CRUISING FOR DATA: DEFINING THE SEABIRD COMMUNITY FROM VESSELS OF OPPORTUNITY IN CANADA'S EASTERN ARCTIC

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ABSTRACT

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Information on marine bird abundance and distribution at sea is required to identify important habitat for protection, mitigate pressures from human activities, and understand the role of seabirds in marine food webs. Arctic waters support millions of marine birds, including globally significant numbers of some species, but the remote location coupled with the financial costs of research and monitoring in this region limit our ability to quantify marine habitat use. We used standardized survey data collected from vessels of opportunity during 2007–2023 to describe the distribution and abundance of marine birds in eastern Canadian Arctic waters and to examine the relative contribution of data collected from two primary platform types: research vessels and cruise ships. Northern Fulmars *Fulmarus glacialis*, Thick-billed Murres *Uria lomvia*, Black-legged Kittiwakes *Rissa tridactyla*, and Dovekies *Alle alle* accounted for 92% of the sightings. The survey area covered by research vessels was 3.5 times greater than that covered by cruise ships, but there was minimal (< 1%) spatial overlap between the two platform types. Cruise ships travelled closer to shore and in shallower water than research vessels, including areas close to major colonies during the breeding season, which resulted in higher densities of birds observed. In addition to providing access to unique survey areas, cruise ships presented opportunities to engage tourists in the process of science and the outcomes of biodiversity monitoring programs. Large-scale monitoring programs that include boat-based surveys from a variety of platform types and collaboration among multiple organizations will remain important for defining marine bird habitat use in an area where human impacts are increasing as sea ice cover declines.

Key words: community composition, cruise ships, eastern Canadian Arctic, research vessels, seabird surveys, ships of opportunity

INTRODUCTION

Understanding the spatiotemporal distribution of seabirds at sea is critical to identify important habitat for protection and to minimize pressures from human activities in areas away from breeding colonies, where these species spend most of their time. Such pressures may include fishery interactions that lead to preyscape alteration or depletion (Grémillet et al., 2018), incidental bird mortality from entanglements (Dias et al., 2019; Hedd et al., 2016), and oil exposure from drilling rigs and vessels (King et al., 2021; Troisi et al., 2016; Wong et al., 2018). Additional pressures include light pollution (Gjerdrum et al., 2021) and marine plastic exposure, for which population impacts are not yet understood (Clark et al., 2023; Mallory et al., 2021). Displacement and collision risk from an emerging offshore wind farm industry has been shown to cause habitat loss and mortality (Garthe et al., 2023; Marques et al., 2021; Peschko et al., 2024). Together with a changing ocean, these factors all add further pressure to a group of birds that is already considered globally imperiled (Croxall et al., 2012). Survey data that can quantify the abundance and distribution of seabirds at sea helps inform the management of their populations (Arimitsu et al., 2023), including status and trends, and it can provide insight into marine ecosystem structure and variation in ocean conditions (Ballance, 2007; Kuletz et al., 2024; Piatt et al., 2007).

Offshore seabird surveys in the Arctic, where direct human impacts have been classified as relatively low due to limited human access (Halpern et al., 2015), are becoming increasingly important as sea ice cover declines and tourism, resource exploration, and coastal development increase (Pizzolato et al., 2014, 2016). The waters off Nunavut and Nunavik[1] in Canada's Eastern Arctic are estimated to support more than two million breeding pairs of seabirds, in addition to countless non-breeding individuals and migrants (Gaston et al., 2012; Mallory & Fontaine, 2004); this includes globally significant numbers of some species (Gaston et al., 2012; Maftei et al., 2012; Spencer et al., 2015). Although limited, baseline surveys through Arctic waters have identified important areas where marine birds congregate (McKinnon et al., 2009; Wong et al., 2014), highlighting conservation concerns where there is overlap with both fishing and shipping activities (Halliday et al., 2022; Hedd et al., 2016; Wong et al., 2018). Vessel traffic associated with multiple industries has more than doubled in the past two decades and is expected to increase further as rates of resource extraction rise (Dawson et al., 2018; Halliday et al., 2022). Understanding how seabirds respond to changing ocean conditions in the Arctic, and to the human activities that are expanding into previously unexploited areas, requires ongoing and repeated survey effort.

Surveys from boats and planes are commonly used to estimate the distribution and abundance of seabirds at sea (Camphuysen &

[1] The political territories in Canada (Yukon, Northwest Territories, and Nunavut) do not encapsulate the full extent of the land claims and governments of the northern Indigenous people of Canada. We refer to the region of Nunavik to be geographically descriptive while acknowledging its sociocultural and political distinctiveness from that region in Quebec.

Garthe, 2004; Gjerdrum et al., 2024). Each platform type comes with advantages and limitations based on specific project goals, although the choice of survey platform often depends on the target species, size of the survey area, distance from shore, safety considerations, and project budget (Briggs et al., 1985; Winiarski et al., 2014). Ideally, these surveys follow a systematic grid with a random starting point, and all parts of the study area have an equal probability of being included in the survey (Buckland et al., 2001). In general, these designed surveys provide a large-scale perspective (on the order of hundreds to thousands of kilometers) of the population-level distribution, abundance, and habitat associations of birds offshore (Louzao et al., 2009), but they can be impractical or prohibitively expensive to conduct, especially in the remote regions of the Arctic (Mallory et al., 2018). For large geographic areas, such as those within the exclusive economic zone (EEZ) of eastern and Arctic Canada, placing trained seabird observers on vessels that are transiting remote areas for other reasons (i.e., vessels of opportunity) to conduct surveys eliminates the costs associated with chartering a vessel or plane and increases the spatiotemporal survey coverage. Since 2006, this has been the approach used by the Eastern Canada Seabirds at Sea (ECSAS) monitoring program coordinated by the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada (Gjerdrum et al., 2012a, 2024). However, it remains unknown how different vessel types with varying itineraries contribute to our understanding of seabird distribution in Eastern Canada.

Hundreds of vessels travel through Canadian Arctic waters every year (Pizzolato et al., 2014), but not all provide suitable seabird survey opportunities. Fishing vessels are most common (Wong et al., 2018) but should generally be avoided as a platform for seabird surveys, as they can attract seabirds looking for food and thus generate counts that overestimate abundance (Hyrenbach, 2001). Merchant vessels or tankers can be too large or the observation areas too far astern, and they may cause birds to flush before they are detected (Borberg et al., 2005; Hyrenbach et al., 2007; but see Sydeman et al., 2010). In Atlantic Canada, supply vessels to offshore industrial sites (Fifield et al., 2009) and ferries (Huettmann, 1998) cover a specific route repeatedly and may allow monitoring of seabird abundance over time, but ships with such set itineraries have yet to be exploited for surveys in the Arctic. To date, the ECSAS monitoring program in the Arctic has instead relied primarily on oceanographic research vessels, both foreign and domestic, from which to conduct seabird surveys (Gjerdrum et al., 2024). These programs are led by large research institutions or governments 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). However, cruise and expedition-style passenger ships are increasingly seeking opportunities to support science. Unlike oceanographic research trips, cruise itineraries stop in communities and places of interest to passengers, which could also include hotspots of biodiversity (Dawson et al., 2016).

