

# Identifying key marine habitat sites for seabirds and sea ducks in the Canadian Arctic

Mark L. Mallory, Anthony J. Gaston, Jennifer F. Provencher, Sarah N.P. Wong, Christine Anderson, Kyle H. Elliott, H. Grant Gilchrist, Michael Janssen, Thomas Lazarus, Allison Patterson, Lisa Pirie-Dominix, and Nora C. Spencer

**Abstract:** The Canadian Arctic hosts millions of marine birds annually, many of which aggregate in large numbers at well-defined sites at predictable times of the year. Marine habitats in this region will be under increasing threats from anthropogenic activities, largely facilitated by climate change and long-term trends of reduced sea ice extent and thickness. In this review, we update previous efforts to delineate the most important habitats for marine birds in Arctic Canada, using the most current population estimates for Canada, as well as recent information from shipboard surveys and telemetry studies. We identify 349 160 km<sup>2</sup> of key habitat, more than doubling earlier suggestions for key habitat extent. As of 2018, 1% of these habitats fall within the boundaries of legislated protected areas. New marine conservation areas currently being finalized in the Canadian Arctic will only increase the proportion protected to 13%.

*Key words:* marine, foraging radius, Canadian Arctic, seabird, marine spatial planning.

**Résumé :** L'Arctique canadien reçoit des millions d'oiseaux marins annuellement, dont beaucoup se rassemblent en grand nombre à des sites bien définis, et ce, à des moments prévisibles de l'année. Les habitats marins dans cette région seront de plus en plus menacés par les activités anthropiques, phénomène en grande partie amplifié par le changement climatique et les tendances à la diminution de l'étendue et de l'épaisseur de la glace de mer à long terme. Dans cette revue, nous mettons à jour les efforts précédents de tracer les habitats les plus importants des oiseaux marins dans l'Arctique canadien, utilisant les évaluations de population les plus actuelles pour le Canada, ainsi que des informations récentes de levés faits à bord de navires et des études de télémétrie. Nous avons recensé 349 160 km<sup>2</sup> d'habitats clés, ce qui a plus que doublé par rapport aux suggestions antérieures concernant l'étendue des habitats clés. En 2018, 1 % de ces habitats se trouvait à l'intérieur des limites des aires protégées prescrites par la loi. Les nouvelles aires marines de conservation dans l'Arctique canadien, en cours de finalisation, n'augmenteront la proportion des aires protégées que de 13 %. [Traduit par la Rédaction]

*Mots-clés :* marin, aire d'alimentation, Arctique canadien, oiseau marin, planification de l'espace marin.

## Introduction

The Arctic marine environment is dominated by sea ice cover for much of the year and a marked seasonal pulse of food resources following sea ice breakup (Welch et al. 1992; Arrigo et al. 2008). The habitats of this region are dynamic: wind, tides, currents, and upwelling zones move pack ice, open and close leads (open water cracks) in the ice, and maintain polynyas (recurrent areas of open water in the ice; Hannah et al. 2009). Many of these open water habitats have a predictable phenology, and consequently these are often important areas for both marine wildlife and Indigenous peoples (Stirling and Cleator 1981; Stirling 1997; Laidre et al. 2008).

Although there is considerable interannual variation in the timing of Arctic sea ice break-up, and Arctic wildlife are well-adapted to this variation (Harington 2008), recent decades have witnessed long-term, unidirectional, rapid reductions in sea ice extent, and

earlier break-up and later ice formation (Laidre et al. 2008; Parkinson and DiGirolamo 2016). Collectively, warming of the Arctic environment is progressing at rates exceeding most other locations on Earth (IPCC 2013). This is the principal driver behind the decline of sea ice extent and thickness, as well as phenological changes (ACIA 2005; Doney et al. 2012; IPCC 2014; Meier et al. 2014). Concomitant with those changes, new anthropogenic threats to wildlife and habitats are emerging, many of which are exploiting the reduction of heavy ice conditions over recent decades (reviewed in Bennett et al. 2015; Lewis and Maslin 2015; Harris et al. 2017).

Globally, efforts are underway to identify and create protected areas and networks for the conservation of marine species, the protection or enhancement of fisheries, and ultimately for societal benefits (e.g., Agardy 2000; Agardy et al. 2011; Asaad et al. 2017). Massive changes in marine environments are not purely an

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**M.L. Mallory.** Acadia University, 33 Westwood Avenue, Wolfville, NS B4P 2R6, Canada; Fulbright Canada Visiting Chair in Arctic Studies, Canadian Studies Center, University of Washington, Box 353650, Seattle, Washington, 98195-3560, USA.

**A.J. Gaston, H.G. Gilchrist, and M. Janssen.** Wildlife and Landscape Science Division, Environment and Climate Change Canada, Carleton University, Ottawa, ON K1A 0H3, Canada.

**J.F. Provencher, S.N.P. Wong, C. Anderson, and N.C. Spencer.** Acadia University, 33 Westwood Avenue, Wolfville, NS B4P 2R6, Canada.

**K.H. Elliott, T. Lazarus, and A. Patterson.** Faculty of Agriculture and Environmental Sciences, McGill University, MacDonald-Stewart Building, MS3-042 Campus, Ste. Anne de Bellevue, QC H9X 3V9, Canada.

**L. Pirie-Dominix.** Canadian Wildlife Service, Environment and Climate Change Canada, Box 1870, Iqaluit, NU X0A 0H0, Canada.

**Corresponding author:** Mark Mallory (email: [mark.mallory@acadiau.ca](mailto:mark.mallory@acadiau.ca)).

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Arctic phenomenon; oceans around the world are threatened by acidification, pollution, overfishing, and other forms of exploitation (e.g., Chan et al. 2008; Cheung et al. 2010; Simpson et al. 2011; Wilcox et al. 2015). The past two decades have seen considerable steps forward in marine conservation planning and implementation, with some efforts to adhere to global principles for sustainable governance and mutual interests (Costanza et al. 1998). Much information exists on approaches and criteria for marine spatial planning (e.g., Ansong et al. 2017; Asaad et al. 2017; Gill et al. 2017). Mumby et al. (2017) argued that global political efforts to increase investments in resource management are required now to ensure the continued sustainability of warming seas, including in the Arctic.

There have been efforts in some Arctic countries to identify key sites (e.g., Russia; Spiridonov et al. 2017), and a push to have a co-ordinated circumpolar plan that recognizes the needs of shared Arctic migratory species (PAME 2015). Identification and protection of Arctic marine sites is urgently required: Harris et al. (2017) suggested that the network of existing Arctic marine protected areas will not be sufficient to protect key wildlife resources, given current predictions for future changes in ice conditions.

Like many parts of the Arctic, there is increasing concern for the health of Canada's Arctic marine environment, as it faces increasing pressures from fisheries, shipping, tourism, oil exploration and spills, pollution discharge, more frequent severe weather, and ice pack changes (e.g., Kelleher 1994; Mercier and Mondor 1995; Day and Roff 2000; Davenport and Davenport 2006; Arctic Council 2009; Mussels et al. 2017; Nyman 2018). Identifying key sites and giving them some form of protection is key while the Arctic is still relatively unaffected by human activities. Research shows that once degradation occurs, we can rarely restore ecosystems to their predisturbance condition (Jones et al. 2018). Some conservation steps are being implemented: in 2017, Canada and other nations signed an agreement for a 16-year moratorium on fishing in the central Arctic Ocean (Hoag 2017), a temporary but important measure. Efforts towards identification and conservation of important marine areas are growing within Canada as well as internationally via the 2020 Aichi Biodiversity targets (e.g., Fisheries and Oceans Canada 1997; Costanza et al. 1998; Day and Roff 2000; Roff and Taylor 2000; Jamieson and Levings 2001; Rice and Houston 2011; Lascelles et al. 2012; Thaxter et al. 2012; Mumby et al. 2017).

While there is a groundswell of activity for the protection of marine environments, marine protection remains limited across the vast Arctic region (Harris et al. 2017; MPAtlas 2017). For example, in Canada there are currently ~100,00 km<sup>2</sup> protected for birds in the Arctic, but only 19% of that is in the marine zone (update to Mallory and Fontaine 2004). More recently, the boundaries of the Tallurutiup Imanga – Lancaster Sound National Marine Conservation Area (NMCA) were recently proposed, greatly improving the proportion of Arctic marine habitat under some form of protection (Government of Canada 2017). This designation represents decades of work and is very important as an Arctic marine protected area, but the implementation of this marine conservation area is ongoing. Moreover, although the agreement in place for the NMCA prevents oil and gas activities and future exploration work in the area, other anthropogenic activities that pose threats to marine life will still take place in this area, including shipping and perhaps fishing. As such, discussions around the use of this conservation area with regards to wildlife still need to consider shipping corridors, fishing zones, and tourism areas that allow for sustainable use of this region.

As highly mobile top predators in the ocean, marine birds (seabirds and sea ducks) can serve as sentinels of productivity and ecological dynamics at several spatial and temporal scales (Gaston et al. 2005; Raymond et al. 2015). Key sites for marine birds tend to be key sites for marine biodiversity and (or) productivity (Lubchenco et al. 2003; Lascelles et al. 2012). The Canadian Arctic hosts large numbers of marine birds (Gaston et al. 2009a, 2012),

almost all of which are migratory. Approximately 10 million birds can be found in Canadian Arctic waters during the spring, summer, and fall, whereas an unknown but much smaller number (probably <500 000) occur at open water sites in the winter (Mallory and Fontaine 2004). Many terrestrial breeding sites for Arctic seabirds have been protected in the Canadian Arctic (Latour et al. 2008), but they contain only limited marine area, typically near breeding sites (Mallory and Fontaine 2004).

Access to adequate, quality habitat is essential to the conservation of all wildlife; therefore, ensuring that both the terrestrial and marine habitat required for seabirds is protected is fundamental to their long-term conservation. Given the changes occurring in the marine environment, there is an urgent need for northern stakeholders (federal and territorial governments, institutes of public government, Indigenous organizations, nongovernment organizations, industry, etc.) to know the locations of important wildlife areas informed by the most up to date research. This knowledge, which can be integrated with other sources of information (e.g., traditional knowledge), is critical to the identification of key wildlife areas and is the first step to ensuring their protection and sustainability.

An earlier summary of key marine sites for migratory birds in Arctic Canada (principally Nunavut and the Northwest Territories) was widely used in the past decade for spatial planning work (Mallory and Fontaine 2004). Here, we update the Mallory and Fontaine (2004) report on key marine habitat sites across Canada's northern coastline (including locations spanning Yukon, Northwest Territories, Nunavut, northern Quebec (Nunavik), and the northern coastlines of Ontario and Manitoba). A wealth of new information on certain sites, population size of different marine bird species, and new developments in technologies have provided insights into marine habitat use by birds. This review is not intended as a catalogue of candidate "marine protected areas," though it identifies where special wildlife conservation measures may be required. Our goal is to review published information from diverse sources on key sites for marine birds in Arctic Canada, to allow the identification and eventual conservation of key sites before they become degraded by anthropogenic activities (Agardy 2000; Cooke et al. 2016). As such, this review seeks to fulfill some of Canada's obligations under the recent Arctic marine protected areas framework (PAME 2015), where identification of key sites for marine birds in the circumpolar Arctic is a deliverable in the plan.

### Types of marine habitats used by marine birds

Habitats in marine ecosystems are diverse (e.g., Day and Roff 2000; Roff and Taylor 2000), but we have grouped these habitats into three zones known to be important to migratory marine birds: (i) coastal, (ii) open sea (including nearshore and offshore components out to the 200-nautical-mile limit of the exclusive economic zone), and (iii) polynyas. These habitats support considerable diversity and abundance of migratory birds in Arctic Canada (Table 1) and can occur in all three oceanographic zones of the Canadian Arctic: high Arctic, low Arctic, and Boreal (as defined by Nettleship and Evans (1985) and used by others, e.g., Mallory et al. (2008a)).

Coastal habitats typically include wetlands, salt marshes, mudflats, and estuaries, but northern sites may also include marine-terminating glaciers (McLaren and Renaud 1982; Meire et al. 2017). Many species of birds, particularly gulls, waterfowl (notably sea ducks and geese), seabirds, and shorebirds, rely on these sites to feed during breeding or migration or to rear young, because these sites are often productive foraging areas (e.g., Wingfield et al. 2011; Nagelkerken et al. 2015). Because they usually incorporate both terrestrial and marine components, most of the key coastal habitat sites in Arctic Canada have been identified previously (Mallory and Fontaine 2004; Latour et al. 2008), and many are protected as migratory bird sanctuaries.

**Table 1.** Birds that occur in marine areas of the Canadian Arctic for part or all of their annual cycle, using sites as principal foraging and/or migratory habitat (reliant) or as secondary habitat (i.e., for brief periods or in response to environmental conditions; facultative).

