas where risks to marine birds from human activities are considered high (Hedd et al. 2011; Fifield et al. 2017b; Wong et al. 2018a; Halliday et al. 2022), and emphasized the value of seabirds in biologically diverse marine communities (Nozères et al. 2015). As sea ice extent declines, industrial and commercial developments are expected to expand as a result, leading to higher levels of vessel activity and associated threats to birds at sea, particularly in the Arctic (e.g., Dawson et al. 2018). As such, there is a need for survey data to help predict areas of overlap between seabirds and human activities (e.g., Renner and Kuletz 2015; Wong et al. 2018a) and document any impacts on the birds.

Unexpected Findings

Seasonal density surface models (DSMs) for seabirds in the sub-arctic waters of the Labrador Sea, based on the ship-based survey data, indicated millions of seabirds using the area throughout the year, but with particularly high densities in the fall (Fifield et al. 2017b). Although consistent with what is known of the migration patterns of seabirds from the

circumpolar Arctic to the North Atlantic (Gaston et al. 2012; Fort et al. 2013; Frederiksen et al. 2016), the magnitude of the population estimates derived from the models (estimated an average of over 15 million birds on the Labrador Shelf in the fall; Fifield et al. 2017b), was unexpected and underlines the need to protect this area from future developments. While the DSMs were a valuable approach to inform conservation initiatives over this large area where survey coverage was incomplete, the time and computer resources needed to execute the models, and the number of surveys needed to minimize model uncertainty, were not trivial (Fifield et al. 2017b) and not entirely expected.

Both PIROP and ECSAS surveys were designed to quantify seabird abundance and distribution within the waters of eastern Canada and address management and conservation initiatives for marine birds. However, those conducting the surveys recognized early-on the unique opportunity to collect data on other taxa, including sightings of non-marine birds (Table S1), marine mammals, pelagic fishes, and marine debris (Table S2) - data that have been shared with academics and institutions with the interest and mandate to use the information. For example, ECSAS has been an important data contributor to the Whale Sightings Database (WSDB) in the North Atlantic, and used in the development of Species at Risk (SAR) recovery documents and identification of critical habitat, protected area network design, risk assessments, oil spill response, environmental assessments, and the development of species distribution models (Fisheries and Oceans Canada 2010; Gomez-Salazar and Moors-Murphy 2014; Fisheries and Oceans Canada 2017a; Gomez et al. 2017; Kowarski et al. 2018; Lesage et al. 2018; Moors-Murphy et al. 2018; Stanistreet et al. 2021; Feyrer et al. 2024). The data collected on floating marine debris were used to quantify macro-plastic litter in marine waters

of Arctic Canada and Greenland (Mallory et al. 2021) and helped inspire a descriptive account of the devastating effects of ocean plastic on marine biodiversity (Hogan 2023). In addition, sightings of snow buntings (*Plectrophenax nivalis*) during at-sea surveys are contributing to our understanding of their migration patterns between Greenland and Labrador over the open ocean (O. Love, University of Windsor, personal communication, 2024).

Contributions from monitoring to policy or legislation

At-sea survey data from PIROP and ECSAS programs formed the core of information used for offshore environmental impact review processes, including environmental effects monitoring (Lock et al. 1994; Montevecchi et al. 1999; Fisheries and Oceans Canada 2012). These data defined offshore areas where seabirds are most at risk from oil pollution and other anthropogenic threats, such as fisheries bycatch, light pollution, and vessel traffic to inform mitigation (Lieske et al. 2014; Wong et al. 2018a; Lieske et al. 2019; Halliday et al. 2022). Importantly, both PIROP and ECSAS data have been used to refine count methods, estimate mortality, and predict the impacts of accidental oil releases on seabird populations (Wilhelm et al. 2007; Fifield et al. 2009a; Fifield et al. 2017a), and recently were used to estimate damages and inform monetary penalties (e.g., <https://www.cnlopb.ca/news/nr07052022/>). ECSAS data with bird tracking information now form the basis of site characterization studies used to evaluate the potential impacts of proposed offshore wind energy developments in Atlantic Canada, and were used to help inform wind energy developments in the northeastern US (Winship et al. 2023).

The data collected by PIROP and ECSAS surveys were critical in the identification of important marine habitat for migratory birds in eastern Canada (Allard et al. 2014) and helped define areas in need of protection as part of Canada's commitment to conserve 30% of Canada's oceans by 2030, including Ecologically and Biologically Significant Area (EBSA) designations (e.g., Fisheries and Oceans Canada 2013; Ollerhead et al. 2017; Serdynska et al. 2021). In addition, the at-sea data have contributed to efforts related to Marine Protected Area (MPA) network design and risk assessments (e.g., Fisheries and Oceans Canada 2017b; 2021), and informed SARA-listed species' status assessments and critical habitat designations (Environment Canada 2014; Spencer et al. 2015).

Importance of long-term monitoring

Ocean ecosystems are highly dynamic, shaped by physical and chemical processes that vary considerably through time (Timmermans and Marshall 2020). Climate change and pressures from human exploitation and pollution (Wassmann 2011; Halpern et al. 2015) add further variability. As conspicuous top consumers in marine food webs, seabirds have long been advocated for use as ecological indicators and sentinels of ecological change (Piatt et al. 2007; Gaston et al. 2009; Moore and Kuletz 2019) as they integrate changes in the marine environment over different temporal and spatial scales. Understanding how seabirds respond to these changes requires long-term monitoring programs, and a combination of data sets (Frederiksen et al. 2007), that can define variability outside what we would consider normal. Seabirds in eastern and Arctic Canada are often monitored at breeding colonies (see papers in

this collection), but at-sea surveys will continue to be important for highlighting conservation issues related to their marine distribution, especially for those species that travel to but do not breed in Canada, such as great and sooty shearwaters. At-sea surveys will also be important for defining habitat use by moulting birds (e.g., Huettmann and Diamond 2000) and sub-adults that may account for more than 50% of the total population (Diamond et al. 1986; Wiese et al. 2004), and for species that are not well monitored on the breeding grounds (e.g., phalaropes and dovekie) and during the months when birds are not at their colonies or nesting areas. Long-term and large-scale monitoring programs are essential for monitoring the status and health of Canada's marine birds, and to assess the state and trajectory of the ecosystems on which they rely (Sydemann et al. 2021).

Future monitoring prospects

Conducting seabird surveys at sea is a priority for CWS, especially in light of existing and emerging offshore activities that impact birds (e.g., Rooney et al. 2023). As such, we anticipate the continuation of this long-term monitoring program that now spans almost 60 years. Survey effort will target priority areas, such as those associated with offshore energy infrastructure developments, areas where conflicts between seabirds and fisheries are likely to be high, proposed areas for marine protection, and areas and times of year where existing data are lacking. Together with colony-based monitoring programs and tracking studies, the data help track the status of marine bird populations in Canada and identify threats as well as conservation priorities. International collaborations that bring data together from monitoring

programs across Baffin Bay (e.g., Aarhus University, DCE – Danish Centre for Environment and Energy) and the North Atlantic (e.g., Wakefield et al. 2021; Winship et al. 2023) will benefit species and populations that cross international boundaries.

Although CWS has led most data collection at sea from 1965 to 2024, data collected by Indigenous partners, industry, academics, students, and others will become an increasingly important component of the dataset. To that end, CWS will continue to encourage the use of the ECSAS protocol in an effort to standardize data collection methods across programs and provide training and data verification where needed. CWS will continue work with our Indigenous partners to enhance capacity for marine bird monitoring and research, and exchange information relevant for emergency preparedness, planning, and response. In addition, a less technical version of the ECSAS protocol that remains analytically compatible to the original (Gjerdrum et al. 2012a) has been developed, which should increase its accessibility to observers with less training and experience, and thus enable more casual participants (i.e., citizen scientists) to make meaningful contributions to this growing database.

Boat-based surveys in marine waters of eastern Canada have been conducted almost exclusively from ships-of-opportunity. Data collection in the future will consider designed surveys that follow a systematic grid of lines (Buckland et al. 2001) that can provide more analytically-robust estimates of population-level distributions, abundance, and habitat associations of birds offshore (Louzao et al. 2009), and fill gaps where ship coverage is poor. The advent of digital aerial survey methods (Buckland et al. 2012) and tracking technologies, with modern model-based analytical approaches that combine various datasets (Bolduc et al. 2018; Miller et al. 2021a), present new opportunities for assessing marine bird abundance and

distribution, and may ultimately replace traditional boat-based visual surveys. In such a scenario, PIROP and ECSAS survey data would serve as the baseline for the detection of future change.