Although monitoring seabirds from vessels of opportunity can be cost-effective, researchers must consider the vessel's type and primary activities when using the data to describe seabird distribution and abundance to ensure biases are acknowledged. In this paper, we describe the distribution and abundance of seabirds in Canada's Eastern Arctic and examine the relative contribution of data collected from two primary platform types: research vessels and cruise ships. Specifically, we compare platform characteristics, survey effort, survey location, species abundance, and seabird community composition between research vessels and cruise ships. We then discuss the contribution that non-traditional collaborations and opportunistic vessels provide in regions where access is limited and the financial costs of research are high.

METHODS

Naming convention

We refer to birds using the Integrated Taxonomic Information System (ITIS) rather than latest edition of the World Bird List (version 14.2) published by the International Ornithological Community.

Study area

We defined the study area as the waters of Nunavut and Nunavik in Canada's Eastern Arctic, north of 60° latitude and east through Canada's EEZ (Fig. 1). The size of the area is approximately 2.5 million square kilometers and encompasses waters within most of the Canadian Arctic Archipelago, including those of Hudson Strait, northern Hudson Bay, Foxe Basin, Lancaster Sound, Jones Sound, and the Canadian territorial waters around Ellesmere Island and in Baffin Bay. This is a relatively shallow, shelf-dominated area that is ice-covered during much of the year (Michel et al., 2015). It connects the Arctic Ocean to Baffin Bay with nutrient-rich inputs from the Bering Sea (Colombo et al., 2021). These productive waters support a variety of marine birds, including important breeding colonies of Thick-billed Murres *Uria lomvia*, Black-legged Kittiwakes *Rissa tridactyla*, and Northern Fulmars *Fulmarus glacialis* (Fig. 1). The area also supports several known Ivory Gull *Pagophila eburnea* colonies and the breeding area for Ross's Gulls *Rhodostethia rosea* (Gaston et al., 2012), which are both currently on Canada's list of species at risk (Species at Risk Act, 2002). The study area includes a network of protected areas such as Canada's largest body of protected waters, the Tallurutiup Imanga National Marine Conservation Area (Halliday et al., 2022).

Seabird surveys

Trained observers conducted seabird surveys aboard vessels following a standardized survey protocol (Gjerdrum et al., 2012a). Observers surveyed from the bridge when the vessel was moving at a minimum speed of 4 knots (kts, 7.4 km/h), looking forward and scanning to a 90° angle on either the port or starboard side of the bridge, recording birds occurring within a transect band 300 m from the observer. Each survey lasted five minutes and observers conducted as many consecutive surveys as possible during daylight hours. At the beginning of each survey, observers recorded the vessel's position, speed, and direction, as well as a number of environmental variables including visibility (estimated in kilometers), glare, swell height, wind speed, wind direction, ice type, ice concentration, and sea state (Gjerdrum et al., 2012a).

Throughout each survey, observers recorded all birds on the water within the transect. Flying birds within transects were recorded using instantaneous counts (i.e., snapshots), the frequency of which was determined by the speed of the vessel (Gjerdrum et al., 2012a). This method of using snapshots documents the number of birds flying through a given area, which often move faster than the ship, and thus inflate density estimates (Gaston et al., 1987; Tasker et al.,

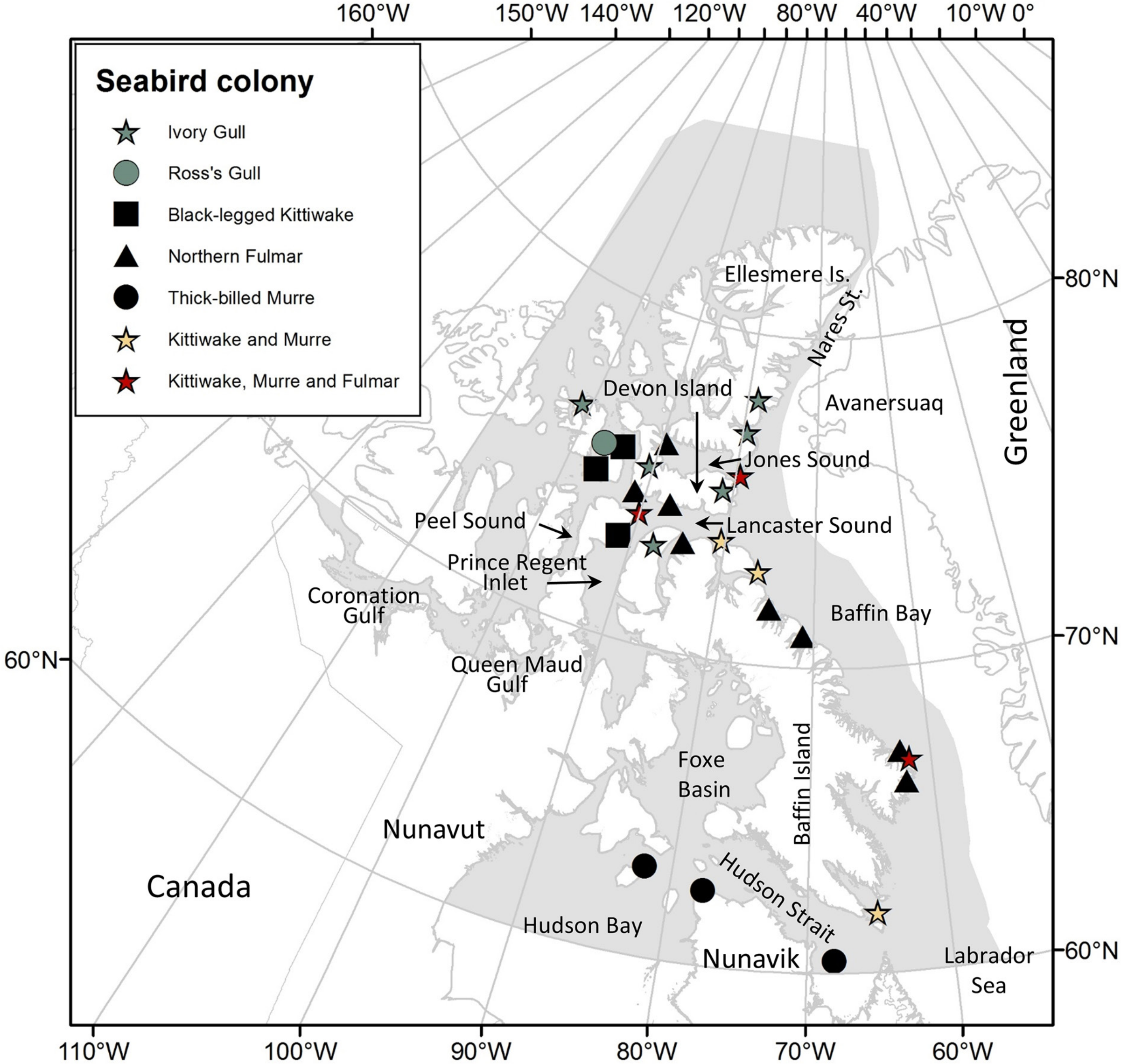

Fig. 1. Study area (grey shaded area) in Canada's Eastern Arctic during 2007–2023 showing the location of major seabird colonies for Thick-billed Murre *Uria lomvia*, Northern Fulmar *Fulmarus glacialis*, and Black-legged Kittiwake *Rissa tridactyla*, as well as known Ivory Gull *Pagophila eburnea* breeding colonies and the breeding area for Ross's Gull *Rhodostethia rosea*.