Common name	Scientific name	Feeding method; habitat	Use of marine habitats*
<b>Principal habitat</b>			
Red-throated loon	<i>Gavia stellata</i>	Piscivore; coastal	B, M
Arctic loon	<i>Gavia pacifica</i>	Piscivore; coastal	B, M
Northern fulmar	<i>Fulmarus glacialis</i>	Piscivore; offshore	B, M, W
Brant	<i>Branta bernicla</i>	Herbivore; coastal	B, M
Common eider	<i>Somateria mollissima</i>	Molluscivore; nearshore	B, M, W
King eider	<i>Somateria spectabilis</i>	Molluscivore; nearshore	M, W
Steller's eider	<i>Somateria stelleri</i>	Molluscivore; nearshore	B, M, W
Spectacled eider	<i>Somateria fischeri</i>	Molluscivore; nearshore	B, M, W
Harlequin duck	<i>Histrionicus histrionicus</i>	Insectivore; nearshore	B, M, W
Long-tailed duck	<i>Clangula hyemalis</i>	Crustacevore; nearshore	B, M, W
Black scoter	<i>Melanitta nigra</i>	Molluscivore; coastal	M
Surf scoter	<i>Melanitta perspicillata</i>	Molluscivore; coastal	M
White-winged scoter	<i>Melanitta fusca</i>	Molluscivore; coastal	M
Red-breasted merganser	<i>Mergus serrator</i>	Piscivore; coastal	B, M
Red-necked phalarope	<i>Phalaropus lobatus</i>	Crustacevore; nearshore	M
Red phalarope	<i>Phalaropus fulicaria</i>	Crustacevore; nearshore	M
Pomarine jaeger	<i>Stercorarius pomarinus</i>	General predator; offshore	M, W
Parasitic jaeger	<i>Stercorarius parasiticus</i>	General predator; offshore	M, W
Long-tailed jaeger	<i>Stercorarius longicaudus</i>	General predator; offshore	M, W
California gull	<i>Larus californicus</i>	Scavenger; nearshore	M
Herring gull	<i>Larus argentatus</i>	General predator; nearshore	B, M, W
Glaucous gull	<i>Larus hyperboreus</i>	General predator; nearshore	B, M
Iceland (+ Thayer's) gull	<i>Larus glaucoides</i>	General predator; nearshore	B, M
Great Black-backed gull	<i>Larus marinus</i>	General predator; nearshore	B, M
Black-legged kittiwake	<i>Rissa tridactyla</i>	General predator; offshore	B, M,
Ross' gull	<i>Rhodostethia rosea</i>	Scavenger; nearshore	B, M
Sabine's gull	<i>Xema sabini</i>	Scavenger; nearshore	B, M
Ivory gull	<i>Pagophila eburnea</i>	Scavenger; offshore	B, M, W
Common tern	<i>Sterna hirundo</i>	Piscivore; nearshore	B, M
Arctic tern	<i>Sterna paradisaea</i>	Piscivore; nearshore	B, M
Dovekie	<i>Alle alle</i>	Piscivore; offshore	B, M, W
Common murre	<i>Uria aalge</i>	Piscivore; offshore	B, M, W
Thick-billed murre	<i>Uria lomvia</i>	Piscivore; offshore	B, M, W
Black guillemot	<i>Cephus grylle</i>	Piscivore; nearshore	B, M, W
Atlantic puffin	<i>Fratercula arctica</i>	Piscivore; offshore	B, M, W
Razorbill	<i>Alca torda</i>	Piscivore; offshore	B, M, W
<b>Secondary habitat</b>			
Common loon	<i>Gavia immer</i>	Piscivore; coastal	M
Yellow-billed loon	<i>Gavia adamsii</i>	Piscivore; coastal	B, M
Tundra swan	<i>Cygnus columbianus</i>	Herbivore; coastal	M
Greater white-fronted goose	<i>Anser albifrons</i>	Herbivore; coastal	M
Snow goose	<i>Chen caerulescens</i>	Herbivore; coastal	B, M
Ross' goose	<i>Chen rossii</i>	Herbivore; coastal	B, M
Common merganser	<i>Mergus merganser</i>	Piscivore; coastal	M
Canada goose	<i>Branta canadensis</i>	Herbivore; coastal	B, M
Greater scaup	<i>Aythya marila</i>	Molluscivore; coastal	M
Lesser scaup	<i>Aythya affinis</i>	Molluscivore; coastal	M
Little gull	<i>Larus minutus</i>	Scavenger; nearshore	M
Bonaparte's gull	<i>Larus philadelphia</i>	Scavenger; nearshore	M

**Note:** Information derived from species accounts at Birds of North America Online (<https://birdsna.org/Species-Account/bna/home>).

\*Use of marine habitats is classified as occurrence at these sites during breeding (B), migration (M), or wintering (W).

In the open sea (typically >1 km from shore), Arctic marine birds use both benthic and pelagic resources, up to a depth of 200 m (Montevicchi and Gaston 1991; K. Elliott, unpublished data). Areas of current convergence or upwellings are particularly important as feeding sites (Shealer 2002). In the Arctic, key open sea habitats include the edge of pack or landfast ice, the location of which is dynamic (e.g., Amélineau et al. 2016). Much of the information we have gathered on open sea habitats has come from surveys related to broadscale environmental assessment work (e.g., McLaren 1982), from opportunistic observations from ships (Huettmann and Diamond 2000; McKinnon et al. 2009; Wong et al. 2014), or

from research using tracking of tagged birds (Falk and Moeller 1995; Chapdelaine 1997; Falk et al. 2001; Mallory et al. 2008b; Frederiksen et al. 2012; Spencer et al. 2014). Offshore sites are important as feeding areas (particularly for colonial-nesting seabirds), as spring migration staging sites (McLaren 1982) and as moulting (Huettmann and Diamond 2000) and overwintering areas for some species (Durinck and Falk 1996; Gaston et al. 2011; Spencer et al. 2014) (Table 1).

Polynyas and shore leads are key open sea habitats and are unique to polar habitats (Stirling 1997). Polynyas are areas of open water surrounded by ice that may be caused by currents, tidal



**Table 2.** Population estimates of selected migratory bird species and subspecies that occur within the Canadian Arctic and that were used in identifying key marine habitats.

Species	Subspecies	Population estimates, Canada*	References
Northern fulmar ( <i>Fulmarus glacialis</i> )	—	175 000	Mallory et al. 2012; Gaston et al. 2012
Long-tailed duck ( <i>Clangula hyemalis</i> )	—	>500 000	Robertson and Savard 2002; Bowman et al. 2015
Common eider ( <i>Somateria mollissima</i> )	<i>borealis</i>	300 000	Gilliland et al. 2009
	<i>sedentaria</i>	125 000	Bowman et al. 2015
	<i>v-nigra</i>	60 000	Bowman et al. 2015
King eider ( <i>Somateria spectabilis</i> )	—	>200 000	Suydam 2000; Bowman et al. 2015
Black scoter ( <i>Melanitta nigra</i> )	—	>70 000	Bordage and Savard 1995; Bowman et al. 2015
Glaucous gull ( <i>Larus hyperboreus</i> )	—	34 600	Gilchrist 2001; Gaston et al. 2012
Ivory gull† ( <i>Pagophila eburnea</i> )	—	<1000	Thomas and MacDonald 1987; Gaston et al. 2012
Ross' gull† ( <i>Rhodostethia rosea</i> )	—	?‡	Maftei et al. 2012
Black-legged kittiwake ( <i>Rissa tridactyla</i> )	<i>tridactyla</i>	205 000	Gaston et al. 2012, 2017
Thick-billed murre ( <i>Uria lomvia</i> )	<i>lomvia</i>	1 543 000	Gaston and Hipfner 2000; Gaston et al. 2012
Dovekie§ ( <i>Alle alle</i> )	<i>alle</i>	7 000 000	Renaud et al. 1982
Black guillemot ( <i>Cephus grylle</i> )	<i>ultimus</i>	192 000	Nettleship and Evans 1985; Butler and Buckley 2002; Gaston et al. 2012

**Note:** Note that there is considerable uncertainty for some estimates, and we have used the maximum credible estimate for each species from the listed sources.

\*Given that many estimates are coarse, values are reported as breeding pairs (number of individuals/2).

†Species listed on Schedule 1 of *Species At Risk Act* in Canada ([http://sararegistry.gc.ca/species/schedules\\_e.cfm?id=1](http://sararegistry.gc.ca/species/schedules_e.cfm?id=1)); ivory gull: endangered; Ross' gull: threatened).

‡Population unknown; a maximum of 12 birds have been reported during the breeding season at one site.

§<1000 are thought to breed in Canada, but most feed in Canadian waters for part of the year.

fluctuations, wind, or upwellings (Stirling 1981; Lewis et al. 1996; Barber et al. 2001; Melling et al. 2001; Hannah et al. 2009). They recur annually as islands of open water in a sea of ice, although size and shape vary from year to year (Smith and Rigby 1981; Hannah et al. 2009). Polynyas and shore leads provide the open water required for access to prey and form important migration corridors, staging sites, and feeding sites for migrating seabirds and waterfowl (McLaren 1982; Renaud et al. 1982; Alexander et al. 1997; Heath and Gilchrist 2010; Black et al. 2012). They also serve as sites where migrating marine mammals can access the surface (for air) before moving through or under sea ice (Stirling 1997). Some polynyas sustain higher biological productivity than nearby areas covered in ice (Hirche et al. 1991; Arrigo and McClain 1994), and thus they support locally high concentrations of wildlife (Stirling 1997; Black et al. 2012; Maftei et al. 2015). Many Arctic seabird colonies are located close to polynyas, recurrent shore leads, or localized areas of early ice break-up (Brown and Nettleship 1981; Maftei et al. 2015a). In cold years when many polynyas and shore leads are small, Arctic marine birds may experience extensive die-offs or lowered reproductive success (e.g., Barry 1968; Fournier and Hines 1994; Robertson and Gilchrist 1998).

### Rationale and approach

The delineation of key marine habitat sites in the Arctic for migratory birds needs to recognize that the nature and distribution of marine biota are influenced by biological, oceanographic, and physiographic factors that vary seasonally and from year to year (Day and Roff 2000; Constable et al. 2003; Hunt et al. 2008). Except for adjacent terrestrial features, there are few obvious physical characteristics at the sea surface that define the limits of sites on the open sea (although bathymetry can be important; e.g., Amélineau et al. 2016). The extremely large size of some marine sites, combined with the lack of strong survey coverage, precludes a simple description of their characteristics or resources like one might be able to produce for a key terrestrial site (Latour et al. 2008). For example, Mallory and Fontaine (2004) included “Foxe Basin” as a key marine site: this marine region covers 170 000 km<sup>2</sup> (the size of Uruguay), and important sites for birds clearly would not fall uniformly across such a vast landscape. In the Arctic, differences in interannual sea ice patterns can have a significant effect on foraging locations among years (Gaston et al. 2005), even for highly recurrent polynyas (e.g., Robertson and Gilchrist 1998).

The occurrence and shape of polynyas varies seasonally and annually, so that establishing a clear, distinct boundary for a polynya may be impractical, although typical, general patterns can be defined (e.g., Hannah et al. 2009). Hence, the precise boundaries of critical (key) sites for marine birds can be hard to define, although small permanent polynyas and bathymetric features such as abrupt changes in water depth are exceptions (Hooker et al. 1999; Reed et al. 2005).

Despite the constraints described above, efforts have been made nationally (e.g., Pritchard et al. 1992; Mallory and Fontaine 2004) and globally (e.g., Butchart et al. 2010; Thaxter et al. 2012) to identify important habitat locations for marine birds. In this review, our goal is to identify key sites of species most likely to be at risk from habitat change or loss, or from marine pollution incidents (following Brooks et al. 2006). We have approached the identification of key habitat sites using the precautionary principle (Myers 1993; Costanza et al. 1998) and with a goal of maintaining scientific credibility in these assessments (Cooke et al. 2016). Based on the biology of the various species, we made the following assumptions:

- (1) Species for which large concentrations of the breeding population are found in a particular wintering or migration staging site; MacDonald et al. 2012; Marra et al. 2015) are more sensitive to local environmental conditions or site-specific threats than more dispersed species.
- (2) Species that occupy habitats of restricted geographic area are vulnerable if their habitat is threatened, especially endangered species like ivory gull (*Pagophila eburnea*) and Ross' s gull (*Rhodostethia rosea*) (see below).

At least 48 species of birds are known to inhabit Canadian Arctic marine waters for part of the year (Table 1). However, survey data, local ecological knowledge, or tracking information are available for only 12 of these species. Hence delineation of key marine habitat sites in the Canadian Arctic was based solely on these 12 species (Table 2) for which we considered sites that support at least 1% of a national population (species or subspecies) to be key marine habitat sites. This criterion has been widely used (Atkinson-Willes 1976; Prater 1976; Fuller 1980; Alexander et al. 1991; Mallory and Fontaine 2004; Latour et al. 2008), and in Canada it is a national criterion for the identification of candidate sanctuaries and national wildlife areas (Government of Canada 2016).

Importantly, it is also one aspect of the International Union for the Conservation of Nature's identification of key global sites for biodiversity (Langhammer et al. 2007) and for identifying key sites for birds on a global scale (UNEP-WCMC 2014).

We also have additional details on seven of these species from focal, species-specific research that yielded critical data for site identification. Specifically, we focused on the thick-billed murre (*Uria lomvia*), black-legged kittiwake (*Rissa tridactyla*), northern fulmar (*Fulmarus glacialis*), black guillemot (*Cepphus grylle*), and common eider (*Somateria mollissima*). Data were also available for herring gulls (*Larus argentatus*) and ivory gulls, which we have included as a proxy for other gull species. The first four are cliff- or scree-nesting species, and along with glaucous gulls (*Larus hyperboreus*) form large, multi-species colonies at several locations in the Canadian Arctic (Latour et al. 2008). Collectively, these are the most populous breeding seabirds of the region (Gaston et al. 2012). Eiders are also common and are the most numerous, ground-nesting species, often inhabiting areas where our other focal species are uncommon (Mallory and Fontaine 2004). We note that for several groups (e.g., terns, phalaropes, loons, geese) we currently lack sufficient information with which to estimate key marine habitat sites.