Acknowledgements

We would like to thank all the observers that have spent long hours counting birds from ships in often uncomfortable conditions. In recent years, that includes significant effort from Sue Abbott, Holly Hogan, Rick Ludkin, and Jeannine Winkel. We acknowledge Regina Wells in particular for her work to enhance migratory bird monitoring and research at sea from communities in Newfoundland and Labrador. We thank Sue Abbott, Karel Allard, Andrew Boyne, Kees Camphuysen, John Chardine, Richard Elliot, Stefan Garthe, Kathy Kuletz, Fulton Lavender, Tony Lock, Bill Montevecchi, Greg Roberston, Rob Ronconi, Pierre Ryan, Dick Veit, Regina Wells, and Sabina Wilhelm for contributions to the early development and testing of the ECSAS protocol. Thank you to Ken Morgan, Kathy Kuletz, George Hunt, Michael Bentley and Eddy Carmack for supporting the first Arctic ECSAS surveys, and Garry Donaldson and a number of Acadia University students for continuing that survey effort with support from Adventure Canada and Students On Ice expedition vessels. We also thank all the science staff, ships' officers and personnel for support at sea, especially those with Canada's Department of Fisheries and Oceans, the Canadian Coast Guard, Amundsen Science, and Craig Lee at the University of Washington. We acknowledge the financial support of Environment and Climate Change Canada, the Environmental Studies Research Funds (2006-2009 and 2013-2014), and

grants US NSF 1022472 and 1902595 for support during surveys in Davis Strait and Baffin Bay. Finally, thanks to Dick Brown for his foundational studies on the marine ecology and distribution of seabirds in eastern Canada that inform our work today. We thank two anonymous referees for suggestions provided on the manuscript.

Article Information

History dates

Received:

Notes

This paper is part of a collection entitled “Long-term vertebrate research and monitoring sites in Arctic Canada”.

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Data availability

Data from the at sea surveys are archived and updated at a Government of Canada Open Data Portal (<https://open.canada.ca/data/en/dataset/f612e2b4-5c67-46dc-9a84-1154c649ab4e>) and publicly available at OBIS-Seamap (<https://obis.org>).

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 517 Competing interests
 518 The authors declare no competing interests for this manuscript.
 519

520 References

- 521 Abbott, S. and Gjerdrum, C. 2015. Red-footed Booby (*Sula sula*): New to Nova Scotia and
 522 Canada. *North American Birds*, **68**:174-177.
- 523 Abraham, K.F. and Finney, G.H. 1986. Eiders of the eastern Canadian Arctic *In* Eider ducks in
 524 Canada, Reed, A. (editor). Canadian Wildlife Service Technical Report Series No. 47. pp. 55-
 525 73.
- 526 Ainley, D.G., Ribic, C.A. and Woehler, E.J. 2012. Adding the ocean to the study of seabirds: a
 527 brief history of at-sea seabird research. *Marine Ecology Progress Series*, **451**:231-243.
- 528 Allard, K., Hanson, A.R. and Mahoney, M. 2014. Summary: Important Marine Habitat Areas for
 529 Migratory Birds in Eastern Canada. Canadian Wildlife Service Technical Report Series No.
 530 530.
- 531 Arimitsu, M.L., Piatt, J.F., Thorson, J.T., Kuletz, K.J., Drew, G.S., Schoen, S.K., et al. 2023. Joint
 532 spatiotemporal models to predict seabird densities at sea. *Frontiers in Marine Science*, **10**.
- 533 Baillie, S.M., Robertson, G.J., Wiese, F.K. and Williams, U.P. 2005. Seabird data collected by the
 534 Grand Banks offshore hydrocarbon industry 1999-2002: results, limitations and suggestions
 535 for improvement. Canadian Wildlife Service Technical Report Series No. 434.
- 536 Ballance, L.T. 2007. Understanding seabirds at sea: why and how? *Marine Ornithology*, **35**:127-
 537 135.
- 538 Birdlife International. 2024. Species factsheet: *Ardenna grisea* [Online]. Available:
 539 <http://www.birdlife.org> [Accessed 04/04/2024].
- 540 Bivand, R. and Rundel, C. 2023. Rgeos, Interface to Geometry Engine - Open Source ('GEOS').
 541 <https://r-forge.r-project.org/projects/rgeos/> <https://libgeos.org> [http://rgeos.r-forge.r-](http://rgeos.r-forge.r-project.org/index.html)
 542 [project.org/index.html](http://rgeos.r-forge.r-project.org/index.html).
- 543 Bolduc, F. and Fifield, D.A. 2017. Seabirds at-sea surveys: The line-transect method outperforms
 544 the point-transect alternative. *The Open Ornithology Journal*, **10**:42-52.
- 545 Bolduc, F., Rousseau, F., Gjerdrum, C., Fifield, D.A. and Christin, S. 2016. Atlas of Seabirds at Sea
 546 in Eastern Canada 2006-2016. [https://data-donnees.az.ec.gc.ca/data/species/assess/atlas-](https://data-donnees.az.ec.gc.ca/data/species/assess/atlas-of-seabirds-at-sea-in-eastern-canada-2006-2016)
 547 [of-seabirds-at-sea-in-eastern-canada-2006-2016](https://data-donnees.az.ec.gc.ca/data/species/assess/atlas-of-seabirds-at-sea-in-eastern-canada-2006-2016).
- 548 Bolduc, F., Roy, C. and Rousseau, F. 2018. R2MCDS: An R package for the analysis of multi-
 549 species datasets collected using distance sampling. *Ecological Informatics*, **47**:23-25.
- 550 Brown, R.G.B. 1966. Sea birds in Newfoundland and Greenland waters, April-May 1966. The
 551 Canadian Field Naturalist, **82**:88-102.
- 552 Brown, R.G.B. 1971. PIROP Instruction Manual. Canadian Wildlife Service, Atlantic Region.

Brown, R.G.B. 1976. The foraging range of breeding Dovekies *Alle alle*. Canadian Field-Naturalist, **90**:166-168.

Brown, R.G.B. 1978. Atlas of eastern Canadian seabirds. Supplement III: Baffin Bay and adjacent sounds. Canadian Wildlife Service, Ottawa, Canada.

Brown, R.G.B. 1979. Atlas of eastern Canadian seabirds. Supplement IV: Hudson and Davis Straits. Canadian Wildlife Service, Ottawa, Canada.

Brown, R.G.B. 1980. The pelagic ecology of seabirds. Transactions of the Linnean Society of New York, **9**:15-22.

Brown, R.G.B. 1986. Revised Atlas of Eastern Canadian Seabirds. Canadian Wildlife Service, Ottawa, Canada.

Brown, R.G.B. 1988. Oceanographic factors as determinants of the winter range of the Dovekie (*Alle alle*) off Atlantic Canada. Colonial Waterbirds, **11**:176-180.

Brown, R.G.B., Nettleship, D.N., Germain, P., Tull, C.E. and Davis, T. 1975. Atlas of eastern Canadian seabirds. Canadian Wildlife Service, Ottawa, Canada.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford, Oxford University Press.

Buckland, S.T., Burt, M.L., Rexstad, E.A., Mellor, M., Williams, A.E. and Woodward, R. 2012. Aerial surveys of seabirds: the advent of digital methods. Journal of Applied Ecology, **49**:960-967.

Burke, C.M., Montevecchi, W.A. and Wiese, F.K. 2012. Inadequate environmental monitoring around offshore oil and gas platforms on the Grand Bank of Eastern Canada: Are risks to marine birds known? Journal of Environmental Management, **104**:121-126.

Carmack, E., McLaughlin, F., Vagle, S. and Melling, H. 2008. Canada's Three Oceans (C3O): a Canadian contribution to the International Polar Year. PICES Press, **16**:22-25.

Clark-Wolf, T.J., Miller, D.L., Drake, H., Fifield, D.A., Rail, J.-F., Wakefield, E.D., et al. *in prep*. Using model-based distance sampling to estimate decadal population change in Northern Gannets (*Morus bassanus*) across periods spanned by different at-sea survey methods. Ornithological Applications.

D'entremont, K.J.N., Pratte, I., Gjerdrum, C., Wong, S.N.P. and Montevecchi, W.A. 2023. Quantifying inter-annual variability on the space-use of parental Northern Gannets (*Morus bassanus*) in pursuit of different prey types. PLOS ONE, **18**:e0288650.

Dawson, J., Pizzolato, L., Howell, S.E.L., Copland, L. and Johnston, M.E. 2018. Temporal and spatial patterns of ship traffic in the Canadian Arctic from 1990 to 2015. Arctic, **71**:15-26.

Diamond, A.W., Gaston, A.J. and Brown, R.G.B. 1986. Converting PIROP counts of seabirds at sea to absolute densities. Canadian Wildlife Service Progress Notes, **164**:1-21.

Diamond, A.W., Gaston, A.J. and Brown, R.G.B. 1993. Studies of high latitude seabirds *In A Model of the Energy Demands of the Seabirds of Eastern Arctic Canada*, Montevecchi, W. A. (editor) Ottawa. Canadian Wildlife Service Occasional Paper. pp. 39.