1984). Observers identified all birds observed within the transect to the species level (or to the lowest taxonomic designation when identification to species was not possible), estimated flock size, and recorded each bird's general behaviour (i.e., swimming, flying, feeding). The perpendicular distance to each sighting from the vessel's trackline was estimated in one of four distance bins (with limits of 50, 100, 200, and 300 m). 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 observers reverted to perpendicular distances when a comparison of methods showed the line-transect method provided superior results (Bolduc & Fifield, 2017). The ship's position was recorded at the beginning and end of each survey via an integrated GPS (Gjerdrum et al., 2024; Robertson et al., 2012); after 2009, observers also recorded the position at the location of each sighting. Observers first participated in a training course prior to data collection or were confirmed to have equivalent experience that met CWS standards (Gjerdrum et al., 2012b).

Within the study area, seabird surveys took place from one of two platform types: research vessels or cruise ships. We defined research vessels as those that supported government and/or academic scientists and had itineraries dedicated to primarily oceanographic scientific studies. In contrast, cruise ships were those that carried passengers and had itineraries focused on tourism and exploration.

Analysis

To determine if there were underlying differences in survey effort and conditions between research vessels and cruise ships, we used *t*-tests to compare the length of the survey trip (d), platform height (m), and platform speed (daily average in kts). We used the Wilcoxon rank sum test for ordered categorical variables to compare sea state (daily average sea state measured on the Beaufort scale). For the location of each survey point, we extracted water depth (m) at a resolution of 15 arc-sec (GEBCO Bathymetric Compilation Group 2024), and distance from shore (km) using the function *dist2Line* in the "geosphere" package in R (Hijmans, 2024). We log-transformed both the depth and the distance from shore because they were highly right-skewed, then we used a Welch's *t*-test to compare the daily mean depth and the daily mean distance from shore between vessel types (Table 1).

Within the study area, we characterized the patterns of marine bird community composition using k-means cluster analysis ("ClusterR" package). We grouped 50-km hexagonal grid cells based on similarity in bird densities and species (or groups of species) following the methods presented by Kuletz et al. (2019). We included only those hexagonal grids that had at least 15 km of survey effort. Densities (i.e., birds seen per km^2) were log-transformed prior to the cluster analysis and based on densities only (i.e., not the coordinates of the grid cell). The optimal number of clusters was determined visually using the elbow method (i.e., plotting explained variance by the number of clusters and choosing the inflection point) and the silhouette method (i.e., measuring how well observations fit into assigned clusters and maximizing the average measure over a range of possible cluster numbers). We used waffle charts to visualize and compare species composition for each cluster type, and then we mapped cluster type within the 50-km hexagonal grid to illustrate the patterns of community composition across the region.

In our cluster analysis, we elected to combine the species that were encountered less frequently into higher-order taxonomic groups or into groups based on ecological niche or foraging guild. Groupings were as follows: loons and cormorants, shearwaters and petrels, geese and ducks (without eiders), eiders, phalaropes, skuas and jaegers, alcids (without Thick-billed Murre, Black Guillemot *Cepphus grylle*, and Dovekie *Alle alle*), and gulls and terns (without Black-legged Kittiwake and Glaucous Gull *Larus hyperboreus*; Table 2). Some observations were not classified to the species level, including unidentified murres (n = 737), unidentified alcids (n = 436), murre or Razorbill *Alca torda* (n = 23), and unidentified gulls (n = 44). These were pro-rated into higher-order taxa based on the corresponding species ratios within each grid cell (refer to Kuletz et al., 2019). In the few cases where there were no corresponding species in the given grid cell (n = 9), the sighting was classified as the species with the highest density in that group (e.g., one sighting of an unidentified gull was classified as Glaucous Gull, as that species accounted for 81% of all gull sightings).

We calculated density for each five-minute survey period by dividing the number of bird sightings by the survey area (birds per square kilometer), then calculated an average density within each grid cell for each vessel type. Although surveys employed fixed-width distance sampling to account for variation in bird detectability (Buckland et al., 2001), we report uncorrected density estimates because the distance-sampling methods for flying birds varied among the surveys within our study period (Bolduc & Fifield, 2017; Gjerdrum et al., 2024). Therefore, we compare relative abundance estimates across platform type and note that density values represent minimum densities.

We calculated the total survey area in ArcGIS (ArcMap 10.8.2) by first creating individual transect polygons using the x- and y-coordinates of the start and end positions, the transect width (to account for variations is visibility due to fog), and side of the vessel where the survey took place (i.e., port or starboard) for each survey. We then unified any overlapping transect polygons for the research

TABLE 1
Comparison of seabird survey effort conducted from research vessels and cruise ships within waters of the eastern Canadian Arctic during 2007–2023

Variable[a]	Research vessel	Cruise ship
Number of survey trips	39	26
Number of days surveyed	342	168
Number of survey vessels	11	6
Number of seabird observers[b]	22	21
Total survey distance (km)	33,887	9,305
Total area surveyed (km^2)	10,441	2,985
Number of individual seabirds observed	67,077	47,716
Number of bird species identified	38	29
Mean platform height (m) ± SD (range)	14.4 ± 4.1 (5.0–17.7)	11.3 ± 4.7 (2.9–16.6)
Mean platform speed (knots) ± SD (range)**	10.9 ± 2.3 (4.4–17.2)	10.3 ± 2.1 (5.0–14.6)
Mean sea state[c] ± SD (range)*	4.0 ± 1.3 (2–7)	3.7 ± 1.2 (2–7)
Mean length (days) of survey trip[d] ± SD (range)**	20.9 ± 9.2 (6–40)	12.8 ± 6.4 (1–33)
Median distance (km) from shore (range)***	40.1 (1.5–338.5)	14.0 (1.5–306.5)
Median depth (m) at survey location (range)***	400.6 (20.3–2,757.9)	272.3 (25.5–2,490.6)

[a] SD = standard deviation. For statistical significance, * indicates $P < 0.05$; ** indicates $P < 0.01$; *** indicates $P < 0.0001$.
[b] Five observers conducted surveys from both research vessels and cruise ships.
[c] Beaufort sea state description code used to describe the sea surface on a scale of 0–9 (Gjerdrum et al., 2012a).
[d] We excluded from the analysis a cruise-ship expedition from Montreal, Quebec, to Iqaluit, Nunavut, during which participants focused on bird surveys for only three of the 44 days.

TABLE 2
Comparison of seabird sightings (number of each species seen) recorded from research vessels and cruise ships within the eastern Canadian Arctic during 2007–2023