Our estimates of national populations and site-specific colony sizes update earlier estimates (Gaston et al. 2009a, 2012) to 2017; we caution that data for some sites remain >40 years old (e.g., Scott Inlet) and require urgent updates (see Gaston et al. 2012 for a list of major Arctic colonies in Canada with most recent survey years). Furthermore, with revised population estimates, we found that some sites no longer support a threshold proportion of a species' population (see below) and, as a result, some previously identified key marine sites in the Canadian Arctic (Mallory and Fontaine 2004) are not listed in this review. Likewise, our current key site suggestions are limited by available information, which may be outdated or based on a single observation.

For recurrent shore leads and polynyas, locations of bird aggregations can be quite predictable (Alexander et al. 1997; Robertson and Gilchrist 1998; Mallory and Fontaine 2004; Black et al. 2012; Maftei et al. 2015a). However, in other areas, the varying patterns of annual ice breakup and corresponding supply of open water mean that concentrations of migrating birds will vary among years within a broad marine area. This is especially true of eastern Lancaster Sound, eastern Hudson Strait, and Amundsen Gulf (McLaren Atlantic Ltd 1978a, 1978b; McLaren 1982; Alexander et al. 1997). Feeding locations for marine birds during the breeding season also vary within and across years (Gaston and Nettleship 1981; Gaston et al. 2005). Consequently, our objective here was to identify these broad regions that are likely to support large concentrations of birds annually, based on at least one observation of >1% of a population in this site, and we recommend additional surveys or research to confirm and refine our boundaries.

## Types of data

### *Data on marine areas determined by surveys or local ecological knowledge*

Many of the sites considered in this paper were first documented by researchers engaged in environmental assessments in the 1970s and 1980s (e.g., McLaren 1982; McLaren and Renaud 1982; Renaud et al. 1982). Hence, we conducted a detailed review of available peer-reviewed and "gray" literature (e.g., internal government reports, consultant reports) to identify those locations where >1% of the species in Table 1 have been reported in marine areas of the Canadian Arctic. Detailed information on methods used are presented in those studies and not described here. Another important information source has been local ecological knowledge (LEK), principally of Inuit, the indigenous residents of the Canadian Arctic. There have been a variety of efforts to gather and publish LEK on important sites for marine birds through the

years, from broad regional coverage (e.g., Riewe 1992) to more local or site-specific work (e.g., Mallory et al. 2001; Gilchrist et al. 2006), which has guided conservation efforts in some cases (Gilchrist et al. 2005; Mallory et al. 2006a).

### *Data on marine areas around breeding sites of colonial species*

During the breeding season, seabirds are central place foragers, constrained both by the energetic costs of flying out from their nest to find food and return to their nest site to feed their young, while simultaneously depleting food resources within that foraging range (Ashmole 1963; Birt et al. 1987; Gaston et al. 2007; Elliott et al. 2009b). This effect creates species-specific upper limits on foraging ranges and colony size for colonial seabirds (e.g., Jovani et al. 2015). Sufficient data are now available to begin assessing typical and maximum foraging ranges for different species (Thaxter et al. 2012; Gaston et al. 2013), which may be used as one means of delineating a key marine site during the breeding season (Soanes et al. 2016). Where possible, we have reviewed the literature to gather data on foraging ranges of the main species in our study, either in the Canadian Arctic or elsewhere, to establish typical foraging ranges for key site identification (Table 3).

There is compelling theory and growing empirical evidence that, within colonial seabird species, foraging ranges are dependent on colony size (Cairns 1989; Gaston et al. 2013). This relationship suggests that using a single, species-specific foraging range is not necessarily appropriate. Gaston et al. (2013) presented a model predicting the relationship of mean maximum foraging distance to colony size for thick-billed murre, based on evidence collected in Nunavut. As the murre is the most numerous species of seabird in the region, with colonies varying by more than an order of magnitude (60 000–800 000 breeding birds; Gaston et al. 2012, Tables 2, 4), we have used the approach of Gaston et al. (2013) to estimate colony-specific mean maximum foraging distances for all thick-billed murre colonies in our key sites, with key site boundaries based on predicted mean foraging ranges. For further details of the methods, see Gaston et al. (2013).

In the past, ship-based surveys have provided geospatial information on seabird aggregations away from their breeding colonies (Wong et al. 2014). More recently, the availability of tracking–telemetry devices, as well as advanced statistical procedures to properly analyze those data, have revolutionized our ability to follow almost any seabird (Phillips and Croxall 2003; Hart and Hyrenbach 2009; Robertson et al. 2012; Bridge et al. 2013). This technology allows identification of the key foraging sites, migration stopover sites, and wintering sites of birds from the poles to the tropics (e.g., Shaffer et al. 2005; Jonsen et al. 2005; McFarlane Tranquilla et al. 2013; Davis et al. 2016). With this increased knowledge, we are now able to assess temporal and spatial threats to seabirds when they are at sea and thereby provide credible scientific data on the need for MPAs or other management strategies and their benefits. Two examples of this approach were recently published by Grecian et al. (2016) for a site in the North Atlantic Ocean and Dias et al. (2017) in the South Atlantic Ocean. In this review, we have used available, published studies where seabirds have been tracked in the Canadian Arctic to identify important habitat sites, at least as they pertain to the breeding season around key colonies.

## Findings and discussion

### *Species-specific foraging ranges around breeding colonies*

#### *Thick-billed murre*

Thick-billed murre are the dominant marine birds in the Canadian Arctic both in numbers and biomass (Gaston et al. 2012). They occupy a few, very large colonies, are susceptible to anthropogenic threats like bycatch in fisheries and mortality from oil spills, and they are a harvested species in Greenland and Newfoundland and Labrador (Gaston and Hipfner 2000). For these

**Table 3.** Estimated maximum and mean (SD, if available) foraging range during the breeding season of marine bird species that occur in Nunavut (NU) and Northwest Territories, from published sources (primary and gray literature).

Species	Site and year	Foraging range (km)		References
		Maximum	Mean	
Thick-billed murre	Cape Hay, NU, 1975	—	<30	Johnson et al. 1976
	Digges Sound, NU, 1981, 1982	—	>100*	Gaston et al. 1985
	NW Greenland, 1998	47	22 (12)	Falk et al. 2001
	NW Greenland, 1997	120	42 (26)	Falk et al. 2002
	Coburg Island, NU, 1998	138	42 (30)	Falk et al. 2002
	Coats Island, NU, 1999–2007	94	30	Elliott et al. 2009b
	SW Greenland, 2009–2011	—	12	Linnebjerg et al. 2013
	Digges Sound, NU, 2012	169	96	Gaston et al. 2013
	NW Greenland, 2012	60	20	Frederiksen et al. 2014
	NW Greenland, 2013	90	50	Frederiksen et al. 2014
	Digges Sound, NU, 2013	200	120	Janssen and Gilchrist 2015a
	Digges Sound, NU, 2014	150	80	Janssen and Gilchrist 2015a
	Digges Sound, NU, 2015	300	150	Janssen and Gilchrist 2015a
	Prince Leopold Island, NU, 2014	225	175	Janssen and Gilchrist 2015a
	Cape Graham Moore, NU, 2015	80	40	Janssen and Gilchrist 2015a
Black-legged kittiwake	Alaska, USA, 2013–2014	300	<100	Yamamoto et al. 2015
	Gannet Islands, NL 2015	70	38 (17)	Pratte 2016
	Alaska, USA, 1989	60	40	Irons 1998
	Alaska, USA, 1995	—	40	Ostrand et al. 1998
	Alaska, USA, 2007	80	50	Kotzerka et al. 2009
	Ireland, 2009–2010	50	20	Chivers et al. 2012
	Global	120	27 (14)	Thaxter et al. 2012
	Alaska, USA, 2008–2010	—	201 (7)	Paredes et al. 2014
	NW Greenland 2012–2013	60	<40	Frederiksen et al. 2014
	Svalbard, Norway, 2008	—	5 (1); 103 (36)	Goutte et al. 2014†
	Svalbard, Norway, 2009	—	4 (1); 326 (146)	Goutte et al. 2014†
	Svalbard, Norway, 2010	—	2 (1); 154 (31)	Goutte et al. 2014†
	Anda, Norway, 2011–2014	64 (2)	—	Christensen-Dalsgaard et al. 2017
	Sør-Gjæslingan, Norway, 2011–2014	304 (6)	—	Christensen-Dalsgaard et al. 2017
	Northern fulmar	Prince Leopold Island, NU, 2014	225	120 (57)
Bjornoya, Norway, 1999		570	100	Weimerskirch et al. 2001
Cape Vera, NU, 2005		600	500	Mallory et al. 2008b
Alaska, USA, 2002–2004		400	<200	Hatch et al. 2010
Global		839	119 (118)	Thaxter et al. 2012
Common eider	Scotland, UK, 2012	2500	<100	Edwards et al. 2013
	Global	80	<3	Thaxter et al. 2012
King eider	East Bay, NU 2015	50	<15	Janssen and Gilchrist 2015b
Black guillemot	Digges Sound	—	<2	Cairns 1987b
	Alaska, USA, 2006–2009	—	9 (7)	Bentzen and Powell 2015
	Scotland, UK, 2013–2014	10	<5	Owen 2015
	Scotland, UK, 2011/2012	7.6	3.3	Masden 2012
Herring gull	Ireland 2013	5	1	Shoji et al. 2015
	Global	100	21 (14)	Thaxter et al. 2012
	East Bay, NU, 2009–2013	225	<50	Janssen and MacDonald 2013; Janssen and Gilchrist 2015b

**Note:** Where mean values were not provided, they were estimated from figures. Note that some distributions were bimodal or sex-biased (e.g., Goutte et al. 2014); we have shown values here to capture the variation among studies and species.

\*Based on aerial surveys, Gaston et al. (1985) showed that most birds travelled at least this far, although they could not distinguish breeders from nonbreeders.

†Values are for birds that foraged inside and outside the fjord.

reasons, they are the best studied marine bird in Arctic Canada (e.g., Gaston et al. 1987, 1993, 2005, 2013; Elliott et al. 2009a, 2009b). Given the detailed information available, we use a slightly different approach to delineating key habitat for murres than for other Arctic species.

Murres are principally pelagic foragers (Gaston and Hipfner 2000), diving to depths of about 150 m, but their foraging range near their colonies during the breeding season varies substantially. Early reports, either from direct observations or aerial surveys, suggested that murres can potentially forage up to 200 km from their colony (Gaston and Nettleship 1981; Hatch et al. 2000), although most foraging likely occurred closer than that (Table 3). New information from tracking technologies suggests that most foraging occurs many kilometres away from the colony, at typical

distances ranging from 12 to 175 km, but as far as 300 km (Table 3). Moreover, the typical foraging distance at a colony can vary within a season and among years, with the foraging range during chick-rearing usually closer to the colony than during incubation (Table 3). In Gaston et al. (2013) and some follow up studies, the mean foraging radius for 326 flights by murres around Arctic colonies was  $70.1 \pm 2.7$  (SE) km, and 95% of foraging trips were  $\leq 162$  km. As well, a critical period comes each year when young murres jump off the breeding cliffs before they can fly, landing on the water near the colony (Gaston and Hipfner 2000), after which they initiate a swimming migration with attending adult males (Gaston et al. 2011). Most murres depart the colony over a two-week period (Gaston and Hipfner 2000), which means that during the chick departure period, adults and chicks may be highly con-



**Table 4.** Revised estimates of colony-specific mean foraging ranges for thick-billed murres in Arctic Canada.

Colony	Colony size (individuals)	Estimated mean foraging range (km)	Measured mean foraging range (km)	Measured maximum foraging range (km; Table 3)
Coburg Island	300 000	80	—	—
Prince Leopold Island	200 000	66	—	225
Cape Hay	170 000	62	—	—
Cape Graham Moore	100 000	48	40	80
Akpait (Minarets)	260 000	75	—	—
Hantzsch Island	100 000	48	—	—
Akpatok Island N	800 000	126	—	—
Akpatok Island S	240 000	72	—	—
Digges Sound	800 000	126	117	300
Coats Island	60 000	38	30	94

**Note:** We used the model developed by Gaston et al. (2013) but with revised colony size values to generate new estimated mean foraging range. Also presented are measured mean foraging ranges for some colonies, as well as the maximum measured foraging ranges. The latter indicates that for some individuals, or in some years, the birds may be travelling much farther from the colony to feed, and thus the foraging ranges we use to calculate key marine areas should be considered conservative. Colony information from Gaston et al. (2012, 2013).

centrated on waters close to the colony prior to their post-fledging dispersal. Males, which are constrained by mobility of the chick, forage in patches of lower quality than patches used by females, and those sites frequented by males and their offspring are critical at that time (Elliott et al. 2017).