Drew, G.S., Schoen, S.K., Hood, M.D., Arimitsu, M.L. and Piatt, J.F. 2005. North Pacific Pelagic Seabird Database (NPPSD) (ver 4.0). U.S. Geological Survey data release: dpi: 10.5066/F7WQ01T3.

Environment Canada. 2014. Recovery Strategy for the Ivory Gull (*Pagophila eburnea*) in Canada. Species at Risk Act Recovery Strategy Series, Ottawa. iv + 21pp.

- 597 Feyrer, L.J., Stanistreet, J.E., Gomez, C., Adams, M., Lawson, J.W., Ferguson, S.H., et al. 2024.
 598 Identifying important habitat for northern bottlenose and Sowerby's beaked whales in the
 599 western North Atlantic. *Aquatic Conservation: Marine and Freshwater Ecosystems*,
 600 **34**:e4064.
- 601 Fifield, D.A., Avery-Gomm, G.L., Mcfarlane Tranquilla, L., Ryan, P.C., Gjerdrum, C., Hedd, A., et
 602 al. 2017a. Effectiveness of observers in visually detecting dead seabirds on the open ocean.
 603 *Environmental Studies Research Funds*, **205**:97pp.
- 604 Fifield, D.A., Baker, K.D., Byrne, R., Robertson, G.J., Burke, C.M., Gilchrist, H.G., et al. 2009a.
 605 Modelling seabird oil spill mortality using flight and swim behaviour. *Environmental Studies*
 606 *Research Funds*, **186**:46pp.
- 607 Fifield, D.A., Hedd, A., Avery-Gomm, G.L., Gjerdrum, C. and Mcfarlane-Tranquilla, L. 2017b.
 608 Employing predictive spatial models to inform conservation planning for seabirds in the
 609 Labrador Sea. *Frontiers in Marine Science*, **4**.
- 610 Fifield, D.A., Hedd, A., Robertson, G.J., Avery-Gomm, G.L., Gjerdrum, C., Mcfarlane Tranquilla,
 611 L., et al. 2016. Baseline surveys for seabirds in the Labrador Sea. *Environmental Studies*
 612 *Research Funds*, **206**:69pp.
- 613 Fifield, D.A., Lewis, K.P., Gjerdrum, C., Robertson, G.J. and Wells, R. 2009b. Offshore seabird
 614 monitoring program. *Environmental Studies Research Funds*, **183**:68pp.
- 615 Finley, K.J. and Evans, C.R. 1984. First Canadian breeding record of the Dovekie. *Arctic*, **37**:195-
 616 320.
- 617 Fisheries and Oceans Canada. 2010. Recovery Strategy for the Northern Bottlenose Whale,
 618 Scotian Shelf population, in Atlantic Canadian Waters. Species at Risk Act Recovery Strategy
 619 Series, vi +61pp.
- 620 Fisheries and Oceans Canada 2012. Proceedings of the Technical Review for Baffinland's Mary
 621 River Project draft Environmental Impact Statement (EIS). DFO Canadian Science Advisory
 622 Secretariat Proceedings Series, 2011/055.
- 623 Fisheries and Oceans Canada 2013. Identification of Additional Ecologically and Biologically
 624 Significant Areas (EBSAs) within the Newfoundland and Labrador Shelves Bioregion. DFO
 625 Canadian Science Advisory Secretariat, Science Advisory Report, 2013/048.
- 626 Fisheries and Oceans Canada. 2017a. Management Plan for the Sowerby's Beaked Whale
 627 (*Mesoplodon bidens*) in Canada. Species at Risk Act Management Plan Series, Ottawa. iv +
 628 46pp.
- 629 Fisheries and Oceans Canada 2017b. Science guidance on design strategies for a network of
 630 Marine Protected Areas in the Newfoundland and Labrador Shelves Bioregion. DFO Canadian
 631 Science Advisory Secretariat, Science Advisory Report, 2017/046.
- 632 Fisheries and Oceans Canada 2021. Biophysical and Ecological Overview of a Study Area within
 633 the Labrador Inuit Settlement Area Zone. DFO Canadian Science Advisory Secretariat,
 634 Science Advisory Report, 2021/003.
- 635 Fort, J., Moe, B., Strøm, H., Grémillet, D., Welcker, J., Schultner, J., et al. 2013. Multicolony
 636 tracking reveals potential threats to little auks wintering in the North Atlantic from marine
 637 pollution and shrinking sea ice cover. *Diversity and Distributions*, **19**:1322-1332.
- 638 Frederiksen, M., Descamps, S., Erikstad, K.E., Gaston, A.J., Gilchrist, H.G., Grémillet, D., et al.
 639 2016. Migration and wintering of a declining seabird, the thick-billed murre *Uria lomvia* on
 640 an ocean basin scale: Conservation implications. *Biological Conservation*, **200**:26-35.

- Frederiksen, M., Mavor, R.A. and Wanless, S. 2007. Seabirds as environmental indicators: the advantages of combining data sets. *Marine Ecology Progress Series*, **352**:205-212.
- Gaston, A.J., Bertram, D.F., Boyne, A.W., Chardine, J.W., Davoren, G., Diamond, A.W., et al. 2009. Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. *Environmental Reviews*, **17**:267-286.
- Gaston, A.J., Mallory, M.L. and Gilchrist, H.G. 2012. Populations and trends of Canadian Arctic seabirds. *Polar Biology*, **35**:1221-1232.
- Gilchrist, H.G. and Mallory, M.L. 2005. Declines in abundance and distribution of the ivory gull (*Pagophila eburnea*) in Arctic Canada. *Biological Conservation*, **121**:303-309.
- Gjerdrum, C. and Bolduc, F. 2016. Non-breeding Distribution of Herring Gull (*Larus argentatus*) and Great Black-backed Gull (*L. marinus*) in eastern Canada from ship-based surveys. *Waterbirds*, **39**:136-142.
- Gjerdrum, C., Fifield, D.A. and Wilhelm, S.I. 2012a. Eastern Canada Seabirds at Sea (ECSAS) standardized protocol for pelagic seabird surveys from moving and stationary platforms. Canadian Wildlife Service Technical Report Series No. 515, Atlantic Region. vi + 37pp.
- Gjerdrum, C., Fifield, D.A. and Wilhelm, S.I. 2012b. Eastern Canada Seabirds at Sea (ECSAS) standardized protocol for pelagic seabird surveys from moving and stationary platforms. Addendum A - ECCC-CWS standards for observers conducting seabird surveys at sea, and for trainers providing instruction on seabird survey methods. Canadian Wildlife Service Technical Report Series 515, Atlantic Region. 2pp.
- Gjerdrum, C., Loch, J. and Fifield, D.A. 2018. The recent invasion of Cory's Shearwaters into Atlantic Canada. *Northeastern Naturalist*, **25**:532-544.
- Gjerdrum, C., Wong, S.N.P. and Mallory, M.L. *in prep*. Cruising for data: defining the seabird community from vessels-of-opportunity in the waters of Canada's eastern Arctic. *Marine Ornithology*.
- Gomez-Salazar, C. and Moors-Murphy, H.B. 2014. Assessing cetacean distribution in the Scotian Shelf Bioregion using Habitat Suitability Models. Canadian Technical Report of Fisheries and Aquatic Sciences, 3088, **3088**:iv + 49p.
- Gomez, C., Lawson, J., Kouwenberg, A.L., Moors-Murphy, H., Buren, A., Fuentes-Yaco, C., et al. 2017. Predicted distribution of whales at risk: identifying priority areas to enhance cetacean monitoring in the Northwest Atlantic Ocean. *Endangered Species Research*, **32**:437-458.
- Guse, N., Markones, N., Bolduc, F. and Garthe, S. 2013. Distribution of seabirds in the Lower Estuary and Gulf of St. Lawrence (Canada) during summer. *Seabird*, **26**:42-70.
- Halliday, W.D., Dawson, J., Yurkowski, D.J., Doniol-Valcroze, T., Ferguson, S.H., Gjerdrum, C., et al. 2022. Vessel risks to marine wildlife in the Tallurutiup Imanga National Marine Conservation Area and the eastern entrance to the Northwest Passage. *Environmental Science & Policy*, **127**:181-195.
- Halpern, B.S., Frazier, M., Potapenko, J., Casey, K.S., Koenig, K., Longo, C., et al. 2015. Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature Communications*, **6**:1-7.
- Hedd, A., Montevecchi, W.A., Mcfarlane Tranquilla, L., Burke, C.M., Fifield, D.A., Robertson, G.J., et al. 2011. Reducing uncertainty on the Grand Bank: tracking and vessel surveys indicate mortality risks for common murre in the North-West Atlantic. *Animal Conservation*, **14**:630-641.