Species	Scientific name	Vessel type	
		Research	Cruise
Loons		**8**	**47**
Yellow-billed Loon	*Gavia adamsii*	2	3
Red-throated Loon	*Gavia stellata*	0	41
Pacific Loon	*Gavia pacifica*	5	0
Unidentified loon	*Gavia* spp.	1	3
Tubenoses		**25,087**	**12,065**
Northern Fulmar	*Fulmarus glacialis*	25,060	12,008
Great Shearwater	*Ardenna gravis*	5	53
Sooty Shearwater	*Puffinus griseus*	2	2
Unidentified shearwater	*Puffinus* or *Calonectris* spp.	2	2
Wilson's Storm-Petrel	*Oceanites oceanicus*	15	0
Leach's Storm-Petrel[a,b]	*Hydrobates leucorhoa*	2	0
Unidentified storm-petrel	*Oceanites* or *Hydrobates* spp.	1	0
Gannets		**1**	**0**
Northern Gannet	*Morus bassanus*	1	0
Cormorants		**12**	**1**
Double-crested Cormorant	*Phalacrocorax auritus*	12	1
Geese		**35**	**5**
Greater White-fronted Goose	*Anser albifrons*	14	0
Snow Goose	*Anser caerulescens*	21	0
Canada Goose	*Branta canadensis*	0	5
Diving ducks		**849**	**1,466**
Common Eider[b]	*Somateria mollissima*	433	94
King Eider	*Somateria spectabilis*	159	26
Unidentified eider	*Somateria* spp.	25	39
Long-tailed Duck[a]	*Clangula hyemalis*	226	1,301
Black Scoter[b]	*Melanitta nigra*	0	4
Unidentified duck	Anatidae	6	2
Phalaropes		**461**	**872**
Red-necked Phalarope[c]	*Phalaropus lobatus*	77	14
Red Phalarope	*Phalaropus fulicarius*	245	728
Unidentified phalarope	*Phalaropus* spp.	139	130
Skuas and jaegers		**169**	**39**
Great Skua	*Stercorarius skua*	1	0
Pomarine Jaeger	*Stercorarius pomarinus*	67	5
Parasitic Jaeger	*Stercorarius parasiticus*	20	17
Long-tailed Jaeger	*Stercorarius longicaudus*	65	11
Unidentified jaeger	*Stercorarius* spp.	16	6
Gulls and terns		**6,873**	**16,054**
Black-legged Kittiwake[a]	*Rissa tridactyla*	5,037	15,151
Ivory Gull[b,e,g]	*Pagophila eburnea*	32	15
Ross's Gull[d,f]	*Rhodostethia rosea*	13	0
Sabine's Gull	*Xema sabini*	110	10
Black-headed Gull	*Chroicocephalus ridibundus*	1	0
Herring Gull	*Larus argentatus*	53	4
Iceland Gull	*Larus glaucoides*	122	48
Glaucous Gull	*Larus hyperboreus*	1,344	748
Thayer's Gull	*Larus thayeri*	42	18
Lesser Black-backed Gull	*Larus fuscus*	2	0
Great Black-backed Gull	*Larus marinus*	12	4
Unidentified gull	Laridae	33	11
Arctic Tern	*Sterna paradisaea*	72	45
Alcids		**33,582**	**17,167**
Razorbill	*Alca torda*	2	0
Common Murre	*Uria aalge*	29	0
Thick-billed Murre	*Uria lomvia*	13,854	14,514
Unidentified murre	*Uria* spp.	727	10
Murre or razorbill	*Uria* or *Alca* spp.	20	3
Dovekie	*Alle alle*	17,870	2,204
Black Guillemot	*Cepphus grylle*	642	412
Atlantic Puffin	*Fratercula arctica*	23	3
Unidentified alcid	Alcidae	415	21
Total sightings		**67,077**	**47,716**
Total species		**38**	**29**

[a] International Union for Conservation of Nature (IUCN, Global) Vulnerable
[b] IUCN Near Threatened
[c] Committee on the Status of Endangered Wildlife in Canada (COSEWIC, Canada) Special Concern
[d] COSEWIC Threatened
[e] COSEWIC Endangered
[f] Species at Risk (Canada) Threatened
[g] Species at Risk (Canada) Endangered

vessel and cruise ship transects (separately) using the Dissolve tool in ArcGIS to remove boundaries between adjacent polygons; this created two survey-area polygons and calculated the total survey area for each. Finally, we calculated the area of overlap between the two final polygons using the Union tool. All other analyses were conducted in R (version 4.2.1).

RESULTS

Survey effort

During 2007–2023, we conducted 65 survey trips within the study area, 39 from research vessels and 26 from cruise ships (Table 1). A total of 22 different observers counted seabirds from 11 research vessels over 342 survey days along 33,887 km (Table 1, Fig. 2A). Within the same area, 21 different observers (five of which also observed aboard the research vessels) conducted surveys from six cruise ships over 168 days along 9,305 km (Table 1, Fig. 2B). Across all years, the total area surveyed from research vessels was 10,441 km^2 compared to 2,985 km^2 from cruise ships, with 84 km^2 of overlap (Fig. 2C) between the two platform types (0.6% of the total survey area). Surveys from research vessels were conducted annually from June until October during 2007–2023 (17 years), while surveys from cruise ships were conducted from July until September in 11 of those 17 years (2008–2010; 2013; 2015–2019; 2022–2023; Fig. 3A, 3B).

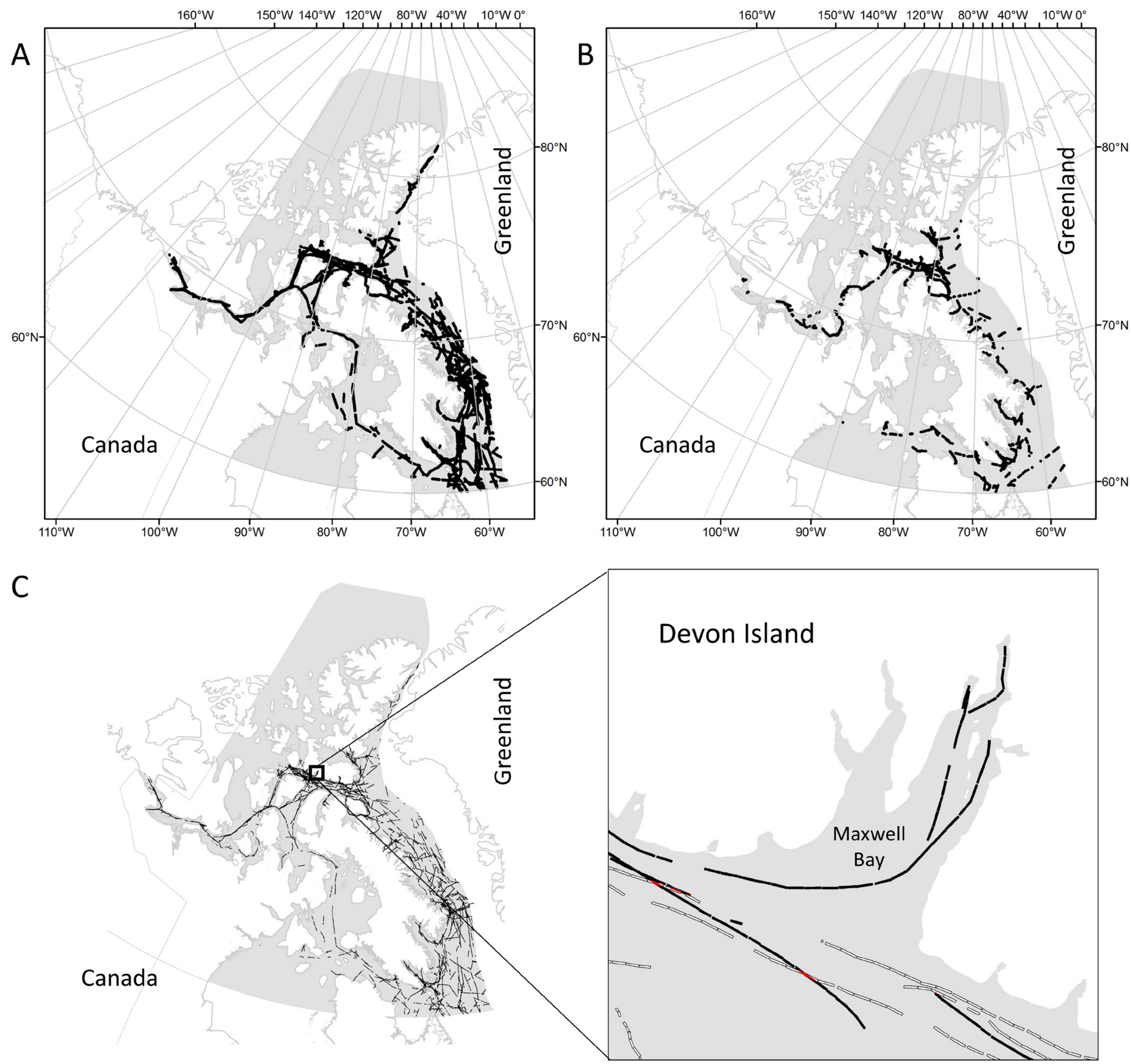

Fig. 2. Location of surveys (black points) conducted within the study area (grey shaded area) in Canada's Eastern Arctic from A) research vessels and B) cruise ships during 2007–2023. Panel C) shows detailed survey transects in Maxwell Bay from research vessels (grey lines) and cruise ships (black lines) as an example of areas where survey areas overlapped (highlighted in red).