From all of the studies in Table 3 published since 2001, the mean estimated mean foraging distance for thick-billed murres was 67 km, approximately double what was suggested in Mallory and Fontaine (2004; 30 km) as a suitable “key site” around Canadian Arctic colonies. Importantly, at every Canadian colony sampled up to 2015, maximum thick-billed murre foraging distance was greater than 70 km, meaning that some murres are foraging far from the colony, particularly during incubation (Table 3).

Given that the foraging range of murres varies according to colony size, with ranges greater at larger colonies (Gaston et al. 2007, 2013; Table 4), we used estimated maximum mean foraging range from the colonies in Canada as the limits of the key sites around murre breeding colonies (Table 4). Note that the use of absolute maximum foraging ranges (listed in Table 4) for sites may overestimate typical foraging ranges for any given species; a more conservative approach is recommended (Soanes et al. 2016). Based on these recent estimates derived from telemetry data, we propose that the key sites defined around thick-billed murre colonies should vary with colony size, as described above, giving limits ranging from 70–140 km in Arctic Canada. Additional tracking studies are required to assess whether foraging may occur principally in one direction at certain sites. At Digges Sound and Coats Island, data to date suggest that murres forage effectively in the 270° available around the colony (Gaston et al. 2013; Janssen and MacDonald 2013; Janssen and Gilchrist 2015a), whereas tracked murres at Prince Leopold Island have moved principally east (Black and Braune 2014) where open water was available in the one year of tracking. We expect that additional tracking at Prince Leopold Island will show that typical foraging movements cover more directions from the colonies, but it is possible that some cases might require truncation of some key marine sites in certain directions. Clearly further studies are required to confirm whether this interpretation is consistent across all years and colonies. As well, we stress that a “core” key site should be identified close to the colony, extending approximately 3 km from the high-water mark. This site should generally include the area where murres land to bathe before departing to feed and where chicks splash down on the water before initiating their swimming migration (Gaston and Nettleship 1981), and therefore where they might be at greatest risk from local pollution and disturbance incidents (Montevecchi 1996).

### Black-legged kittiwakes

Black-legged kittiwakes are a broadly distributed, marine gull with most of their North Atlantic population in the Boreal marine zone (Nettleship and Evans 1985), but with substantial numbers of birds in Arctic waters (Hatch et al. 2009). Kittiwakes are at their colonies from June through September, often with thousands of young birds on the water below the nesting cliffs just after fledging (September; Hatch et al. 2009). Older information, or that from southern areas, suggested that kittiwakes foraged <50 km from their colonies (Baird 1994; Table 3), perhaps even as little as <5 km (Montevecchi 1996), and thus Mallory and Fontaine (2004) suggested the use of a foraging radius of 30 km as the limit of the key site around colonies in the Canadian Arctic.

With new data, we know that 30 km vastly underestimates kittiwake foraging range. Reviewing information from a variety of approaches, Thaxter et al. (2012) found a maximum foraging range of 120 km, a mean maximum of 60 km, and a mean foraging range of 25 km from 18 studies on kittiwakes. More recent telemetry research suggests that the foraging range for kittiwakes in the Arctic may often be much greater than this, with maximum foraging ranges >300 km reported at some sites (Table 3). Moreover, Goutte et al. (2014) demonstrated that kittiwakes may forage close to or distant from their colonies, and that maximum foraging range varied by nearly 100% across years (Table 3). Christensen-Dalsgaard et al. (2017) found that maximum foraging range for kittiwakes at a small Norwegian colony was five times greater than that of a colony twice its size and situated only 300 km away. This was driven by the fact that the shelf break, the key feeding area for both colonies, was much closer to the larger colony.

There has only been one telemetry study in Arctic Canada on kittiwakes, at Prince Leopold Island, where mean foraging range was 120 km (Table 3), four times greater than previously recommended by Mallory and Fontaine (2004). In the absence of tracking data from other colonies, however, it is unclear whether at smaller colonies where they are the only breeding species (apart from a few glaucous gulls; Batty Bay, Browne Island, Baillie-Hamilton Island) kittiwakes travel as far to feed. Wong et al. (2014) found kittiwakes widely distributed in July and August at distances >100 km from the closest colony, although they could not distinguish breeding and nonbreeding birds. Thus, we propose that a radius of 120 km around kittiwake colonies should encompass most of the foraging sites used by birds at most Arctic colonies and in most years, although there will be exceptions for late ice years. Importantly, at larger kittiwake colonies (Coburg Island, Cape Hay, Prince Leopold Island, Hantzsch), the birds nest symp-

trically with large colonies of murre, and hence the “key marine site” for kittiwakes at each site will fall within the larger boundaries delineated for the murre at these locations. Like murre, however, a “core” key site should be delineated close to the colony, extending approximately 3 km from the high-water mark, to protect the area where young kittiwakes congregate below the cliffs around the time of fledging and where adults loaf and bathe throughout the year.

#### Northern fulmars

Northern fulmars are principally pelagic foragers (Mallory et al. 2012) and can travel very long distances to feed (e.g., Edwards et al. 2013). Early reports in the Canadian Arctic suggested that birds from the Cape Searle colony might forage in Davis Strait, several hundred kilometres from their breeding site (McLaren Atlantic Ltd. 1978a, 1978b), and surveys suggested that fulmars breeding in the high Arctic might leave that region altogether during their exodus to feed, possibly 1000 km away (McLaren 1982). In Greenland, Falk and Moeller (1995) found that fulmar foraging took place 40–200 km away from their colonies. Since that earlier work, we know that fulmars forage even farther than imagined (Table 3). Research in Svalbard found that most fulmars foraged within 100 km of the colony, but maximum foraging range was about 600 km (Weimerskirch et al. 2001). Mallory et al. (2008c) showed that fulmars from Cape Vera were flying ~500 km one-way to forage near Bylot Island or leaving Canada for Greenland. In Alaska, fulmars tend to forage within 200 km of their colony, but as far as 400 km (Hatch et al. 2010), and Edwards et al. (2013) found one fulmar, possibly a failed breeder, travelling 2500 km from its breeding site in the northern United Kingdom to feed.

Based on studies conducted before 2003, Mallory and Fontaine (2004) suggested a 15 km radius around fulmar colonies to protect fulmars on the water near their colony on the assumption that birds foraged farther away from the colony than this. Since 2003, research on fulmars (e.g., Gaston et al. 2005, Mallory et al. 2008b, 2008c) has substantially enhanced our knowledge of this species' biology in the Canadian Arctic. In some years, fulmars, presumably non- or failed breeders, aggregate in flocks along the shore within 2 km of the colony (generally <1 km; Allard et al. 2008), feeding on zooplankton, but otherwise, relatively few birds are found near the colony except in flight. Indeed, surveys (e.g., Nettleship and Gaston 1978), tracking (Mallory et al. 2008b), or direct observations indicate that fulmars are on the water either very close to the colony, or very distant from it (Table 3). Consequently, we recommend a 10 km radius around fulmar colonies to delineate those areas that have a high probability of large fulmar densities on the water. We note that this is different in principle from the boundaries for the other seabirds, as this zone would not protect key foraging sites but rather known concentration sites near the colonies; fulmars forage too far from their colony to delineate a practical range for feeding sites.

#### Black guillemots

Unlike the previous species, there has been limited tracking of black guillemots to date. As guillemots typically feed on benthic fish, including benthic Arctic cod (*Boreogadus saida*), after ice has left, they are limited to areas within their dive limits (typically <30 m). Mallory and Fontaine (2004) suggested a 15 km radius around guillemot colonies, because guillemots forage principally near shore (Nettleship and Evans 1985). Butler and Buckley (2002) summarized data that suggested most foraging is within 4 km of colonies, often <1 km, and birds foraging >10 km away were probably nonbreeders (Cairns 1987a). Telemetry studies seem to support these interpretations. In the United Kingdom, the maximum foraging distance for a black guillemot was 10 km, but the majority of foraging was within 5 km (Table 3). Based on these new data, we recommend a 10 km radius be used to define the key marine habitat around guillemot colonies, which should include many of

the sites they frequent early in the season while there is still substantial landfast ice. Note that like kittiwakes, guillemots breeding in the Arctic may forage farther than their counterparts in the Boreal zone, but we lack data to compare at this time.

#### Common eiders

Common eiders are shallow-water benthic feeders, generally foraging in waters <20 m deep, although they can dive deeper (Goudie et al. 2000; Heath et al. 2006). In the winter and during migration, eiders are close to shore and (or) the floe edge, generally <10 km from the coast (McLaren Atlantic Ltd 1978a, 1978b; Merkel et al. 2006). During the breeding season they inhabit coastal islands in colonies of tens to thousands of birds. Colonies are sensitive to disturbance (Goudie et al. 2000). For these reasons, Mallory and Fontaine (2004) recommended a 15 km buffer around eider colonies in the Canadian Arctic.

Since the early 2000s there has been much international tracking of common eiders, but this has principally occurred with implanted satellite transmitters to determine year-round migration routes, affiliations between breeding and wintering sites, and possible hotspots for harvest activities on various populations (Mosbech et al. 2006; Dickson and Smith 2013). Unlike the other species above, which have biparental incubation, male common eiders abandon the female early in incubation (Goudie et al. 2000) and depart to flock in molting areas; our information on male molting sites is still poor (but see Site 30, and Mosbech et al. 2006), and we have not delineated any of those as key sites, although additional research should focus on identifying these in the future. The female has very high incubation constancy (>95%) and relies principally on stored fat reserves to fuel incubation (Goudie et al. 2000). Nonetheless, occasionally the female does leave to feed or get fresh water, and prior to incubation the female may move to forage for some local, exogenous nutrient supplies (Sénéchal et al. 2011). Limited telemetry or survey work during breeding has suggested that maximum foraging distances for eiders during breeding is 50–80 km (Table 3), but that the vast majority of foraging occurs within 3 km in areas not influenced by sea ice, although they may feed ~15 km where landfast or pack ice may still be present during breeding (Janssen and Gilchrist 2015b). Thus, with limited new data, we maintain a recommended 15 km buffer be used to define the key marine site around common eider breeding colonies, which will likely also capture much of the area used by females and broods early after hatching and generally identify those sites with a high probability of large bird densities on the water (Goudie et al. 2000; Iverson et al. 2014).

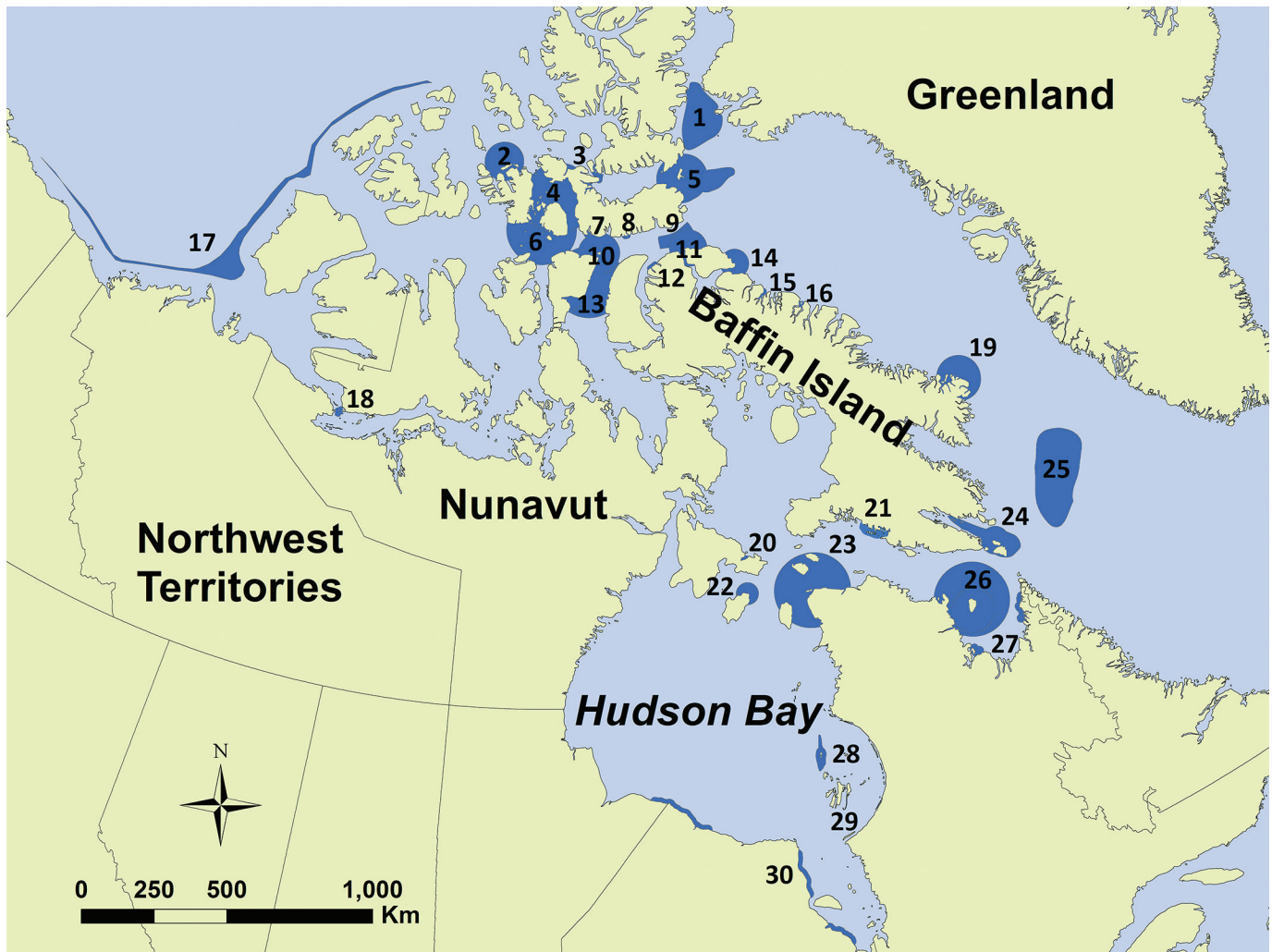
#### Large gulls

Large gulls are opportunistic omnivores, capable of exploiting terrestrial or marine foods as well as anthropogenically altered habitats (Mallory et al. 2008d; Nisbet et al. 2017). There are three common, large white gulls in Nunavut (herring gulls, Iceland gulls (*Larus glaucooides*), and glaucous gulls (*L. hyperboreus*)), all of which appear to feed on land and at sea (although during the breeding season, Iceland gulls appear to be principally at-sea foragers), but only the herring gull has been tracked to date. Herring gulls may forage up to 225 km from their colony, but the vast majority of trips occurred within 50 km (Table 3), with a global average foraging range of 21 km (Thaxter et al. 2012). During at-sea surveys, Wong et al. (2014) reported glaucous gulls generally close to shore in July and August, and other gulls were uncommon.