- 685 Hedd, A., Pollet, I.L., Mauck, R.A., Burke, C.M., Mallory, M.L., Mcfarlane Tranquilla, L., et al.
 686 2018. Foraging areas, offshore habitat use, and colony overlap by incubating Leach's storm-
 687 petrels *Oceanodroma leucorhoa* in the Northwest Atlantic. PLOS one, **13**:1-18.
- 688 Hogan, H. 2023. Message in a Bottle: Ocean Dispatches from a Seabird Biologist. Knopf Canada.
- 689 Huettmann, F., Artukhin, Y., Gilg, O. and Humphries, G. 2011. Predictions of 27 Arctic pelagic
 690 seabird distributions using public environmental variables, assessed with colony data: a first
 691 digital IPY and GBIF open access synthesis platform. Marine Biodiversity, **41**:141-179.
- 692 Huettmann, F. and Diamond, A.W. 2000. Seabird migration in the Canadian northwest Atlantic
 693 Ocean: moulting locations and movement patterns of immature birds. Canadian Journal of
 694 Zoology, **78**:624-647.
- 695 Huettmann, F. and Diamond, A.W. 2001. Seabird colony locations and environmental
 696 determination of seabird distribution: a spatially explicit breeding seabird model for the
 697 Northwest Atlantic. Ecological Modelling, **141**:261-298.
- 698 Huettmann, F. and Lock, A.R. 1997. A new software system for the PIROP database: data flow
 699 and an approach for a seabird-depth analysis. ICES Journal of Marine Science, **54**:518-523.
- 700 Hyrenbach, D., Huettmann, F. and Chardine, J.W. 2012. PIROP Northwest Atlantic 1965-1992.
 701 Data from OBIS-SEAMAP (<http://seamap.env.duke.edu/dataset/280>).
- 702 Hyrenbach, K.D. 2001. Albatross response to survey vessels: implications for studies of the
 703 distribution, abundance, and prey consumption of seabird populations. Marine Ecology
 704 Progress Series, **212**:283-295.
- 705 Johansen, K.L., Bråthen, V.S., Gjerdrum, C., Wong, S.N.P. and Mosbech, A. *in prep*. Major little
 706 auk (*Alle alle*) post-breeding staging area faces threats from climate change and potential
 707 future increases in ship traffic.
- 708 Joiris, C.R., Humphries, G.R.W. and De Broyer, A. 2013. Seabirds encountered along return
 709 transects between South Africa and Antarctica in summer in relation to hydrological
 710 features. Polar Biology, **36**:1633-1647.
- 711 Kowarski, K., Evers, C., Moors-Murphy, H., Martin, B. and Denes, S.L. 2018. Singing through
 712 winter nights: Seasonal and diel occurrence of humpback whale (*Megaptera novaeangliae*)
 713 calls in and around the Gully MPA, offshore eastern Canada. Marine Mammal Science,
 714 **34**:169-189.
- 715 Kuletz, K., Cushing, D. and Labunski, E. 2020. Distributional shifts among seabird communities of
 716 the Northern Bering and Chukchi seas in response to ocean warming during 2017–2019.
 717 Deep Sea Research Part II: Topical Studies in Oceanography, **181-182**:104913.
- 718 Kuletz, K.J., Cushing, D.A., Osnas, E.E., Labunski, E.A. and Gall, A.E. 2019. Representation of the
 719 Pacific Arctic seabird community within the Distributed Biological Observatory array, 2007–
 720 2015. Deep Sea Research Part II: Topical Studies in Oceanography, **162**:191-210.
- 721 Kuletz, K.J., Gall, A.E., Morgan, T.C., Prichard, A.K., Eisner, L.B., Kimmel, D.G., et al. 2024.
 722 Seabird responses to ecosystem changes driven by marine heatwaves in a warming Arctic.
 723 Marine Ecology Progress Series, **HEAT**:HEATav13.
- 724 Lavoie, R.A., Tetreault, M., Bolduc, F., Bergeron, G. and Lieske, D.J. 2022. Predicting at-sea
 725 distribution of Razorbill in the St. Lawrence Gulf and Estuary, Québec, Canada during the
 726 breeding period using GPS telemetry. Avian Conservation and Ecology, **17**.

727 Lesage, V., Gosselin, J.-F., Lawson, J.W., Mcquinn, I., Moors-Murphy, H., Plourde, S., et al. 2018.
 728 Habitats important to blue whales (*Balaenoptera musculus*) in the western North Atlantic.
 729 DFO Canadian Science Advisory Secretariat Research Document, 2016/080:ic + 50 p.
 730 Lieske, D.J., Fifield, D.A. and Gjerdrum, C. 2014. Maps, models, and marine vulnerability:
 731 Assessing the community distribution of seabirds at-sea. *Biological Conservation*, **172**:15-28.
 732 Lieske, D.J., Mcfarlane Tranquilla, L., Ronconi, R.A. and Abbott, S. 2019. Synthesizing expert
 733 opinion to assess the at-sea risks to seabirds in the western North Atlantic. *Biological*
 734 *Conservation*, **233**:41-50.
 735 Lieske, D.J., Mcfarlane Tranquilla, L., Ronconi, R.A. and Abbott, S. 2020. Seas of risk: Assessing
 736 the threats to colonial-nesting seabirds in Eastern Canada. *Marine Policy*, **115**:103863.
 737 Lock, A.R., Brown, R.G.B. and Gerriets, S.H. 1994. Gazetteer of Marine Birds in Atlantic Canada:
 738 An atlas of sea bird vulnerability to oil pollution. Canadian Wildlife Service, Atlantic Region.
 739 Lock, A.R., Petrie, J. and Griswold, A. 1997. PIROP. Canadian Wildlife Service, Atlantic Region.
 740 Louzao, M., Bécarea, J., Rodríguez, B., Hyrenbach, K.D., Ruiz, A. and Arcos, J.M. 2009. Combining
 741 vessel-based surveys and tracking data to identify key marine areas for seabirds. *Marine*
 742 *Ecology Progress Series*, **391**:183-197.
 743 Maftai, M., Davis, S.E., Jones, I.L. and Mallory, M.L. 2012. Breeding Habitats and New Breeding
 744 Locations for Ross's Gull (*Rhodostethia rosea*) in the Canadian High Arctic. *Arctic*, **65**:283-
 745 288.
 746 Mallory, M.L., Baak, J., Gjerdrum, C., Mallory, O.E., Manley, B., Swan, C., et al. 2021.
 747 Anthropogenic litter in marine waters and coastlines of Arctic Canada and West Greenland.
 748 *Science of The Total Environment*, **783**:146971.
 749 Mallory, M.L. and Fontaine, A.J. 2004. Key marine habitat sites for migratory birds in Nunavut
 750 and the Northwest Territories. Canadian Wildlife Service Occasional Paper Number 109,
 751 Ottawa.
 752 Michel, C., Hamilton, J., Hansen, E., Barber, D., Reigstad, M., Iacozza, J., et al. 2015. Arctic Ocean
 753 outflow shelves in the changing Arctic: A review and perspectives. *Progress in*
 754 *Oceanography*, **139**:66-88.
 755 Miller, D.L., Fifield, D.A., Wakefield, E.D. and Sigourney, D.B. 2021a. Extending density surface
 756 model to include multiple and double-observer survey data. *PeerJ*, **6**:e12113.
 757 Miller, D.L., Rexstad, E., Burt, L., Bravington, M.V. and Hedley, S. 2021b. DSM: density surface
 758 modelling of distance sampling data. R package version 2.3.1., **Available at** [https://cran.r-](https://cran.r-project.org/package=dsm)
 759 [project.org/package=dsm](https://cran.r-project.org/package=dsm).
 760 Montevecchi, W.A., Wiese, F.K., Davoren, G., Diamond, A.W., Huettmann, F. and Linke, J. 1999.
 761 Seabird Attraction to Offshore Platforms and Seabird Monitoring from Offshore Support
 762 Vessels and other Ships: Literature Review and Monitoring Designs. Environmental Studies
 763 Research Funds, Report 138, Calgary, Alberta, Canada, 56pp.
 764 Moore, S.E. and Kuletz, K.J. 2019. Marine birds and mammals as ecosystem sentinels in and
 765 near Distributed Biological Observatory regions: An abbreviated review of published
 766 accounts and recommendations for integration to ocean observatories. *Deep Sea Research*
 767 *Part II: Topical Studies in Oceanography*, **162**:211-217.
 768 Moors-Murphy, H., Lawson, J.W., Rubin, B., Marotte, E., Renaud, G. and Fuentes-Yaco, C. 2018.
 769 Occurrence of Blue Whales (*Balaenoptera musculus*) off Nova Scotia, Newfoundland, and