The height from which observers conducted their surveys (i.e., the height of the vessel's bridge above the water) was similar between vessel types ($t_{15} = -1.15$, $p = 0.14$; Table 1). Most surveys (94.1% from research vessels and 96.8% from cruise ships) were conducted when vessel speed exceeded 6 kts, although research vessels averaged a faster speed than cruise ships ($t_{354.7} = -2.80$, $p = 0.005$; Table 1). Average daily sea state during research-vessel surveys was also significantly higher compared to surveys from cruise ships (W = 25935, $p = 0.030$; Table 1). However, differences in platform speed and sea state between platform types were small: the average platform speed differed by 0.6 kts (1.1 km/h), and the average sea state differed by less than one level (Table 1). Therefore, we expected no difference in species detection rates, composition, or abundance estimates as a result of these differences. The total trip length (number of days at sea between port calls) was significantly longer on research vessels than on the cruise ships ($t_{62} = 3.84$, $p = 0.003$; Table 1). Overall, the geographic extent of the survey effort was similar between platform types (Fig. 2), although research vessels travelled further north (maximum latitude 81.7°N) than did cruise ships (maximum latitude 77.4°N). On average, surveys from research vessels were conducted further from shore ($t_{499} = -9.18$, $p < 0.0001$) and in deeper waters ($t_{495.3} = -6.78$, $p < 0.0001$; Table 1).

Species abundance and distribution

A total of 114,793 birds were sighted: 67,077 individuals (38 species) from research vessels and 47,716 individuals (29 species) from cruise ships (Table 2). Northern Fulmars, Thick-billed Murres, Black-legged Kittiwakes, and Dovekies accounted for 92.2% of the sightings from research vessels and 92.0% from cruise ships (Table 2). Compared to surveys from cruise ships, surveys from research vessels sighted a higher proportion of Dovekies, other alcids (excluding Thick-billed Murres), skuas and jaegers, eiders, other geese and ducks (excluding Long-tailed Ducks *Clangula hyemalis*), Northern Fulmars, Glaucous Gulls, and other gulls and terns (excluding Black-legged Kittiwakes; Fig. 4). Conversely, cruise-ship surveys recorded proportionally more Thick-billed Murres, phalaropes, shearwaters and petrels, loons and cormorants, Black-legged Kittiwakes, and Long-tailed Ducks (Fig. 4). Research-vessel surveys identified 12 species that were not observed from cruise ships (Table 2), whereas Red-throated Loons *Gavia stellata*, Canada Geese *Branta canadensis*, and Black Scoters *Melanitta nigra* were observed only from cruise ships (Table 2). Both platform types documented species of conservation concern (Table 2).

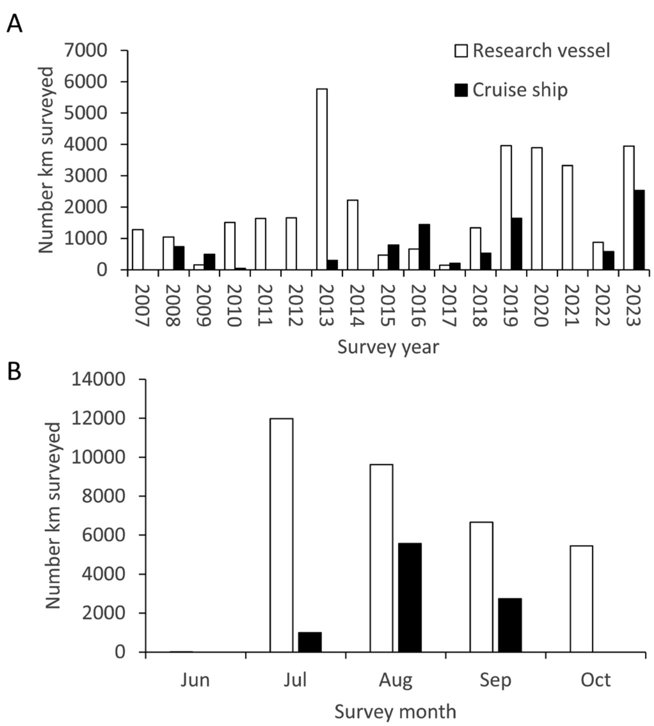

Fig. 3. Number of kilometers surveyed from research vessels (open bars) and cruise ships (solid bars) by year in Canada's Eastern Arctic from A) 2007 to 2023; and B) by month within the study area.

Seabirds were observed throughout the study area. Out of 528 cells, we recorded zero sightings in just 38 cells (7.2%), the majority of those occurring within Foxe Basin, Queen Maud Gulf, and Coronation Gulf (Fig. 5A, B). Average cell densities were highest (> 10 birds/km^2) through Lancaster Sound, Jones Sound, Baffin Bay, Davis Strait, the northern part of Labrador Sea, and parts of Hudson Strait, particularly around seabird colonies (Fig. 5A, B). Research vessels recorded densities greater than 10 birds/km^2 in 18% of the cells surveyed, with a maximum average cell density of 161.3 birds/km^2 (all Dovekies) recorded in Nares Strait near Dovekie colonies in Avanersuaq, Greenland (Fig. 5A). In comparison, cruise-ship surveys recorded average densities greater than 10 birds/km^2 in 30% of cells, with the greatest average densities (> 100 birds/km^2) adjacent to Northern Fulmar and Thick-billed Murre colonies (Fig. 5B). The maximum average cell density (1,343.8 birds/km^2) from cruise-ship survey data occurred in the vicinity of Prince Leopold Island in western Lancaster Sound, where an estimated 145,000 Thick-billed Murres, Northern Fulmars, and Black-legged Kittiwakes breed (Gaston et al., 2012; Fig. 1).