The ivory gull, smaller than the *Larus* gulls, has been tracked up to 270 km from the Seymour Island colony, but 50% of all trips were within 120 km (Spencer et al. 2014). Elsewhere, they may breed >50 km inland, necessitating long flight to the sea. Their preference for foraging in ice-covered habitats during the breeding season (Gilg et al. 2016) makes their ecology very distinct from those of other gulls. Based on these limited data, we recommend



**Fig. 1.** Map of recommended key marine habitat sites in the Canadian Arctic. Numbers correspond to the sites in the text, as well as the descriptions in Table 5. Geographic information system shapefiles are available upon request from the corresponding author. Map produced from ArcGIS 10 (ESRI 2011).



a 120 km radius be used to delineate the key marine habitat around ivory gull colonies.

For other large Arctic gulls, we propose that a 50 km radius will identify key marine sites around most large gull colonies in Nunavut. At present, however, there are no sites where large concentrations of gulls occur (i.e., meet the 1% criterion for identification); additional surveys are required to confirm and examine the similar Iceland gull colonies in Cumberland Sound, which may represent another key marine site (Latour et al. 2008).

#### Key marine habitat sites in Arctic Canada

Using the approaches outlined above, notably revised foraging ranges around colonies (Table 4), we have identified 30 key marine sites for migratory birds in the Canadian Arctic (Fig. 1; Table 5), presented in order from northermost to southernmost latitude (summarized in Table 6). These represent an adjustment to the lists previously compiled by Alexander et al. (1997) and Mallory and Fontaine (2004), with a delisting of some sites due to new information on bird populations, an addition of new sites (principally based on telemetry data), and an adjustment to the boundaries of many sites (again principally based on current estimates of typical foraging range).

#### Site 1. North Water Polynya

This site is large, year-round expanse of open water in northern Baffin Bay between Ellesmere Island and Greenland. It is the largest, best-known, and well-studied polynya in the Canadian Arctic, although part of this oceanographic feature lies outside Canadian territorial waters (e.g., Barber et al. 2001). Situated in the high Arctic oceanographic zone (Nettleship and Evans 1985), varying amounts of open water are maintained year-round by currents (Tooma 1978), wind (Nutt 1969; Melling et al. 2001), and upwelling (Smith and Rigby 1981; Steffen 1985), which also leads to higher productivity on the east side of the polynya than on the west (Lewis et al. 1996). The polynya connects to the open water of Davis Strait in July (Smith and Rigby 1981). It is one of the most productive polynyas in the northern hemisphere (Stirling 1980; Hobson et al. 2002).

The North Water Polynya hosts millions of seabirds. Approximately 30 000 pairs of black-legged kittiwakes (15% of the Canadian population) nest at Cambridge Point, Coburg Island (Gaston et al. 2012). Over 350 000 pairs of thick-billed murres nest in six colonies around the margin of the North Water Polynya (Falk et al. 2001). The colony at Coburg Island supports 150 000 pairs of thick-billed murres (10% of the Canadian population; Gaston et al. 2012). On the Greenland side, approximately 50% of the Greenland

**Table 5.** Locations and characteristics of key marine habitat sites for marine birds in Arctic Canada.

Map number	Name	Coordinates of centre		Oceanographic zone*	CBMP–CSG Area–ecoregion†	Size of feature (km <sup>2</sup> )		Key avian value‡	Conservation status	Protection status
		Latitude (°N)	Longitude (°W)			Marine	Terrestrial			
1	North Water Polynya	77.00	75.00	HA	DB-8	21 500	0	BLKI 12%; TBMU 10%; IVGU 70%; BLGU 2%; DOVE	NU010, NU014	Partial NWA (1995)
2	Seymour Island	76.80	101.27	HA	AA-7	11 901	330	IVGU 10%	NU045	Partial MBS (1975)
3	Hell Gate/Cardigan Strait	76.42	90.00	HA	AA-8	964	10	NOFU 6%	NU052, NU053	None
4	Queens Channel	76	95.50	HA	AA-8	20 768	359	BLKI 2%	NU049, NU051	None
5	Eastern Jones Sound	75.58	80.00	HA	DB-8	31 100	426	BLKI 12%; TBMU 10%	NU010, NU057	Partial NWA (1995)§
6	Browne Island	74.82	96.35	HA	AA-8	30 126	330	BLKI 1%	—	None§
7	Cape Liddon	74.62	91.17	HA	AA-8	312	0	TBMU 4%	NU059	None§
8	Hobhouse Inlet	74.47	86.83	HA	AA-8	301	0	TBMU 9%	NU060	None§
9	Eastern Lancaster Sound	74.25	80.00	HA	DB-8	6583	0	BLKI 26%; NOFU 33%; TBMU 16%	NU058	None§
10	Prince Leopold Island	74.01	90.00	HA	AA-8	12 761	64	TBMU 7%; BLKI 14%; NOFU 9%; BLGU 1%	NU006	Partial MBS (1995)§
11	Cape Hay	73.75	80.37	HA	AA-8	8060	1	TBMU 6%; BLKI 8%	NU004	Partial MBS (1965)§
12	Baillarge Bay	73.42	84.5	HA	AA-8	436	0	NOFU 11%	NU067	None§
13	Batty Bay	73.23	91.42	HA	AA-8	22 145	0	BLKI 3%	—	None
14	Cape Graham Moore	72.92	76.08	HA	DB-8	19 325	40	TBMU 3%; BLKI 1%	NU068	Partial MBS (1965)§
15	Buchan Gulf <sup>  </sup>	71.83	74.50	HA	DB-8	387	14	NOFU 6%	NU069	None§
16	Scott Inlet <sup>  </sup>	71.05	71.13	HA	DB-8	263	37	NOFU 6%	NU070	None
17	Amundsen Gulf*	71.00	125.00	LA	AA-6	32 693	29	KIEI 10%; COEI 3%; LTDU 6%	NT039, NT041, NT040, NT038 NT037, NT016, NT017	None
18	Lambert Channel <sup>  </sup>	68.58	114.00	LA	AA-6	725	0	COEI 7%	—	None
19	Qaulluit/Akpait	67.08	62.00	HA	DB-10	12 894	446	NOFU 29%; TBMU 9%; BLKI 1%	NU003, NU072	Partial NWA (2010)
20	East Bay	64.05	81.83	LA	HC-9	260	1	COEI 2%	NU023	Partial MBS (1959)
21	Markham Bay	63.5	72.5	LA	HC-9	4508	423	COEI 7%	—	None
22	Coats Island	62.95	82	LA	HC-9	3383	11	TBMU 2%	NU005	None
23	Digges Sound	62.52	77.58	LA	HC-9	35 677	125	TBMU 26%	NU001	None
24	Frobisher Bay	62.5	65	LA	DB-10	35 156	2000	TBMU 3%; BLKI 3%	NU025	None
25	Central Davis Strait	63	48	LA	DB-10	42 476	0	IVGU >50%	—	None
26	Akpatok Island	60.42	68.13	LA	HC-9	64 297	859	TBMU 34%	NU007	None
27	Ungava Bay Archipelagoes	60.17	69.5	LA	HC-9	5775	5	COEI 16%	NU027, NU028, NU029	None
28	Sleeper Islands	57.5	79.75	LA/BO	HC-9	2582	90	COEI 26%	NU033	None
29	Belcher Islands	56.5	79.5	LA/BO	HC-9	<100	0	COEI 3%	NU031, NU100	None
30	Northern Ontario Coastline <sup>  </sup>	54	82	LA/BO	HC-9	8133	41	BLSC >50%	—	None

**Note:** Key avian value reports the code for a species and the percentage of the Canadian population thought to use the feature for part of the year; other species that occur in high numbers are listed. Oceanographic zone refers to categories from [Nettleship and Evans \(1985\)](#), while CBMP–CSG categories are Circumpolar Biodiversity Monitoring Program (CBMP) and Circumpolar Seabird Group (CSG) Arctic marine areas and ecoregions ([Irons et al. 2015](#)). Conservation status refers to recognition of the site as important through the Important Bird Areas of Canada (NU, Nunavut; NT, Northwest Territories), [www.ibacanada.com](http://www.ibacanada.com) and Commission for Environmental Cooperation (CEC 1999), whereas protection status refers to formal, legal protection of some of the marine site as a National Wildlife Area (NWA) or Migratory Bird Sanctuary (MBS).

\*Oceanographic zones as follows: HA, high Arctic; LA, low Arctic; BO, Boreal.

†CBMP marine areas as follows: AA, Arctic Archipelago; DB, Davis–Baffin; HC, Hudson Complex.

‡Shortforms for species as follows: BLKI, black-legged kittiwake (*Rissa tridactyla*); TBMU, thick-billed murre (*Uria lomvia*); IVGU, ivory gull (*Pagophila eburnea*); BLGU, black guillemot (*Cepphus grylle*); DOVE, dovekie (*Alle alle*); NOFU, northern fulmar (*Fulmarus glacialis*); KIEI, king eider (*Somateria spectabilis*); COEI, common eider (*Somateria mollissima*); LTDU, long-tailed duck (*Clangula hyemalis*); BLSC, black scoter (*Melanitta nigra*).

§Some or all of the key site will be part of the new Tallurutiup Imanga–Lancaster Sound National Marine Conservation Area.

||Site description largely based on old data; new information required to validate.

**Table 6.** Summary of revised recommendations for distances encompassing key marine habitat sites around Arctic marine bird colonies in Canada.

Species	Tracking studies		Recommended radius around colonies (km)
	High Arctic	Low Arctic	
Thick-billed murre ( <i>Uria lomvia</i> )	Yes	Yes	Variable (38–126)
Northern fulmar ( <i>Fulmarus glacialis</i> )	Yes	No	10
Black-legged kittiwake ( <i>Rissa tridactyla</i> )	Yes	Yes	120
Black guillemot ( <i>Cepphus grille</i> )	No	No	10
Common eider ( <i>Somateria mollissima</i> )	No	Yes	15
Herring gull ( <i>Larus argentatus</i> )	n/a	Yes	50
Ivory gull ( <i>Pagophila eburnea</i> )	Yes	No	120

**Note:** Table 3 includes references to tracking studies included in this assessment.

thick-billed murre population nests in the Thule district near the North Water Polynya (Kampp 1990; Falk and Kampp 1997). We currently lack information on where most seabirds from Coburg Island feed, although it may change through the year, and thus we consider that they likely use both the North Water Polynya and Eastern Jones Sound (below). Most of the extant Canadian population of ivory gulls, a species at risk in Canada, breeds on south-eastern Ellesmere Island near this polynya, supporting ~700 adults (70% of the Canadian population; Thomas and MacDonald 1987; Robertson et al. 2007). Moreover, the North Water Polynya is important foraging habitat for ivory gulls from other colonies during migration and at other times of year as well (e.g., Spencer et al. 2014). An estimated 175 pairs of black guillemots breed at Coburg Island (Robards et al. 2000), and 3000–4000 pairs (2% of the Canadian population) may overwinter in this area (Renaud and Bradstreet 1980). Coburg Island also supports the northernmost breeding colony of Atlantic puffins (*Fratercula arctica*) in Canada (Robards et al. 2000). Although very few breed in Canada, an estimated 30 million dovekies breed in northwest Greenland near the North Water Polynya (Freuchen and Salomonsen 1958; Roby et al. 1981; Boertmann and Mosbech 1998). Many of these birds (an estimated 14 million) migrate north in the spring along shore leads near eastern Baffin Island and the North Water Polynya (Renaud et al. 1982).

In addition to the tremendous marine bird resources in this area, the North Water is a key habitat for beluga (*Delphinapterus leucas*), bowhead whale (*Balaena mysticetus*), narwhal (*Monodon monoceros*), Atlantic walrus (*Odobenus rosmarus*), ringed seal (*Pusa hispida*), bearded seal (*Erignathus barbatus*), harp seal (*Pagophilus groenlandica*), and polar bear (*Ursus maritimus*) (Stirling et al. 1981, Finley et al. 1983, Riewe 1992, Holst et al. 2001, Heide-Jørgensen et al. 2006, 2017).