- 770 Labrador. DFO Canadian Science Advisory Secretariat Research Document, 2011/055:iv + 55
 771 p.
- 772 Morgan, K.H., Vermeer, K. and Mckelvey, R.W. 1991. Atlas of pelagic birds of western Canada.
 773 Canadian Wildlife Service Occasional Paper Number 72, Ottawa.
- 774 Mueter, F.J., Iken, K., Cooper, L.W., Grebmeier, J.M., Kuletz, K.J., Hopcroft, R.R., et al. 2021.
 775 Changes in diversity and species composition across multiple assemblages in the eastern
 776 Chukchi Sea during two contrasting years are consistent with borealization. *Oceanography*,
 777 **34**:38-51.
- 778 Nagelkerken, I. and Connell, S.D. 2015. Global alteration of ocean ecosystem functioning due to
 779 increasing human CO₂ emissions. *Proceedings of the National Academy of Sciences*,
 780 **112**:13272-13277.
- 781 Nisbet, I.C.T. and Veit, R.R. 2015. An explanation for the population crash of red-necked
 782 phalaropes *Phalaropus lobatus* staging in the Bay of Fundy in the 1980s. *Marine Ornithology*,
 783 **43**:119-121.
- 784 Nozères, C., Bourassa, M.-N., Gendron, M.-H., Plourde, S., Savenkoff, C., Bourdages, H., et al.
 785 2015. Using annual ecosystemic multispecies surveys to assess biodiversity in the Gulf of St.
 786 Lawrence. *Canadian Technical Report of Fisheries and Aquatic Sciences*, **3149**:vii + 126 p.
- 787 Ollerhead, L.M.N., Gullage, M., Trip, N. and Wells, N. 2017. Development of Spatially
 788 Referenced Data Layers for Use in the Identification and Delineation of Candidate
 789 Ecologically and Biologically Significant Areas in the Newfoundland and Labrador Shelves
 790 Bioregion. DFO Canadian Science Advisory Secretariat Research Document, 2017/036:v + 38
 791 pp.
- 792 Piatt, J.J.F., Sydeman, W.J. and Wiese, F. 2007. Introduction: a modern role for seabirds as
 793 indicators. *Marine Ecology Progress Series*, **352**:199-204.
- 794 Pizzolato, L., Howell, S.E.L., Dawson, J., Laliberté, F. and Copland, L. 2016. The influence of
 795 declining sea ice on shipping activity in the Canadian Arctic. *Geophysical Research Letters*,
 796 **43**:12,146-12,154.
- 797 Powers, K.D., Pittman, B.G.C. and Burrell, G.C. 1979. Distribution of Marine Birds on the Mid-
 798 and North-Atlantic U.S. Outer Continental Shelf. Manomet Bird Observatory Technical
 799 Progress Report, Manomet, MA.
- 800 Prach, R.W. and Smith, A.R. 1985. Marine bird distribution in Lancaster Sound and potential
 801 impacts of marine transport. Canadian Wildlife Service, Western and Northern Region,
 802 Edmonton, Alberta.
- 803 Renner, M. and Kuletz, K.J. 2015. A spatial–seasonal analysis of the oiling risk from shipping
 804 traffic to seabirds in the Aleutian Archipelago. *Marine Pollution Bulletin*, **101**:127-136.
- 805 Renner, M., Parrish, J.K., Piatt, J.F., Kuletz, K.J., Edwards, A.E. and Hunt, G.L. 2013. Modeled
 806 distribution and abundance of a pelagic seabird reveal trends in relation to fisheries. *Marine*
 807 *Ecology Progress Series*, **484**:259-277.
- 808 Robertson, G.J., Fifield, D.A., Montevecchi, W.A., Gaston, A.J., Burke, C.M., Byrne, R., et al.
 809 2012. Miniaturized data loggers and computer programming improve seabird risk and
 810 damage assessments for marine oil spills in Atlantic Canada. *Journal of Ocean Technology*,
 811 **7**:42-58.
- 812 Romano, M.D., Renner, H.M., Kuletz, K.J., Parrish, J.K., Jones, T., Burgess, H.K., et al. 2020. Die-
 813 offs, reproductive failure, and changing at–sea abundance of murre in the Bering and

- 814 Chukchi Seas in 2018. Deep Sea Research Part II: Topical Studies in Oceanography, **181-**
815 **182**:104877.
- 816 Ronconi, R.A., Lieske, D.J., Mcfarlane Tranquilla, L.A., Abbott, S., Allard, K.A., Allen, B., et al.
817 2022. Predicting seabird foraging habitat for conservation planning in Atlantic Canada:
818 Integrating telemetry and survey data across thousands of colonies. Frontiers in Marine
819 Science, **9**.
- 820 Rooney, R.C., Daniel, J., Mallory, M., Hedd, A., Ives, J., Gilchrist, G., et al. 2023. Fuzzy cognitive
821 mapping as a tool to assess the relative cumulative effects of environmental stressors on an
822 Arctic seabird population to identify conservation action and research priorities. Ecological
823 Solutions and Evidence, **4**:e12241.
- 824 Searing, G.F., Kuyt, E., Richardson, W.J. and Barry, T.W. 1975. Seabirds of the southeastern
825 Beaufort Sea: aircraft and group observations in 1972 and 1974. Beaufort Sea Technical
826 Report #3b, Victoria, B.C.
- 827 Serdyska, A.R., Pardy, G.S. and King, M.C. 2021. Offshore Ecological and Human Use
828 Information considered in Marine Protected Area Network Design in the Scotian Shelf
829 Bioregion. Canadian Technical Report of Fisheries and Aquatic Sciences, **3382**:xi + 100pp.
- 830 Smith, M.A., Walker, N.J., Free, C.M., Kirchhoff, M.J., Drew, G.S., Warnock, N., et al. 2014.
831 Identifying marine Important Bird Areas using at-sea survey data. Biological Conservation,
832 **172**:180-189.
- 833 Spencer, N.C., Gilchrist, H.G. and Mallory, M.L. 2015. Annual movement patterns of endangered
834 ivory gulls: The importance of sea ice. PLOS ONE, **9**:e115231.
- 835 Stanistreet, J.E., Feyrer, L.J. and Moors-Murphy, H. 2021. Distribution, movements, and habitat
836 use of northern bottlenose whales (*Hyperoodon ampullatus*) on the Scotian Shelf. DFO
837 Canadian Science Advisory Secretariat Research Document, 2021/074:vi + 34pp.
- 838 Sydeman, W.J., Schoeman, D.S., Thompson, S.A., Hoover, B.A., García-Reyes, M., Daunt, F., et
839 al. 2021. Hemispheric asymmetry in ocean change and the productivity of ecosystem
840 sentinels. Science, **372**:980-983.
- 841 Tasker, M.L., Hope Jones, P., Dixon, T. and Blake, B.F. 1984. Counting seabirds at sea from ships:
842 a review of methods and a suggestion for a standardized approach. Auk, **101**:567-577.
- 843 Timmermans, M.-L. and Marshall, J. 2020. Understanding Arctic Ocean circulation: A review of
844 ocean dynamics in a changing climate. Journal of Geophysical Research: Oceans,
845 **125**:e2018JC014378.
- 846 Wadhams, P. 2009. Hudson-70: The first circumnavigation of the Americas. Oceanography
847 **22**:226-235.
- 848 Wakefield, E.D., Miller, D.L., Bond, S.L., Le Bouard, F., Carvalho, P.C., Catry, P., et al. 2021. The
849 summer distribution, habitat associations and abundance of seabirds in the sub-polar frontal
850 zone of the Northwest Atlantic. Progress in Oceanography, **198**:102657.
- 851 Wassmann, P. 2011. Arctic marine ecosystems in an era of rapid climate change. Progress in
852 Oceanography, **90**:1-17.
- 853 Wiese, F.K., Robertson, G.J. and Gaston, A.J. 2004. Impacts of chronic marine oil pollution and
854 the murre hunt in Newfoundland on thick-billed murre *Uria lomvia* populations in the
855 eastern Canadian Arctic. Biological Conservation, **116**:205-216.

- Wiese, F.K. and Ryan, P.C. 2003. The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached bird surveys 1984-1999. *Marine Pollution Bulletin*, **46**:1090-1101.
- Wilhelm, S.I., Mailhiot, J., Arany, J., Chardine, J.W., Robertson, G.J. and Ryan, P.C. 2015. Update and trends of three important seabird populations in the western North Atlantic using a geographic information system approach. *Marine ornithology*, **43**:211-222.
- Wilhelm, S.I., Robertson, G.J., Ryan, P.C. and Schneider, D.C. 2007. Comparing an estimate of seabirds at risk to a mortality estimate from the November 2004 Terra Nova FPSO oil spill. *Marine Pollution Bulletin*, **54**:537-544.
- Winship, A.J., Leirness, J.B., Coyne, M., Howell, J., Saba, V.S. and Christensen, J. 2023. Modelling the distributions of marine birds at sea to inform planning of energy development on the US Atlantic Outer Continental Shelf. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 413 p.pp.
- Wong, S., Gjerdrum, C., Morgan, K.H. and Mallory, M.L. 2014. Hotspots in cold seas: the composition, distribution and abundance of marine birds in the North American Arctic. *Journal of Geophysical Research - Oceans*, **119**:1691-1705.
- Wong, S.N.P., Gjerdrum, C., Gilchrist, H.G. and Mallory, M.L. 2018a. Seasonal vessel activity risk to seabirds in waters off Baffin Island, Canada. *Ocean & Coastal Management*, **163**:339-351.
- Wong, S.N.P., Ronconi, R.A. and Gjerdrum, C. 2018b. Autumn at-sea distribution and abundance of Phalaropes *Phalaropus* and other seabirds in the lower Bay of Fundy, Canada. *Marine Ornithology*, **46**:1-10.
- Yurkowski, D.J., Auger-Méthé, M., Mallory, M.L., Wong, S.N.P., Gilchrist, G., Derocher, A.E., et al. 2019. Abundance and species diversity hotspots of tracked marine predators across the North American Arctic. *Diversity and Distributions*, **25**:328-345.
- Zipkin, E.F., Kinlan, B.P., Sussman, A., Rypkema, D., Wimer, M. and O'connell, A.F. 2015. Statistical guidelines for assessing marine avian hotspots and coldspots: A case study on wind energy development in the U.S. Atlantic Ocean. *Biological Conservation*, **191**:216-223.