Seabird community composition

Seabird sightings within the study area (all data combined) clustered into five community types, four of which were dominated (> 70%) by a single species (Fig. 6A). The Thick-billed Murre community (75.0% of cluster 1) had the highest density (31.2 birds/km^2) and also included Black-legged Kittiwakes, Northern Fulmars, Dovekies, Glaucous Gulls, and phalaropes. The Dovekie community (79.8% of cluster 2) had a density of 12.9 birds/km^2 and included Thick-billed Murres, Northern Fulmars, and Black-legged Kittiwakes. The Northern Fulmar community (73.4% of cluster 3) had a similar density (13.9 birds/km^2) to the Dovekie community and included Thick-billed Murres, Black-legged Kittiwakes, Glaucous Gulls, and Black Guillemots. The fourth cluster was defined as a low-density community (1.8 birds/km^2) with no dominant species. It included Northern Fulmars, Thick-billed Murres, Black-legged Kittiwakes, Dovekies, eiders, and Black Guillemots. The final cluster also had a low density (1.9 birds/km^2) but was composed almost entirely of Long-tailed Ducks (Fig. 6A). Several classification groups (Table 2) included species that were observed infrequently (i.e., loons and cormorants, shearwaters and petrels, Northern Gannets *Morus bassanus*, other geese and ducks, skuas and jaegers, other gulls and terns, other alcids) and made negligible contribution to the overall density. Therefore, these were not assigned to any community.

The Thick-billed Murre community was distributed among colonies in Lancaster Sound, around Devon Island, on eastern Baffin Island, and throughout Hudson Strait and northern Hudson Bay (Fig. 6B). The Dovekie community was dominant offshore through Baffin

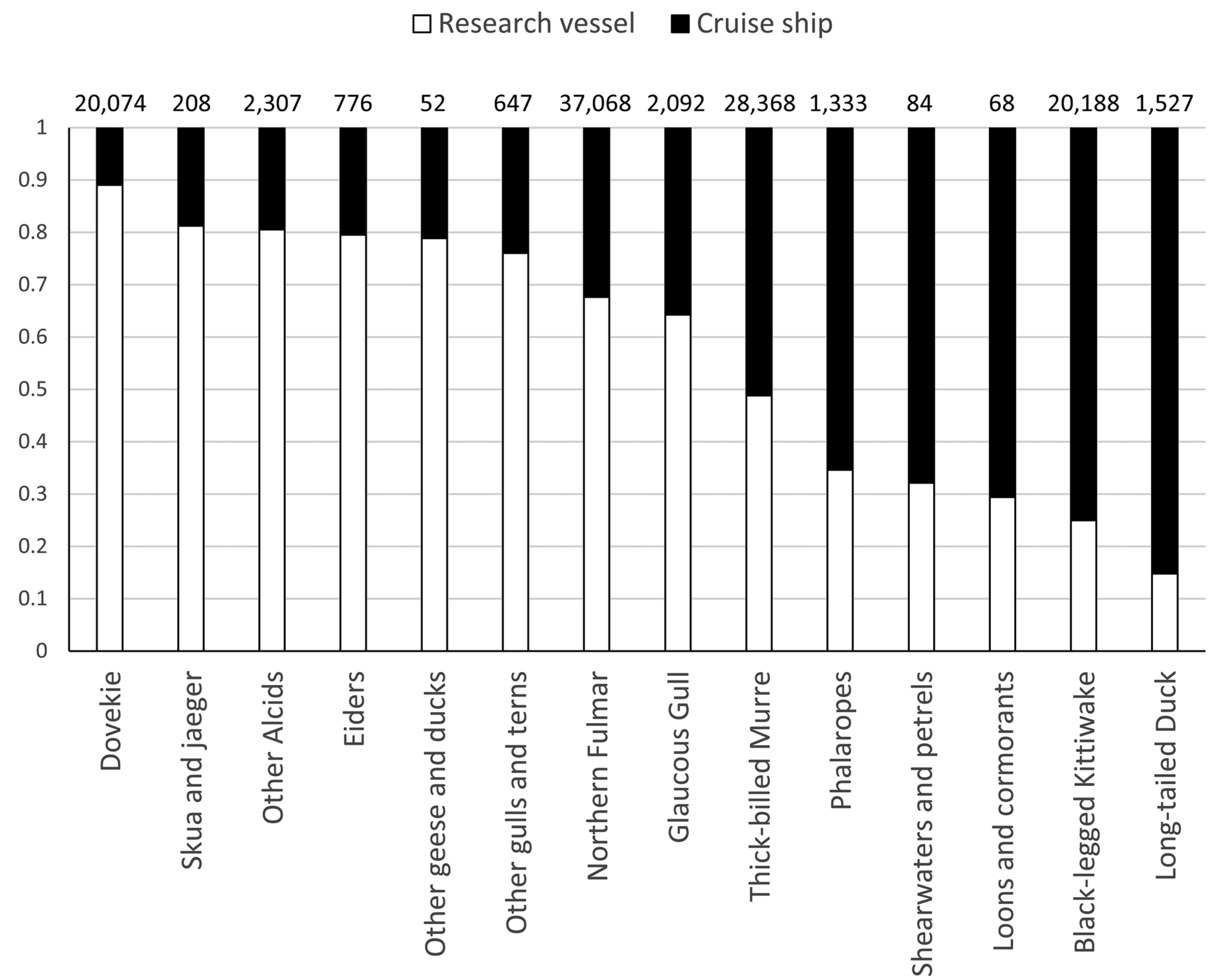

Fig. 4. Proportion of species (see Table 2 for classification groups and scientific names) sighted from research vessels (open bars) and cruise ships (solid bars) within the study area in Canada's Eastern Arctic during 2007–2023.

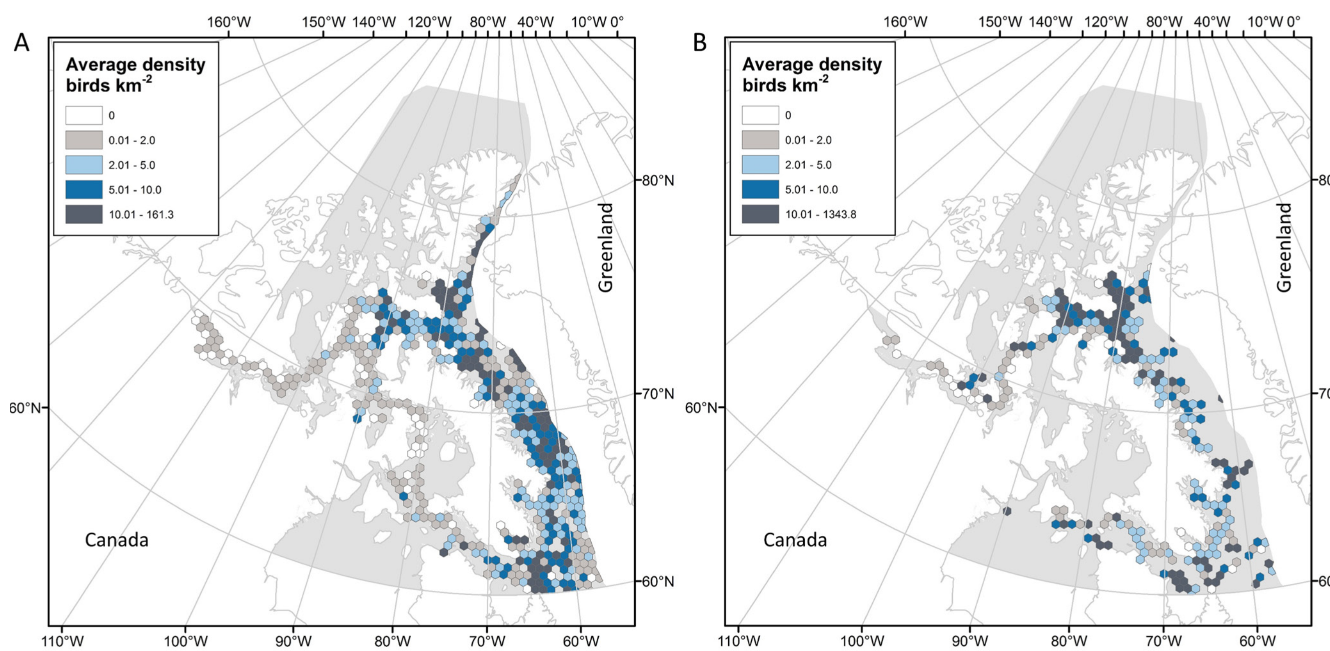

Fig. 5. Average seabird density (birds/km^2) within each 50-km hexagon grid cell as assessed by A) research vessels and B) cruise ships in Canada's Eastern Arctic during 2007–2023.