### Site 2. Seymour Island

This site is a barren, gravel and rock island less than 3 km long, rising 28 m out of the pack ice, and located approximately 30 km north of Bathurst Island. The water surrounding the island remains ice covered into August, and ice forms again by October (Smith and Rigby 1981).

The island is Canada's largest known breeding colony of ivory gulls, and thus the marine zone surrounding the island is key for this species. It formerly supported an estimated 200–250 adults (100–125 pairs) (Mallory et al. 2008d), but since 2002 it has typically had fewer than 100 adults at the site (Gilchrist and Mallory 2005; Robertson et al. 2007), which is still about 10% of the known Canadian population. They occupy this site from the end of May to September (Thomas and MacDonald 1987) and then move to Davis Strait or the coast of Labrador for the winter (Spencer et al. 2014). The site also supports lesser numbers of a variety of marine birds including brant geese and terns (Mallory and Fontaine 2004; Maftei et al. 2015a).

### Site 3. Hell Gate and Cardigan Strait

Hell Gate and Cardigan Strait form a relatively shallow, high-Arctic polynya between northern Devon and southwestern Ellesmere islands through which strong currents flow from Norwegian Bay to Jones Sound (Smith and Rigby 1981; Nettleship and Evans 1985; Mallory and Fontaine 2004, Hannah et al. 2009). Due to the pattern of break up farther north, the region does not usually become completely ice-free in summer.

Sverdrup (1904) observed “myriads” of black guillemots when he overwintered in this site, and Renaud and Bradstreet (1980) confirmed that some black guillemots overwinter at this site. Despite earlier references to large numbers of guillemots in this vicinity (Nettleship 1974, Gaston et al. 2012), recent work at the site and nonsystematic surveys by the authors have suggested that there are only a few hundred birds present now (although guillemots are notoriously difficult to census). Currently we suggest that the site does not appear to support >1% of the Canadian population of this species, but recommend that a systematic census be undertaken to verify this assessment. However, an estimated 11 000 pairs of northern fulmars nest at Cape Vera at the eastern entrance to Cardigan Strait (Gaston et al. 2012). This is considerably fewer than previous estimates of 50 000 individuals (Hatch and Nettleship 1998), but still represents 6% of the Canadian population. Fulmars arrive by early May, numbers peak by about 10 May (Mallory and Forbes 2007), and then they fledge and depart the colony in September and the high Arctic by late October (Mallory et al. 2008b).

The polynya attracts early season migrating birds and islands in the polynya are nesting sites for common eiders, black guillemots, Iceland gulls, and glaucous gulls (Prach et al. 1986; Black et al. 2012). The site also supports other marine species, notably nonmigratory walrus, bearded seal, and polar bear (Stirling and Cleator 1981; Riewe 1992).

### Site 4. Queens Channel

This site comprises shallow, high Arctic marine waters between Bathurst, Devon, and Cornwallis islands, which produce a series of small polynyas kept open as water flows south from Penny Strait through Queens Channel and Wellington Channel to Lancaster Sound (Nettleship and Evans 1985; Mallory and Fontaine 2004). The small polynyas usually develop in January and remain open and enlarge until ice disappears by mid-July (Smith and Rigby 1981; Hannah et al. 2009).

The site supports many small marine bird colonies, comprising 17 species (Mallory and Gilchrist 2003; Maftei et al. 2015a), most of which rely on ice edge habitats early in the breeding season (Sekarak and Richardson 1978). Ross's gulls, a threatened species at risk in Canada, nest at the Cheyne Islands and Nasaruaalik Island in this region, with a maximum of 12 birds (~6 pairs) observed at any time between 2002 and 2014 (Maftei et al. 2015b). Nasaruaalik Island is the only site in the Canadian Arctic known



to support Ross's gulls every year (Maftei et al. 2012), and birds from here migrate to the Labrador Sea for the winter (Maftei et al. 2015b). Approximately 1500 common eiders and 1500 arctic terns nest in the region (Davis et al. 1974; Maftei et al. 2015a). An estimated 4500 pairs of black-legged kittiwakes (2% of the Canadian population) nest on the cliffs of southeastern Baillie-Hamilton Island at Washington Point (Gaston et al. 2012). Other than a few overwintering black guillemots (Renaud and Bradstreet 1980), birds inhabit this marine region from May through early October annually. Queens Channel is also an important region for nonmigratory walrus, bearded seal, ringed seal, and polar bear (Riewe 1992).

#### Site 5. Eastern Jones Sound

Eastern Jones Sound lies between southern Ellesmere Island, Coburg Island, northeastern Devon Island, and Baffin Bay. A polynya occurs here annually, usually starting in January, near Coburg Island which eventually links to the North Water Polynya (Site 1) in May or June. Leads extend south to join Lancaster Sound by April (Smith and Rigby 1981).

More than 500 000 breeding marine birds may use the waters of this site from nearby colonies annually (McLaren and Renaud 1979, 1982; Renaud and McLaren 1982). Approximately 30 000 pairs of black-legged kittiwakes and about 150 000 pairs of thick-billed murres (15% and 10% of the Canadian populations, respectively) nest at Coburg Island (Gaston et al. 2012, 2017). We currently lack information on where most seabirds from Coburg Island feed, although it may change through the year, and thus we consider that they likely use both the North Water Polynya (Site 1) and Eastern Jones Sound. Numerous nesting black guillemots, glaucous gulls, and ivory gulls also can be found in the site, although at levels <1% of the Canadian populations (except for ivory gulls). This is the northernmost nesting location for Atlantic puffins in Canada (Robards et al. 2000, Robertson et al. 2007). Thousands of northern fulmars also use this site (McLaren and Renaud 1979, 1982), although the nearest colony is at Hell Gate, 200 km away, but within easy foraging range (Mallory et al. 2008b). Eastern Jones Sound is an important maternity area for polar bear and a summer area for seal, narwhal, and walrus (Riewe 1992).

#### Site 6. Browne Island

The island is in western Barrow Strait, about 12 km southwest of Cornwallis Island and is less than 50 km from Resolute Bay (Qausuittuq). The marine area lies at the boundary between the annual consolidated and unconsolidated ice in Barrow Strait, and there is only about five weeks of open water at the island each year (Dickins et al. 1990).

Browne Island supports a colony of black-legged kittiwakes whose size has varied over the years, from estimates of 500 pairs (1975) to 2800 pairs (2007), with most counts representing about 1% of the Canadian population (Alliston et al. 1976; Mallory et al. 2009; Gaston et al. 2012). Kittiwakes use the area between May and September each year, and presumably sea ice extent influences annual nesting effort at this colony, although this has not been assessed. Small numbers of Thayer's and glaucous gulls also nest here and use the local marine area (Alliston et al. 1976).

#### Site 7. Cape Liddon

The waters around Cape Liddon, at the southwestern tip of Devon Island, form one of several key marine sites in Lancaster Sound—in many respects the entire Sound could be a single, valued location. Ice covers this area typically from early October through the following July (Dickins et al. 1990). Strong currents flow south through Wellington Channel to the west and meet west-flowing currents in northern Lancaster Sound, producing nutrient-rich waters (Gaston and Nettleship 1981).

The cliffs of Cape Liddon support a northern fulmar colony for which the numbers of nesting birds have variously been esti-

mated at 1000 to 10 000 pairs (Alexander et al. 1991; Mallory et al. 2012). The most recent and systematic survey in 2002 (Gaston et al. 2012) estimated 7000 pairs, 4% of the Canadian population. Fulmars use Cape Liddon between April and early October. Radstock Bay, beside the Cape, is an aggregation site for northern fulmars, thick-billed murres, black-legged kittiwakes, and black guillemots between August and October (Fisheries and Oceans Canada 1999), and those and other waters around the Cape are an important feeding area for thick-billed murres breeding at Prince Leopold Island (Bradstreet 1979, 1980; Gaston and Nettleship 1981). Large numbers of beluga whales, walrus, and polar bears inhabit or migrate through these waters annually, making this an important hunting area for Inuit from Resolute Bay (Schweinsburg et al. 1982; Dickins et al. 1990; Riewe 1992; Fisheries and Oceans Canada 1999).

#### Site 8. Hobhouse Inlet

This site lies along the indented southern coast of Devon Island in central Lancaster Sound (Mallory and Fontaine 2004; Latour et al. 2008). Ice covers the region by mid-October, and open water is available in leads starting the following April (Smith and Rigby 1981), with normal break up by mid-June (Dickins et al. 1990). Currents flow from east to west along southern Devon Island.

Hobhouse Inlet supports a large northern fulmar colony, estimated at 75 000 pairs in 1972 (Nettleship 1974, Brown et al. 1975), but reassessed systematically in 2001 and estimated at 15 000 pairs or 9% of the Canadian population (Gaston et al. 2012). Some glaucous gulls and black guillemots also nest here (Latour et al. 2008). The marine area around Hobhouse Inlet is also important for certain mammals, especially beluga, polar bear, and walrus (Schweinsburg et al. 1982; Dickins et al. 1990; Riewe 1992; Fisheries and Oceans Canada 1999).

#### Site 9. Eastern Lancaster Sound

This large region includes the waters between southeastern Devon Island and northern Bylot Island as they meet Baffin Bay. This area usually forms as an open-water feature during spring ice breakup and then turns to unconsolidated ice but with leads or a distinct floe edge in the autumn and winter. The annual shape and size of the key site varies according to the extent of the Lancaster Sound ice shelf and wind and ice movement (Smith and Rigby 1981; Dickins et al. 1990). Water is open for ~18 weeks in most years (Dickins et al. 1990).

Six major seabird colonies occur around this area at Baillarge Bay, Prince Leopold Island, Cape Liddon, Hobhouse Inlet, Cape Hay, and Coburg Island (Mallory and Fontaine 2004; Latour et al. 2008). Most birds inhabiting these colonies move through eastern Lancaster Sound during migration (e.g., McFarlane Tranquilla et al. 2013) or use it as a feeding site (Nettleship and Gaston 1978, McLaren 1982). Consequently, 74 000 pairs of black-legged kittiwakes (36% of the Canadian population), 135 000 pairs of northern fulmars (33%), and 240 000 pairs of thick-billed murres (16%) likely use this marine feature during the year (Gaston et al. 2012), along with tens of thousands of other breeding and nonbreeding birds including those species, black guillemots, Arctic terns, phalaropes, jaegers, and sea ducks (McLaren and Renaud 1979; McLaren 1982; Wong et al. 2014). In particular, >2,000,000 dovekies have been observed using this region in the spring on their way to nesting sites in Greenland (Johnson et al. 1976; Renaud et al. 1982). Finally, this feature is also a key site for marine mammals including narwhal, harp seal, beluga, bowhead whale, and polar bear (Schweinsburg et al. 1982; Dickins et al. 1990; Riewe 1992; Richard et al. 1998; Fisheries and Oceans 1999; Dietz et al. 2008).

#### Site 10. Prince Leopold Island

The waters around Prince Leopold Island lie at the junction of Prince Regent Inlet and Barrow Strait at the western edge of Lancaster Sound. The island is 13 km north of Somerset Island (Gaston and Nettleship 1981; Latour et al. 2008). Ice has broken up to

varying degrees between April and October most years, providing 12 weeks of open water to the east with breakup at the island typically in the first two weeks of July (Smith and Rigby 1981; Dickins et al. 1990). Strong currents flow west along the southern coast of Devon Island, east along the northern coast of Somerset Island with a substantial water transfer south into Prince Regent Inlet, and north into Lancaster Sound from eastern Prince Regent Inlet (Welch et al. 1992). The major current interactions around Prince Leopold Island (65–100 cm/s; Dickins et al. 1990) are thought to create local enrichment of nutrients and enhance phytoplankton growth, with consequent effects up the food chain, resulting in highly suitable conditions for seabirds (Gaston and Nettleship 1981).

Prince Leopold Island is the single most important seabird monitoring site in the Canadian Arctic (e.g., Gaston et al. 2005; Braune et al. 2016), in part because it supports important populations of five species. The waters around Prince Leopold Island are critical for a variety of Arctic seabirds (Wong et al. 2014), including thick-billed murres (100 000 pairs), black-legged kittiwakes (29 000 pairs), northern fulmars (16 000 pairs), and black guillemots (2000 pairs; Gaston et al. 2012). These numbers represent 6%, 14%, 9%, and 1% of the national populations of these species, respectively. The island also supports 70 pairs of glaucous gulls (Gaston et al. 2012), a substantial decline from the 1970s (Gaston 2014). The marine region is occupied by seabirds from early May to the end of September; in years of extensive, late sea ice, attendance at the colony and hence birds using the marine site may be reduced (Gaston et al. 2005). Murres from the colonies on Prince Leopold Island forage from Prince Regent Inlet across to south Devon Island (Gaston and Nettleship 1981), east to Croker Bay, and west to the ice edge at Wellington Channel (Bradstreet 1979, 1980). Murres and kittiwakes from Prince Leopold Island migrate eastwards from the colony and south through Davis Strait to spend the winter principally in the Labrador Sea (Frederiksen et al. 2012; McFarlane Tranquilla et al. 2013). This marine region is also an important area for Arctic whales, bears and all of the ice seals (Dickins et al. 1990; Riewe 1992; Fisheries and Oceans Canada 1999; Gaston 2014).