Table 1. Attributes of the at-sea survey field stations within study area, 1969-2023.

Field Station Features	
Organization that created the station	Canadian Wildlife Service (now part of ECCC)
Organization that maintains the sites	Vessel operators
Location (degrees)	52° - 82°N, 50° - 141°W
Distance to nearest community	Surveys take place at sea but pass by communities
Transportation access	Domestic or charter flight to embarkation/disembarkation
Number of permanent buildings	0 buildings; vessel lengths range from 10-172 m
Number of people supported at one time	1-2
Station equipment	Laptop/tablet, GPS, voice dictation software and headset, binoculars, range finder; food and lodging provided
Station power	Vessel power (110W or 220W; need converters)
Key limitations for station	Routes variable based on vessel itinerary; modified by ice and weather. Survey times limited when transit occurs at night and when vessel is stationary during the day Frequent rough seas may preclude observers from conducting surveys (motion sickness, safety concerns, low bird detectability)
Key collaborating organizations since creation	Environment and Climate Change Canada (Canadian Wildlife Service) Fisheries and Oceans Canada (Canadian Coast Guard) Amundsen Science Environmental Studies Research Funds Expedition companies (Adventure Canada, Students On Ice, Lindblad Expeditions, One Oceans Expeditions) Acadia University University of Washington
Focal species for monitoring (in Arctic)	Northern fulmar (<i>Fulmarus glacialis</i>) Black-legged kittiwake (<i>Rissa tridactyla</i>) Thick-billed murre (<i>Uria lomvia</i>) Dovekie (<i>Alle alle</i>)
Ancillary species monitored	Gulls, shearwaters, storm-petrels, eiders, phalaropes, alcids, marine mammals
Thesis students and post-docs using primary data from site (starting year)	Falk Huettmann (PhD, Univ. of New Brunswick, 1998) Nils Guse (PhD, University of Kiel, Germany, 2007) Sarah Wong (Post-doc, Acadia University, 2013) Hannah Drake (Honours, Dalhousie University, 2019)

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Table 2. Summary of at-sea survey effort for PIROP and ECSAS seabird monitoring programs within study area.

Effort Variable	PIROP	ECSAS
Survey years (range)	17 (1969-1987)	18 (2006-2023)
Number of survey trips	100	132
Number of survey days	944	1102
Number of unique survey vessels ¹	26	30
Number of seabird observers	33	56
Total survey distance (km)	36,357	88,215

¹Two vessels were used across both programs (CCG Hudson and CCG Des Groseilliers)

Table 3. Summary of marine birds sighted (number of individuals and percent of total) during PIROP (1969-1987) and ECSAS (2006-2023) surveys in study area, indicating breeding (B = breeder; NB = non-breeder) and conservation status (listed by federal Species at Risk Act - SARA or Canada's Committee on the Status of Endangered Wildlife in Canada - COSEWIC) in Canada.

Species	Latin	PIROP		ECSAS		Grand Total
		#	(%)	#	(%)	
Gaviidae		61	0.0%	462	0.1%	523
Common loon (B)	<i>Gavia immer</i>	16		20		36
Yellow-billed loon (B)	<i>Gavia adamsii</i>	0		29		29
Red-throated loon (B)	<i>Gavia stellata</i>	44		68		112
Pacific loon (B)	<i>Gavia pacifica</i>	0		299		299
Unidentified loon	Gaviidae	1		46		47
Procellariidae		249161	41.8%	192929	44.4%	442090
Northern fulmar (B)	<i>Fulmarus glacialis</i>	217380		185558		398614
Manx shearwater (B)	<i>Puffinus puffinus</i>	14		20		34
Great shearwater (NB)	<i>Ardenna gravis</i>	26141		6659		32513
Sooty shearwater (NB)	<i>Ardenna griseus</i>	5435		672		6079
Cory's shearwater (NB)	<i>Calonectris borealis</i>	3		0		3
Unidentified shearwater	Procellariidae	188		20		208
Hydrobatidae		1868	0.3%	1009	0.2%	2877
Wilson's storm-petrel (NB)	<i>Oceanites oceanicus</i>	503		262		761
Leach's storm-petrel ¹ (B)	<i>Oceanodroma leucorhoa</i>	1242		569		1752
Unidentified storm-petrel	Hydrobatidae	123		178		282
Sulidae		125	0.0%	112	0.0%	237
Northern gannet (B)	<i>Morus bassanus</i>	125		112		234
Phalacrocoracidae		0	0.0%	44	0.0%	44
Double-crested cormorant (B)	<i>Phalacrocorax auritus</i>	0		8		8
Great cormorant (B)	<i>Phalacrocorax carbo</i>	0		1		1
Unidentified cormorant	<i>Phalacrocorax</i>	0		35		35
Anatidae		16464	2.8%	12706	2.9%	29170
Canada goose (B)	<i>Branta canadensis</i>	457		251		708
Brant (B)	<i>Branta bernicla</i>	0		30		30
Greater white-fronted goose (B)	<i>Anser albifrons</i>	0		14		14
Snow goose (B)	<i>Chen caerulescens</i>	304		133		435
Unidentified goose	<i>Branta, Anser, Chen</i>	28		3		31
American black duck (B)	<i>Anas rubripes</i>	108		11		119
Common eider (B)	<i>Somateria mollissima</i>	9636		6042		15678
King eider (B)	<i>Somateria spectabilis</i>	0		1723		1723
Steller's eider ² (NB)	<i>Polysticta stelleri</i>	17		0		17
Unidentified eider	<i>Somateria</i>	3004		1789		4793
Harlequin duck (B)	<i>Histrionicus histrionicus</i>	0		15		15
Long-tailed duck (B)	<i>Clangula hyemalis</i>	1072		2118		3190

Table 3. (continued).

Species	Latin	PIROP		ECSAS		Grand Total
		#	(%)	#	(%)	
Anatidae (continued.)						
Surf scoter (B)	Melanitta perspicillata	0		25		25
Black scoter (B)	Melanitta nigra	25		33		58
White-winged scoter (B)	Melanitta fusca	15		216		231
Unidentified scoter	Melanitta	553		40		593
Unidentified goldeneye (B)	Bucephala	0		4		4
Red-breasted merganser (B)	Mergus serrator	302		3		305
Unidentified merganser	Mergus or Lophodytes	3		6		9
Unidentified waterfowl	Anatidae	940		250		1190
Scolopacidae		25318	4.3%	5636	1.3%	30954
Red-necked phalarope ¹ (B)	Phalaropus lobatus	321		782		1103
Red phalarope (B)	Phalaropus fulicaria	18003		3312		21314
Unidentified phalarope	Scolopacidae	6994		1542		8514
Laridae		125930	21.1%	70553	16.2%	196483
Great skua (NB)	Stercorarius skua	76		33		109
South polar skua (NB)	Stercorarius maccormicki	1		12		13
Unidentified skua	Stercorarius	2		9		11
Pomarine jaeger (B)	Stercorarius pomarinus	880		323		1193
Parasitic jaeger (B)	Stercorarius parasiticus	355		154		502
Long-tailed jaeger (B)	Stercorarius longicaudus	890		270		1153
Unidentified jaeger or skua	Stercorariidae	731		138		869
Black-legged kittiwake (B)	Rissa tridactyla	96377		45896		141651
Red-legged kittiwake ² (NB)	Rissa brevirostris	0		1		1
Unidentified kittiwake	Rissa	0		9		9
Ivory gull ¹ (B)	Pagophila eburnea	3864		113		3977
Ross's gull ¹ (B)	Rhodostethia rosea	0		18		18
Sabine's gull (B)	Xema sabini	283		229		504
Black-headed gull (B)	Larus ridibundus	3		2		5
Bonaparte's gull (B)	Larus philadelphia	18		1		19
Laughing gull (B)	Larus atricilla	107		0		107
Franklin's gull (B)	Larus pipixcan	0		1		1
Ring-billed gull (B)	Larus delawarensis	0		3		2
Herring gull (B)	Larus argentatus	4045		3986		7954
Iceland gull (B)	Larus glaucoides	2531		2054		4552
Glaucous gull (B)	Larus hyperboreus	9215		13928		23107
Thayer's gull (B)	Larus thayeri	734		219		953
Lesser black-backed gull (NB)	Larus fuscus	5		28		29
Great black-backed gull (B)	Larus marinus	3030		667		3694
Unidentified gull	Laridae	766		1978		2641
Common tern (B)	Sterna hirundo	15		0		15
Arctic tern (B)	Sterna paradisaea	1699		282		1970
Unidentified tern	Sternidae	303		199		502

Table 3. (concluded).