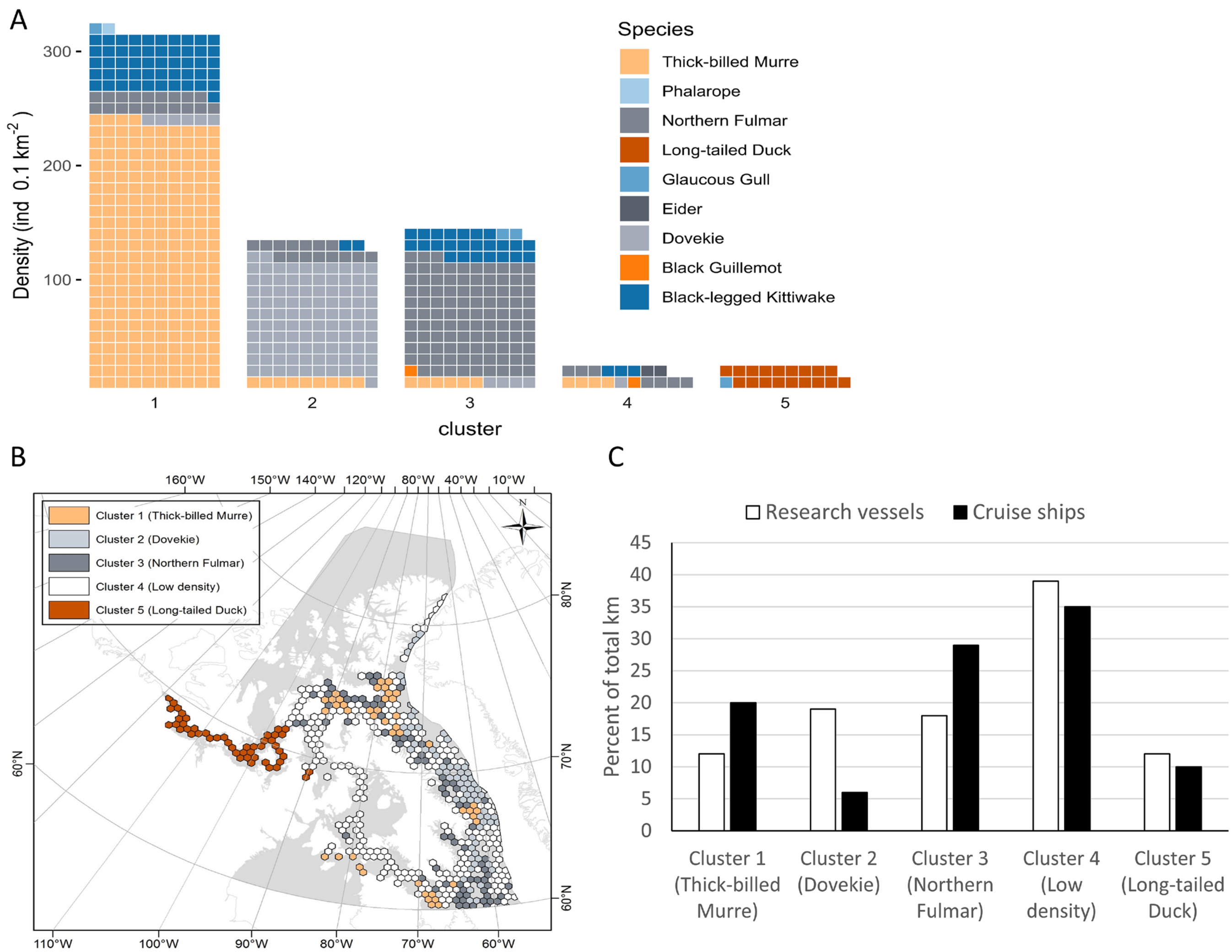

Fig. 6. Species composition and relative abundance of A) five seabird communities identified with cluster analysis using all survey data collected in Canada's Eastern Arctic during 2007–2023. Each waffle cell represents 0.1 birds/km^2. Also shown are B) the distribution of community types using 50-km hexagonal grid cells, and C) the distribution of survey effort (percent of total survey kilometers) within each cluster by ship type (research vessel vs. cruise ship). See Table 2 for scientific names.

Bay and up through Nares Strait towards the northern extent of our study area. The Northern Fulmar community also occupied areas around breeding colonies but was more widely dispersed than the Thick-billed Murre community, particularly offshore in the northern Labrador Sea. The low-density community occupied areas throughout the study area but dominated through Hudson Strait, along the western edge of Foxe Basin, in Prince Regent Inlet, and in Peel Sound. The low-density Long-tailed Duck community was confined to the westernmost survey area in Queen Maud Gulf and Coronation Gulf (Fig. 6B). In general, a higher proportion of the cruise-ship survey effort (measured as percent of total survey kilometers) occurred in the Thick-billed Murre and Northern Fulmar community types compared to research-vessel surveys, which had a higher proportion of effort in the Dovekie community type (Fig. 6C).

DISCUSSION

General considerations: Vessel comparisons

Our results show that cruise ships, with varied routes in remote regions of Canada's Eastern Arctic, provided added value to a pelagic seabird monitoring program that has previously relied primarily on oceanographic research vessels (Gjerdrum et al., 2024). Although the survey area covered by research vessels was 3.5 times greater than the area covered by cruise ships, there was minimal spatial overlap between the two platform types (< 1%). Cruise ships travelled closer to shore and in shallower waters than research vessels, providing coverage near colonies of Thick-billed Murres, Northern Fulmars, and Black-legged Kittiwakes during the breeding season. That effort resulted in the highest densities of birds that were observed. As a result, surveys from cruise ships sighted proportionally more nearshore species than did surveys from research vessels, such as loons, cormorants, and Long-tailed Ducks, and fewer offshore species, such as Dovekies. Both platform types documented species of conservation concern (Table 2).

The surveys from cruise ships, which travelled closer to shore than research vessels, were an important source of information around colonies (Gaston et al., 2012) and in areas where human activities such as fishing and shipping are most intense (Halliday et al., 2022; Halpern et al., 2015). Ship-based counts, together with bird tracking data and included within predictive models, can identify important foraging areas of breeding populations and provide key information for designating Marine Protected Areas and other conservation measures (Arcos et al., 2012; Augé et al., 2018; Mallory et al., 2019; Ronconi et al., 2022; Sonntag et al., 2012). When resources allow, dedicated survey vessels that follow a systematic grid of lines (Buckland et al., 2001) would provide the most robust estimates of distribution and abundance across the region (Louzao et al., 2009) and particularly around colonies. Aerial surveys (digital or visual) may provide broader spatial coverage in less time than ship-based surveys (Buckland et al., 2012; Pettex et al., 2017), and they can be an important source of data when vessel activity is limited (i.e., beyond the shipping season; Halliday et al., 2022). However, rare birds and groups that are difficult to discriminate (i.e., small gulls and alcids) are most efficiently identified from ships (Briggs et al., 1985).