#### Site 11. Cape Hay

Cape Hay is at the northwestern tip of Bylot Island at the eastern entrance to Lancaster Sound in the high-Arctic oceanographic zone (Nettleship and Evans 1985). Ice cover of the marine site begins in mid-October and breaks up in mid-June, resulting in approximately 18 weeks of open water annually (Smith and Rigby 1981; Dickins et al. 1990). Water currents are dominated by the Baffin Bay intrusive current, which moves east along northern Bylot Island at velocities up to 1 m/s (Dickins et al. 1990).

Approximately 100 000 pairs of thick-billed murres and 15 000 pairs of black-legged kittiwakes, representing 6% and 7% of their Canadian populations, respectively, nest at Cape Hay (Gaston et al. 2017). The ice edge around the Cape is also a critical staging and feeding site for hundreds to thousands of murres, fulmars, guillemots, kittiwakes, and dovekeys early in the breeding season (May, June; McLaren 1982; Renaud et al. 1982; Riewe 1992).

Narwhal, beluga, and bowhead as well as harp seals and walrus move past Cape Hay, and polar bears use this area for maternity denning and as a summer retreat (Schweinsburg et al. 1982; Riewe 1992; Fisheries and Oceans Canada 1999; Heide-Jorgensen et al. 2006; Dietz et al. 2008). The region is also an important hunting area for Inuit from the community of Pond Inlet (Riewe 1992; Fisheries and Oceans Canada 1999).

#### Site 12. Baillarge Bay

The marine site at Baillarge Bay lies at the northeastern tip of Admiralty Inlet on northern Baffin Island, approximately 40 km north of the community of Arctic Bay. Unlike the other sites near Lancaster Sound, this site only supports nine weeks of open water

(late July to mid-October), but within 50 km, the water stays open for 13–15 weeks in Lancaster Sound (Dickins et al. 1990).

A major northern fulmar colony breeds along 16 km of rugged, incised cliffs between Baillarge Bay and Elwin Inlet on the eastern shore of Admiralty Inlet. This colony has been estimated between 10 000 and 100 000 pairs (Latour et al. 2008), although systematic surveys undertaken in 2002 suggested 20 000 pairs of fulmars, representing approximately 11% of the Canadian population of this species (Gaston et al. 2012). Fulmars and black guillemots congregate in vast numbers near the colony and floe edge in the spring, according to surveys and traditional ecological knowledge (Gaston and Nettleship 1981; Dickins et al. 1990; Riewe 1992). This is also a key area for narwhal, ringed seal, harp seal, beluga, and polar bear (Sergeant and Hay 1979; Stirling et al. 1979; Dickins et al. 1990; Dietz et al. 2008).

#### Site 13. Batty Bay

This site is a 10-km-long inlet on the eastern side of Somerset Island, which drains into Prince Regent Inlet through a 5-km-wide mouth. Although ice begins to break up in late June, the site often contains up to 90% ice cover until the start of August, freezing up at the start of October and yielding 10 weeks of open water (Smith and Rigby 1981).

In the 1970s, numbers of black-legged kittiwake pairs varied between 350 and 2000 (1% of the Canadian population (Alliston et al. 1976), but this has increased to 8000 pairs (4%) in the 2000s (Mallory et al. 2009; Gaston et al. 2012). Migrating eiders may stage along the east coast of Somerset Island in significant numbers (McLaren and Alliston 1985). Beluga, walrus, and polar bear are seasonally abundant here as well (Sergeant and Hay 1979; Riewe 1992).

#### Site 14. Cape Graham Moore

Cape Graham Moore is located on southeastern Bylot Island, which lies northeast of Baffin Island at the eastern entrance to Lancaster Sound. Recurring offshore leads form in sea ice off Cape Graham Moore, with a relatively narrow landfast ice band (although this may vary greatly between years; McLaren 1982) so that the floe edge is usually not far from shore (Dickins et al. 1990). The leads often join to the Lancaster Sound Polynya and North Water Polynya (Smith and Rigby 1981). Melt, breakup, and movement of ice mean that >90% total ice cover remains until mid-July near the Cape, resulting in 11–12 weeks of open water (Dickins et al. 1990). Ice freeze-up usually occurs by the third week of October.

The waters around Cape Graham Moore are used by thousands of Arctic marine birds (Wong et al. 2014). Surveys in 2015 suggested that the terrestrial colony site supported approximately 60 000 pairs of thick-billed murres (4% of Canadian population) and 3000 pairs of black-legged kittiwakes (1% of the Canadian population; Gaston et al. 2017). In May and June, the floe edge off Cape Graham Moore is a key site for marine birds (up to 18 species including fulmars, kittiwakes, murres, guillemots, dovekeys) migrating north to the high Arctic to breed (Brown and Nettleship 1981; Bradstreet 1982; McLaren 1982; Renaud et al. 1982), and it is a critical hunting and ecotourism site for local Inuit as the area also hosts many marine mammals (notably narwhal, beluga, bowhead whale, and polar bear) in the spring (Riewe 1992).

#### Site 15. Buchan Gulf

This marine site lies on the northeastern coast of north Baffin Island, where the geology supports high, steep cliffs suitable for seabird nesting. Recurring offshore leads form in sea ice off Buchan Gulf during the winter, although they may open and close, but ice near the site remains until July and freezes again in late October (Smith and Rigby 1981).

This site is one of the locations that has either the least convincing and most outdated data or perhaps has evidence of recent change. Birds are common in this general area from mid-April



through October (Riewe 1992; Wong et al. 2014). Early survey work suggested that Buchan Gulf supported approximately 25 000 pairs of northern fulmars, about 11% of the Canadian population of this species, along the two promontories in the 1970s (CEC 1999; Mallory et al. 2012). However, reassessment of the original photographs taken in 1972 adjusted the population to be substantially lower than previously reported, perhaps 10 000 pairs (Gaston et al. 2012) or 6% of the Canadian population. It is conceivable that this colony could have been in decline for some time, or that it has been previously overestimated like many Baffin fulmar colonies (Gaston et al. 2006). New surveys are needed to confirm these estimates. As many as 25 000 eiders (3% of the Canadian population) have been observed in leads off the cliffs in spring (McLaren and Renaud 1979; McLaren and McLaren 1982). Finally, this region is particularly important for narwhal, ringed seal, and polar bear (Riewe 1992).

#### Site 16. Scott Inlet

The marine region near Scott Inlet is located on the east coast of Baffin Island, north of Clyde River (Kangiqtugaapik). Like Buchan Gulf, recurring offshore leads form along the east coast of Baffin Island during the winter, although they may open and close, but ice near the site remains until July and freezes again in late October (Smith and Rigby 1981).

This region was thought to support 25 000 pairs of northern fulmars, which was increased to 30 000 pairs based on a recount of the original 1973 photographs (Gaston et al. 2012), but this estimate was revised to 10 000 pairs from a 1986 survey (Mallory et al. 2012), and information is now quite dated. This represents about 6% of the Canadian population of this species, but if the colony size is closer to 30 000, it represents ~17% of the Canadian population. The marine region also supports up to 100 pairs of glaucous gulls and a few thousand migrating black guillemots and eiders (Renaud and Bradstreet 1980; McLaren and Renaud 1979; McLaren 1982; McLaren and McLaren 1982; Latour et al. 2008). This marine region is occupied by seabirds from mid-April through October (Riewe 1992; Wong et al. 2014) and supports high numbers of breeding or migrating narwhal, beluga, harp seal, bearded seal, ringed seal, and polar bear (Riewe 1992).

#### Site 17. Amundsen Gulf and Bathurst Polynya

This marine site includes the large, recurring polynya that forms in western Amundsen Gulf (Hannah et al. 2009) as well as the associated leads along Banks Island and the Tuktoyaktuk Peninsula. Marine currents and a variable bathymetry result in marine upwellings that produce a rich marine environment in multiple locations, and a recurrent crack and lead system develops annually around the 30-m-depth contour (Marko 1975). This is critical because the key sites for marine birds are patches of open water less than 25 m in depth (Barry et al. 1981; Dickson and Smith 2013). Open water is available in various locations throughout the winter, although freeze-up normally begins between October and November and lasts until mid-June (Smith and Rigby 1981; Alexander et al. 1997). The recurrent leads in this area serve as a migration corridor for marine birds (particularly king and common eiders), and the polynya near Cape Bathurst serves as a major staging site (Alexander et al. 1997; Dickson and Smith 2013).

Relatively few seabirds use this marine region (Wong et al. 2014), mainly black guillemots, glaucous gulls, yellow-billed loons (*Gavia adamsii*), ivory gulls, and Ross's gulls (Barry 1976; Barry et al. 1981; Barry and Barry 1982; Johnson and Ward 1985), but updated survey information is required. However, it is a critical site for Arctic waterfowl, especially sea ducks. Populations of most of these species have been in decline in the western Arctic since the 1970s (Dickson and Gilchrist 2002), making recognition and conservation of their habitat very important. Reports of massive flocks of sea ducks using these sites are well known. For king eiders, there are reports of flocks of 16 000 birds (2.5% of the Canadian

population; Barry and Barry 1982), 20 000 birds (3%; Barry et al. 1981), and single-day surveys of 63 000 and 39 000 birds (10% and 6% of the Canadian population, respectively; Alexander et al. 1997). Common eiders tend to concentrate in the southern portion of this marine area (Barry et al. 1981), with observations of 50 000 birds (50% of the Canadian population of common eider (*Somateria mollissima v-nigra*) Barry 1976) in one site and 75 000 elsewhere at the same time (Searing et al. 1975). In 1993, 25 000 common eiders were observed near the Baillie Islands in 1993 (36% of Canadian *v-nigra* eider) population; Alexander et al. 1997). These eiders form a key component of the traditional diet of indigenous residents of nearby communities (Byers and Dickson 2001). Long-tailed ducks (*Clangula hyemalis*) can also occur in very large flocks; more than 24 000 were observed in the shore lead west of Storkerson Bay in 1974 (Searing et al. 1975), representing perhaps 1% of the Canadian population, while other flocks of 17 000 and 40 000 birds are reported (Barry 1976). Elsewhere, molting birds can occur in huge flocks; 160 000 long-tailed ducks (6% of the Canadian population) have been documented in some areas from late July to mid-August (Barry et al. 1981; Barry and Barry 1982). Beluga, bowhead whale, ringed seal, and polar bears are common at different times of the year as well (Alexander et al. 1991).

#### Site 18. Lambert Channel

This marine channel is a narrow stretch of water between the mainland and Victoria Island where a small polynya forms in Dolphin and Union Strait due to the strong current (Smith and Rigby 1981). The polynya starts to open in February and generally persists until break up in July before freezing over at the end of October.

Many eiders that stage in the Amundsen Gulf region move into Lambert Channel as they move to and from their breeding grounds (Dickson and Smith 2013). The site appears to be critical for feeding prior to nest initiation (Allen 1982). Single groups of 18 000 birds, and collective counts of 64 000 and 70 000 common eiders (64% of the Canadian *v-nigra* eider population; 7% of the Canadian common eider population) have been observed, although survey data are several decades old. Large but lesser numbers of long-tailed ducks, yellow-billed loons, geese, other ducks, and raptors also use the site (Riewe 1992; Alexander et al. 1997). Populations of most sea ducks have declined in the western Arctic since the 1970s (Dickson and Gilchrist 2002), meaning that conservation of key habitat should be high priority.

#### Site 19. Qaqqulluit (Cape Searle) and Akpait (Reid Bay)

These two seabird colonies are located about 30 km apart, and thus the marine area around them forms one large, key site along eastern Baffin Island near the point where it is closest to Greenland (Mallory and Fontaine 2004; Latour et al. 2008). It is at the southern limit of high Arctic oceanographic zone waters (Nettleship and Evans 1985). The terrestrial characteristics of Cape Searle and Reid Bay are described in Alexander et al. (1991) and Latour et al. (2008). The site is ice covered by late October but leads in the ice expand north from Cumberland Sound to this region by April (Smith and Rigby 1981). Nearby fjords stay frozen until mid-June, and pack ice may remain along this coast well into August (McLaren Atlantic Inc 1978a, 1978b). Between the two colonies, waters are deep (>200 fathoms) and good for ship navigation, and thus islands in this area supported military installations and a small community until the late 1960s (Mallory et al. 2006a).

This marine region is used by seabirds from mid-April through October (Wynne-Edwards 1952). Significant concentrations of marine birds may be distributed throughout this region, depending on the annual patterns of ice breakup and the distribution of prey (McLaren Atlantic Ltd 1978a, 1978b; Riewe 1992). Long thought to support >100,000 pairs of fulmars (Wynne-Edwards 1952; Alexander et al. 1991; Latour et al. 2008), it also may have been overestimated previously. Recent survey estimates (2001) suggest



that 35 000 pairs of marine birds inhabit the colony (Gaston et al. 2006, 2012), still the largest fulmar colony in Canada, representing 20% of the Canadian population. Akpait is one of Canada's largest thick-billed murre colonies (Gaston and Hipfner 2000), estimated at 130 000 pairs, or about 8% of the Canadian population (Gaston and Smith 1987; Gaston et al. 2012). Approximately 15 000 pairs of fulmars (9%) also breed at Akpait as well as 1900 pairs (1%) of black-legged kittiwakes (Gaston and Smith 1987; Gaston et al. 2012). Glaucous gulls, Iceland gulls, and black guillemots are numerous here, as suggested by surveys and local ecological knowledge (Riewe 1992; Mallory et al. 2006a). Inuit traditional knowledge suggested that Atlantic puffins occurred here (Mallory et al. 2006a), and one was collected in recent surveys (the high-Arctic subspecies *Fratercula arctica naumanni*; Gaston and Provencher 2012). Wynne-Edwards (1952) suggested that the fulmars of Qaqqulluit forage within 80 km of the colony, but probably travel much farther (Mallory et al. 2008b). This marine site supports locally important numbers of marine mammals, especially walrus, ringed seal, bearded seal, harp seal, polar bear, and bowhead whale (Wynne-Edwards 1952; Stirling et al. 1980; Riewe 1992), all of which remain important prey to Inuit hunters in Qikiqtarjuaq (Mallory et al. 2006a).