Species	Latin	PIROP		ECSAS		Grand Total
		#	(%)	#	(%)	
Alcidae		176723	29.7%	151347	34.8%	328070
Tufted puffin ² (B)	<i>Fratercula cirrhata</i>	1		0		1
Atlantic puffin (B)	<i>Fratercula arctica</i>	2827		2097		4846
Horned puffin ² (B)	<i>Fratercula corniculata</i>	0		1		1
Unidentified puffin	<i>Fratercula</i>	108		0		108
Crested auklet ² (NB)	<i>Aethia cristatella</i>	0		1		1
Ancient murrelet ^{1,2} (B)	<i>Synthliboramphus antiquus</i>	0		1		1
Black guillemot (B)	<i>Cepphus grylle</i>	4932		2503		7338
Pigeon guillemot ² (B)	<i>Cepphus columba</i>	0		1		1
Unidentified guillemot	<i>Cepphus</i>	8		0		8
Dovekie ³ (B)	<i>Alle alle</i>	73974		67278		140937
Razorbill (B)	<i>Alca torda</i>	585		283		867
Common murre (B)	<i>Uria aalge</i>	4001		1156		5140
Thick-billed murre (B)	<i>Uria lomvia</i>	59196		66439		124757
Unidentified murre	<i>Uria</i>	23583		5878		29327
Unidentified auk	Alcidae	7508		5709		12500
Grand Total		595650		434798		1030448
Total number of species		47		59		64

¹SARA or COSEWIC-listed.
²Species' range restricted to North Pacific and/or Western Arctic waters.
³A small population of just a few hundred pairs is known to breed in Canada at a single site (Finley and Evans 1984).

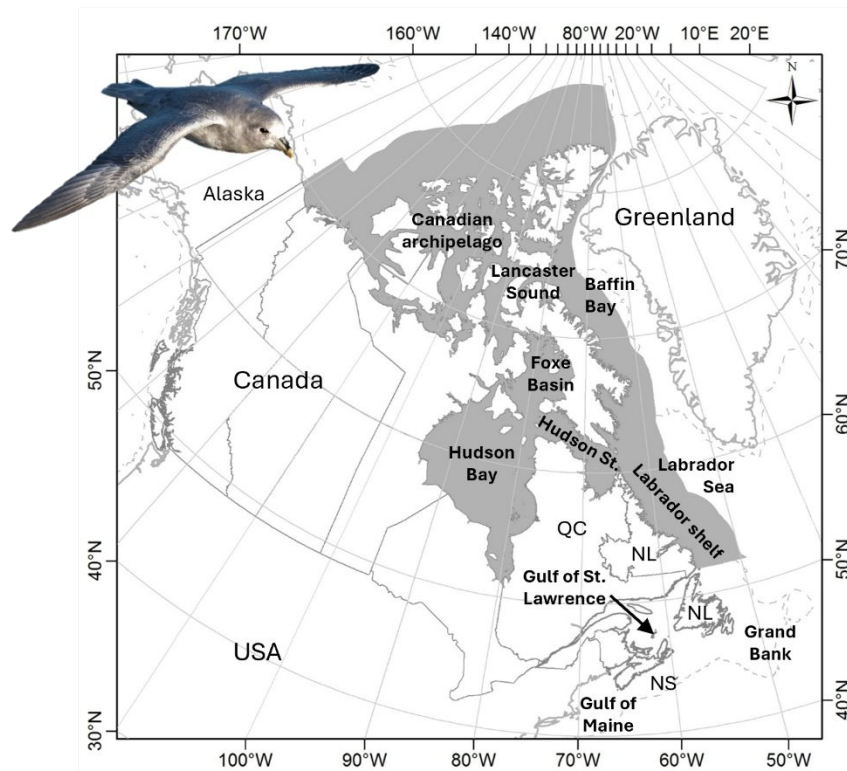


Fig. 1. Eastern Canada marine waters (and 1000-m isobath; dashed line) where the Canadian Wildlife Service (CWS) have conducted vessel-based seabird surveys since 1965, showing the study area (gray shading) where surveys have been done since 1969. Place names are those discussed in the text, including the Provinces of Quebec (QC), Newfoundland and Labrador (NL), and Nova Scotia (NS). Photo insert of northern fulmar (*Fulmarus glacialis*) in flight (photo Carina Gjerdrum). Map display is Quebec Lambert Conformal Conic projection

(https://epsg.org/crs_2138/NAD27-CGQ77-Quebec-Lambert.html?sessionkey=fs2k8ri1m4).

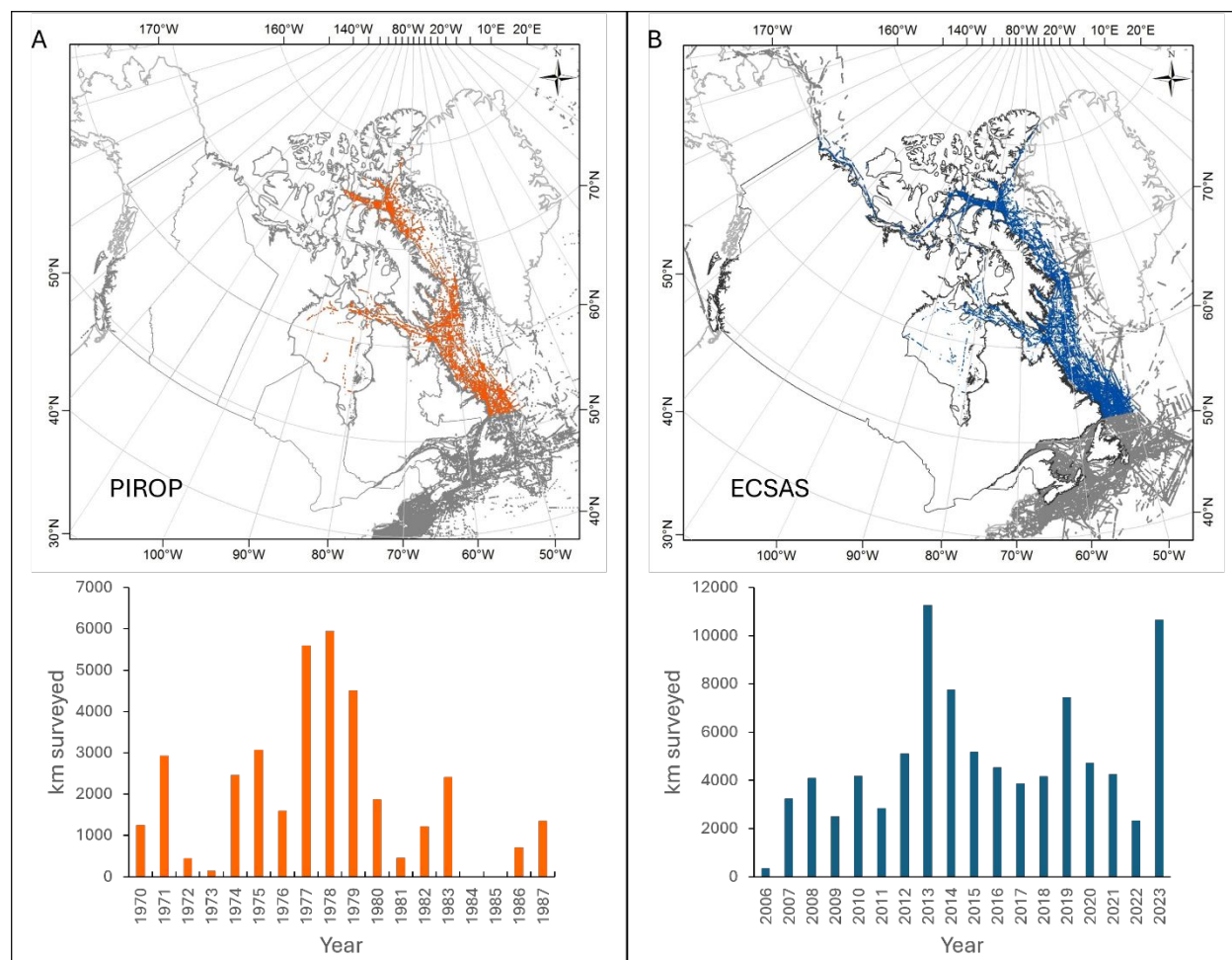


Fig. 2. At-sea seabird survey locations for A. PIROP (1969-1987) and B. ECSAS (2006-2023) monitoring programs by the Canadian Wildlife Service (CWS) in eastern Canada, showing the distribution of survey effort (total km) across the study periods (note different scale on y-axis between programs). Orange (PIROP) and blue (ECSAS) points highlight survey locations within our study area, and grey points represent survey locations outside the study area. Map display is Quebec Lambert Conformal Conic projection (https://epsg.org/crs_2138/NAD27-CGQ77-Quebec-Lambert.html?sessionkey=fs2k8ri1m4).