Boat-based tourist traffic, which has increased significantly in recent decades along the eastern side of Baffin Island and the southern route of the Northwest Passage, provides seabird survey opportunities in prime locations for spotting wildlife (Dawson et al., 2016, 2018). Included are marine waters adjacent to seabird colonies that are not necessarily focal areas for oceanographic research. In the Southern Ocean, survey data from cruise ships have been used to describe seabird distribution relative to habitat characteristics in biodiversity hotspots of interest for tourists (Ollus et al., 2023). As an aside, Henderson et al. (2023) demonstrated the potential use of tourist-vessel surveys to predict baleen whale abundance and distribution. In addition to providing access to unique survey areas, cruise ships with itineraries focused on passenger experience present opportunities to engage tourists in the process of science and the outcomes of biotic monitoring programs. When not conducting surveys, wildlife observers travelling on cruise ships interact both formally (e.g., data-focused seminars) and informally with passengers, who are typically outside of academia and the field of conservation science. This results in positive outcomes for both the public and the seabird observers (Varner, 2014). In addition, cruise-ship itineraries can support student and volunteer observers (e.g., Mallory et al., 2021), as the trips are typically shorter than research itineraries (Table 1) and do not require security clearance or marine safety training, which are mandatory for travel on government research vessels. As a result, surveys from cruise ships provide early-career and citizen scientists the opportunity to gain valuable experience and collect useful data, although new observers should receive training to ensure they meet minimum standards (Gjerdrum et al., 2012b) to maintain data consistency among observers.

Research vessels in our study area provided survey coverage further offshore than cruise ships and extended the seasonal coverage beyond September (Fig. 3B), when cruise ships have largely left the region ahead of advancing sea ice. Conducting seabird surveys from research vessels that focus on chemical and biological oceanographic sampling has the added benefit of exploring the underlying mechanisms of observed seabird distributions (Kuletz et al., 2019; Renner et al., 2013; Sydeman et al., 2010). Integrating the collection of seabird data into oceanographic research programs facilitates an appreciation of the role seabirds play in marine food webs (Ainley et al., 2012). Such integration also provides data that can offer insights into ecosystem status and change (Piatt et al., 2007) and informs conservation initiatives such as Marine Protected Area designations (Fisheries and Oceans Canada, 2017). For the extensive eastern and Arctic waters of Canada, surveys from a variety of vessel types that can provide complementary information will remain important for monitoring seabirds throughout this area.

Seabird communities

By combining data collected from both research vessels and cruise ships, we identified five seabird community types within our study area, four of which were dominated by a single species. Thick-billed Murre is the most abundant seabird species in the eastern Canadian Arctic (Gaston et al., 2012; Mallory et al., 2019), likely explaining why the Thick-billed Murre community had the highest density of the five clusters. This community occupied areas around major (> 1,000 pairs) colonies in Jones Sound, Lancaster Sound, Hudson Strait, and eastern Baffin Island, where colony estimates suggest a total population of 1.54 million breeding pairs (Gaston et al., 2012). The spatial distribution of the Thick-billed Murre community reaffirms key marine habitat sites that were previously identified for Thick-billed Murres using tracking data (Mallory et al., 2019). Similarly, the Northern Fulmar community occupied marine areas near colonies, specifically around Devon Island and along eastern Baffin Island, where 174,000 pairs are estimated to breed (Gaston et al., 2012). The Northern Fulmar community also occupied offshore areas in the northern Labrador Sea that were largely beyond the foraging range of colonies (Mallory et al., 2019) but likely included non-breeding birds and individuals of European origin (Fifield et al., 2016).

Black-legged Kittiwakes were the second largest contributor to both the murre and fulmar community clusters, which occurred where colonies of three common Arctic species are also located, including Coburg Island, Cape Hay, Prince Leopold Island, and Hantzsch Island (Gaston et al., 2012; Mallory et al., 2019). The Dovekie community, dominant in offshore Baffin Bay through Nares Strait, likely represents post-breeding birds from the Avanersuaq region of northwestern Greenland, where breeding estimates exceed 10 million pairs (Montevecchi & Stenhouse, 2020). The vast majority of Dovekies recorded during our surveys (76.6%) were sighted in August and September, when breeders from Greenland colonies move into Baffin Bay to stage (Fort et al., 2013), although sightings may also have included individuals from the small colony on eastern Baffin Island (Finley & Evans, 1984). The community composed almost entirely of Long-tailed Ducks was observed in low densities through Queen Maud Gulf and Coronation Gulf in the heart of the species' breeding range, although the majority (97.4%) were observed in September during their peak moulting period (Robertson & Savard, 2020).

The low-density community, made up of the four most abundant Arctic species (fulmars, murres, kittiwakes, and Dovekies) plus eiders and Black Guillemots, dominated from western Hudson Strait through to Peel Sound. There are no large seabird colonies in this region (Gaston et al., 2012), as ice cover may remain relatively late into the breeding season and restrict foraging options (Andrews et al., 2018). Fulmars, kittiwakes, and murres in this region are likely non-breeders or failed breeders; the area is more suited to shallow-diving or nearshore species (i.e., eiders, guillemots, and small gulls). A similar study describing seabird assemblages in the Gulf of Mexico also identified a broadly distributed, low-density community that lacked any dominant species (Michael et al., 2023). Such low-density assemblages may capture non-aggregating behaviours such as commuting, migrating, or dispersal (Michael et al., 2023) that nevertheless convey important biological information with conservation value (Marchese, 2015).

Considerations for future surveys

In the Canadian Arctic, vessel traffic has more than doubled in the past two decades and is expected to increase further as ice cover declines and rates of resource extraction rise (Dawson et al., 2018; Halliday et al., 2022). As a result, a greater variety of vessel types, such as pleasure craft, cargo ships, oil and gas exploration vessels, and container ships, could be exploited for seabird surveys (Gjerdrum et al., 2024; Renner et al., 2013; Sydeman et al., 2010). Such an expansion of survey effort would however require a corresponding increase in participation by trained industry observers, such as those assessing the impacts of offshore industrial activities on marine wildlife (e.g., Fisheries and Oceans Canada, 2012). Collectively, these ships may provide cost-effective opportunities to collect data at sea across large geographic areas and beyond the breeding season. There is also potential to provide inter- and intra-seasonal abundance estimates for some species when established routes are travelled repeatedly, such as those used by ferries and resupply ships. Partnering with Indigenous governments and organizations will further enhance our ability to describe the Arctic seabird community, particularly in nearshore areas, and provide information relevant to emergency preparedness and response in remote regions. For example, during a 2020 diesel spill in the remote community of Postville in Newfoundland and Labrador, Canada, ECSAS-trained Inuit wildlife observers from the community conducted at-sea surveys to assess marine bird distribution and abundance in the area, contributing valuable information to the response measures. Large-scale monitoring programs that include boat-based surveys from a variety of survey platforms in collaboration with multiple organizations will remain important for defining marine habitat use by one of the most imperiled bird groups on the planet.

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AUTHOR CONTRIBUTIONS

CG: Data curation, formal analysis, funding acquisition, investigation, project administration, visualization, writing – original draft. SNPW: Conceptualization, data curation, formal analysis, investigation, visualization, writing – review and editing. MLM: Conceptualization, funding acquisition, investigation, project administration, writing – review and editing.

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