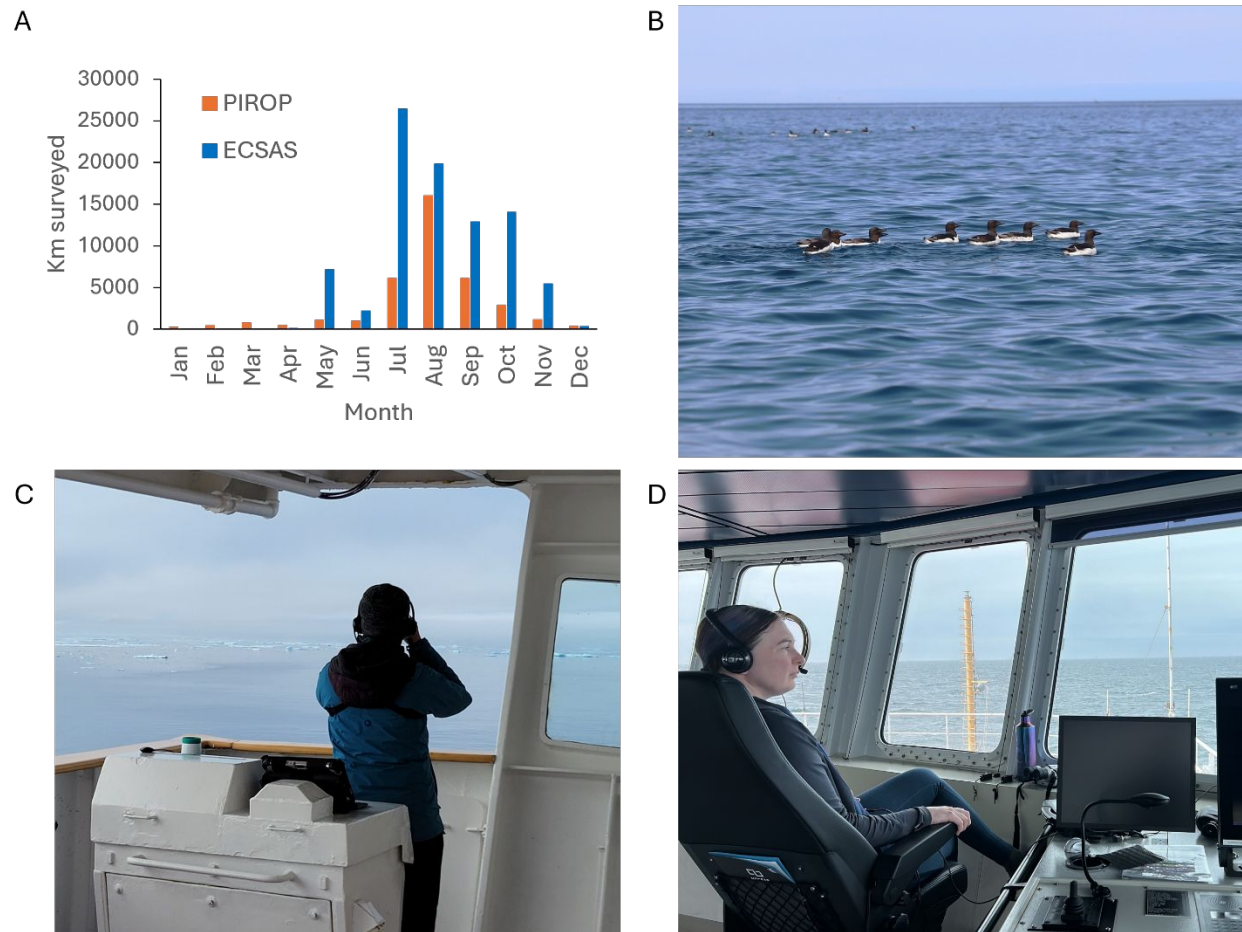


Fig. 3. Seasonal seabird survey effort (total km surveyed) across A. PIROP (1969-1987) and ECSAS (2006-2023) monitoring programs within our study area in eastern Canada; B. Thick-billed murre in water (photo Carina Gjerdrum); Seabird observers conducting surveys at sea, C. outside from the bridge wing of vessel (photo Garry Donaldson), and D. from inside vessel on bridge (photo Chris Ward).

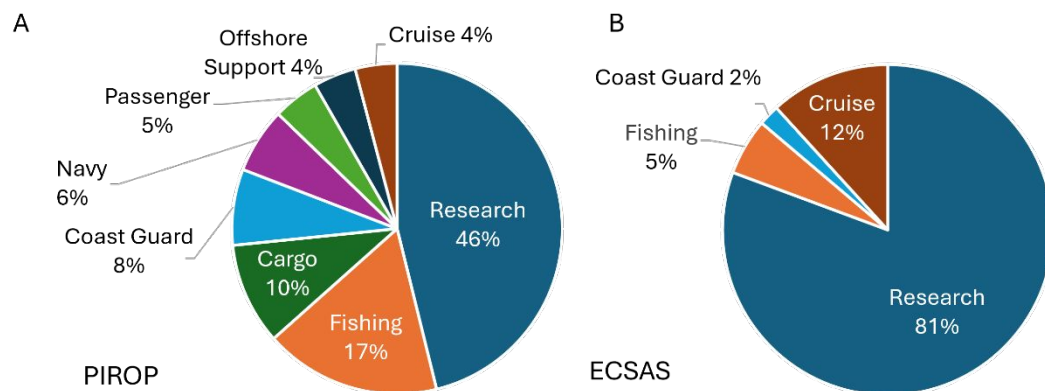


Fig. 4. The proportion of survey effort from different vessel types during A. PIROP (1969-1987) and B. ECSAS (2006-2023) monitoring programs within our study area in eastern Canada.

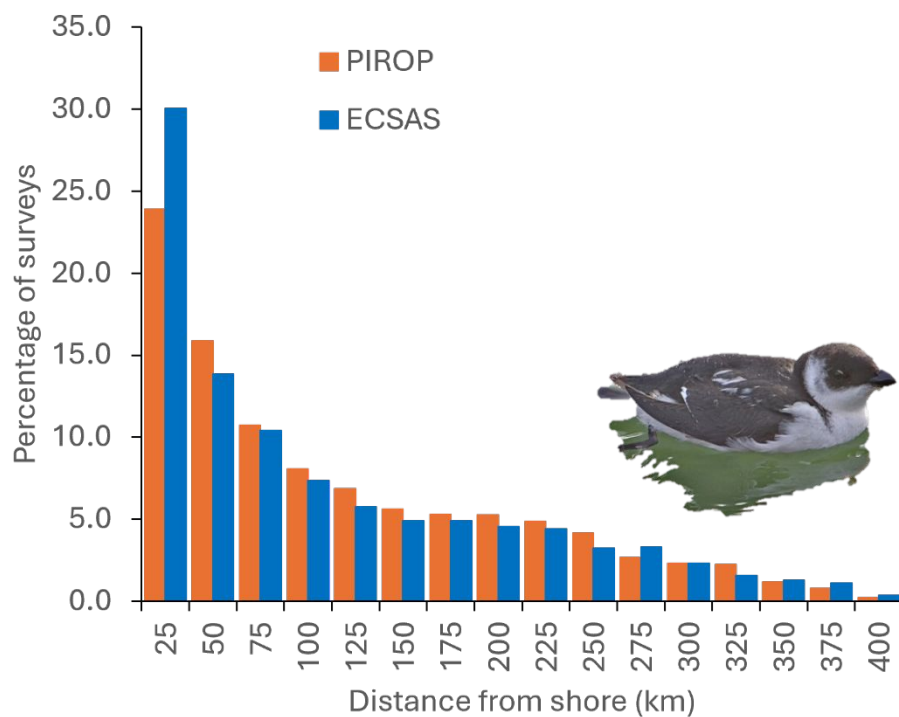


Fig. 5. Distribution of survey effort (percentage of surveys) as a function of distance from shore for PIROP (1969-1987) and ECSAS (2006-2023) monitoring programs within our study area in eastern Canada. Distance to shore calculated using Universal Transverse Mercator (UTM) distances with function gDistance from package Rgeos (Bivand and Rundel 2023). Photo insert of dovekie (*Alle alle*) on the water (photo Dave Fifield).