#### Site 20. East Bay

This marine site is a very flat, shallow bay of eastern Southampton Island, where water flowing south through Foxe Channel meets western Hudson Strait. Ice freeze-up usually occurs by mid-October with landfast ice forming in East Bay (Gaston et al. 1985), although the ice remains unconsolidated in the more pelagic areas (Larnder 1968). Ice breakup begins in April or May (Gaston and Hipfner 1998), but pack ice moves in and out of East Bay through July (Jean-Gagnon et al. 2018).

This marine site has been a site of intensive international research on eiders (Robertson et al. 2001; Wayland et al. 2001; Descamps et al. 2009, 2011), as it supports Arctic Canada's largest single colony of common eiders, up to 8000 pairs (3% of the Canadian population; Abraham and Ankney 1986). Other abundant marine and coastal birds include black guillemots (Berzins et al. 2009), brant (*Branta bernicla*), Sabine's gulls (*Xema sabini*), and various populations of shorebirds, as well as 2% of the Canadian breeding population of lesser snow geese (*Chen caerulescens*) (Alexander et al. 1991; Stenhouse et al. 2001; Latour et al. 2008; Smith et al. 2010). The marine site provides key habitat for beluga, walrus, and polar bear as well (Riewe 1992).

#### Site 21. Markham Bay

Markham Bay is an island-studded section of southern Baffin Island, along the northern coast of Hudson Strait. Currents flow west in this region, and ice freeze-up usually occurs by mid-October, although the ice remains unconsolidated and mobile from January to April, with landfast ice formed around coastlines (Larnder 1968). Ice breakup begins in April near persistent shore leads, such as the lead that opens along southern Baffin Island; by May, large patches of open water occur, and little ice remains by July. Patterns of ice breakup and the location of the floe edge can change considerably among years (McDonald et al. 1997).

Between April and October (Gaston and Cooch 1986), this region supports a large portion of the breeding population of common eiders (*borealis* race) in Hudson Strait. Gaston and Cooch (1986) saw groups of 8000 staged eiders and estimated 10 000 pairs of eiders (2% of the Canadian population) nesting in this region, but those numbers were markedly increased in 1997 and 1998 when 44 500 eiders were counted in aerial surveys (5%; Mallory and Fontaine 2004). Iverson et al. (2014) estimated >32,000 eiders in this region (3%) during their work in the late 2000s. Markham Bay and the surrounding area also support substantial numbers of Iceland gulls and black guillemots (Riewe 1992) and is an impor-

tant area for beluga, ringed seal, walrus, and polar bear (Stirling et al. 1980; Riewe 1992).

#### Site 22. Coats Island

This marine site is in northern Hudson Bay, approximately 100 km south of Coral Harbour on Southampton Island. Ice freeze-up usually occurs by mid-October, remaining largely unconsolidated (Larnder 1968). Ice breakup begins in May, and a period of rapid change in ice cover occurs between May and June when coverage decreases from about 90% to 60% (Gaston and Hipfner 1998). Landfast ice generally persists around Coats Island into June and mobile pack ice may persist into July, although open water can be found near the island (Gaston and Hipfner 1998). Ice break-up has been earlier since the mid-1990s than in former years. Waters remain relatively ice-free from late July until November.

Coats Island supports two thick-billed murre colonies, estimated at 30 000 pairs or about 2% of the Canadian population (Gaston et al. 1993, 2012). These colonies have increased substantially in size from estimates in the 1950s (Tuck 1961; Gaston et al. 1987), and the western colony constitutes one of the key seabird research sites in eastern Canada (Gaston and Elliot 1991; Gaston et al. 1993; Donaldson et al. 1997; Gilchrist and Gaston 1997; Gaston and Hipfner 1998; Hipfner et al. 1999; Elliott et al. 2009a, 2009b). Murres from this colony winter in the Labrador Sea (Gaston et al. 2011). Small numbers of black guillemots, razorbills (*Alca torda*), and glaucous and herring gulls use the area (Riewe 1992; Gaston and Woo 2008) as well as an Iceland gull colony supporting about 50 pairs (Gaston and Elliot 1990). Large numbers of walrus, beluga, and polar bears occur in these waters (Riewe 1992; Gaston 2000).

#### Site 23. Digges Sound

This marine site lies in the northeastern corner of Hudson Bay, between the Digges Islands and the mainland of Ungava Peninsula, Quebec. Waters move north from southern Hudson Bay and east through Hudson Strait (McDonald et al. 1997), and ice cover persists from mid-October until April. By May patches of water are open in Digges Sound, with most ice gone by late July (Larnder 1968; Gaston et al. 1985; McDonald et al. 1997; Gaston and Hipfner 1998).

Collectively, the two colonies of thick-billed murres in Digges Sound represent approximately 400 000 pairs or 26% of the Canadian population (Gaston et al. 1985, 2012), one of the largest concentrations of thick-billed murres in Canada (Gaston and Hipfner 2000), although numbers since 1980 are substantially smaller than those estimated by Tuck in 1955 (Tuck 1960; Gaston et al. 1993, 2012). Seabirds occur from late April through November (Gaston et al. 1985, 2012) including black guillemots, glaucous gulls, Iceland gulls, herring gulls, Atlantic puffins, and Arctic terns (Gaston and Mallone 1980). A key period occurs in August when male parents disperse from the colony with their young into offshore areas of northern Hudson Bay. In early September 1980, chicks were concentrated in an area about 140 km north and west of Digges Sound. At least 40 000 chicks were present, and at least 140 000 adults were scattered east of 72°W (Gaston 1982). These waters also support important populations of beluga, bearded seal, and ringed seal (Gaston et al. 1985; Riewe 1992). The site also supports some polar bears (Riewe 1992). The site is an important hunting location for the community of Ivujivik.

#### Site 24. Frobisher Bay

This site comprises a relatively shallow bay running approximately 200 km northwest to southeast in southern Baffin Island. A large polynya forms here annually (Stirling and Cleator 1981), and there are numerous islands surrounded by many small polynyas kept open by the intense tidal activity (Smith and Rigby 1981). Sea

ice develops over the bay in late October and begins to break up in April, with the entire bay normally navigable by early July.

Significant concentrations of marine birds are distributed throughout this region, generally from May to October, depending on the annual patterns of ice breakup and the distribution of prey (McLaren Atlantic Ltd 1978a, 1978b; Riewe 1992). Colonies of 50 000 pairs of thick-billed murrelets and 7000 pairs of black-legged kittiwakes breed at Hantzsch Island (Alexander et al. 1991; Gaston et al. 2012), representing about 3% of their respective Canadian populations (Gaston 1986, 1991; Gaston et al. 2012). Additional, smaller kittiwake colonies are found on other islands near the entrance to the bay (McLaren Atlantic Ltd. 1978a, 1978b; McLaren Marex Inc 1979) as well as Nunavut's only permanent colony of razorbills (Brown et al. 1975). Large numbers of black guillemots, Iceland gulls, and common eiders nest in this region, although systematic counts are unavailable (McLaren Atlantic Ltd 1978a, 1978b; Abraham and Finney 1986; Fontaine et al. 2001; Iverson et al. 2014). Many ivory gulls, probably representing >1% of the Canadian population, may occur here in some winters (McLaren Marex Inc 1979; Spencer et al. 2014). Harlequin ducks (*Histrionicus histrionicus*), another species at risk, occur in Frobisher Bay in unknown numbers (Mallory et al. 2001). Inuit ecological knowledge suggests that the mouth of Frobisher Bay is an important feeding, staging, and breeding site for more than 15 species of marine birds (Riewe 1992) as well as bearded, harp, and ringed seal; walrus; and beluga (Riewe 1992). Other survey data have noted the importance of this region for bottlenose whales (*Hyperoodon ampullatus*) (Stirling and Cleator 1981) and polar bears (Stirling et al. 1980).

#### Site 25. Central Davis Strait

One of the few entirely offshore sites that we delineate in the Canadian Arctic, the site in central Davis Strait is located approximately half way between Baffin Island and Southern Greenland. In this region, bathymetric profiles show that ocean depths change from 200–500 m deep to the north, dropping rapidly to >2000 m deep in the south. This rapid change in depth closely matches the annual extent of pack ice in Davis Strait (Crane 1978), and mirrors a split in the north-flowing, warmer West Greenland Current, which branches west at this latitude to join the Baffin Current and flow south (Curry et al. 2011). Ice builds in this site by December and remains as mobile pack ice through April and into May, depending on annual temperatures.

The region is used by hundreds of thousands of seabirds at different seasons (Wong et al. 2014). Dovekies, northern fulmars, thick-billed murrelets, and black-legged kittiwakes migrate through, forage, or overwinter in this area (Mallory et al. 2008d; Gaston et al. 2011; Frederiksen et al. 2012; Fort et al. 2013; Wong et al. 2014). The region outlined is also the key, long-term wintering site for most of the Canadian population of endangered ivory gulls (Spencer et al. 2014) as well as many ivory gulls from colonies in Svalbard and Greenland (Gilg et al. 2010). The marine site in central Davis Strait is important as a migratory pathway and foraging site for many marine mammals, especially hooded seals (*Cystophora cristata*) (Johnston et al. 2005) that haul out in this region to give birth to their pups and the little-known population of northern bottlenose whales (COSEWIC 2011).

#### Site 26. Akpatok Island

This marine site lies in northwestern Ungava Bay and Hudson Strait, about 65 km offshore from the northern mainland of Quebec (Nunavik) and surrounds Akpatok Island (Chapdelaine et al. 1986a; Latour et al. 2008). Unconsolidated ice forms in the area by mid-October, and mobile pack ice dominates Hudson Strait from January to April, with landfast ice formed around coastlines (Larnder 1968). Ice breakup begins in April near persistent shore leads and large patches of open water are found by May, with most ice gone by late July.

Akpatok Island supports Canada's largest concentration of thick-billed murrelets, separated in two colonies, which collectively are comprised of 520 000 pairs of birds or 34% of the Canadian population (Tuck 1960; Gaston 1991; Gaston and Hipfner 2000; Gaston et al. 2012). Murrelets arrive in early May and depart at the end of August. The marine site may also support large numbers of migrating marine birds (e.g., eiders, other murrelets, guillemots), depending on the annual patterns of ice breakup and the distribution of prey (McLaren Atlantic Ltd 1978a, 1978b; Riewe 1992). The island and surrounding waters form the traditional hunting area for several Inuit communities from Nunavik (northern Québec), which hunt walrus, ringed seal, and polar bear in this region (Smith et al. 1975; Hentzel 1992; Riewe 1992).

#### Site 27. Ungava Bay Archipelagoes

This large bay in northern Québec is rimmed with countless islands (Latour et al. 2008). The region is usually covered by unconsolidated ice from mid-October through early July, although landfast ice forms around coastlines (Larnder 1968). Little ice remains by late July.

This site supports a large portion of the breeding population of common eiders, with up to 48 000 pairs of eiders using various island clusters, representing 16% of the Canadian population (Nakashima 1986; Chapdelaine et al. 1986b; Falardeau et al. 2003). Eiders occur in this site from early May through late October or early November (Gaston and Cooch 1986; Savard et al. 2011). About two-thirds of these birds overwinter in Greenland, with the remainder along Newfoundland and Labrador and the Gulf of St. Lawrence (Savard et al. 2011). Population declines or colony abandonment have been observed throughout Hudson Strait in recent years, attributable to greater predation and disturbance by polar bears (Iverson et al. 2014) as well as disease outbreaks (Descamps et al. 2009).

#### Site 28. Sleeper Islands

This archipelago in eastern Hudson Bay includes over 360 islands (Alexander et al. 1991). Waters around the Sleeper Islands are relatively shallow and are situated on the boundary between the Low Arctic and Boreal oceanographic zones (Nettleship and Evans 1985). Ice forms along shorelines in October and expands coverage through November and December, such that by January open water is only found in polynyas and recurrent leads at the Sleeper Islands and the Belcher Islands to the south (Montgomery 1950; Larnder 1968; Freeman 1970). Shallow coastal areas break up in May and, in most years, Hudson Bay is relatively ice-free by mid-July (Larnder 1968).

Hudson Bay common eiders (subspecies *sedentaria*) are year-round residents of James Bay and Hudson Bay, with a nonmigratory population that has increased to approximately 125 000 pairs (Abraham and Finney 1986; Bowman et al. 2015). In 1985, an estimated 5900 pairs of eiders (12% of the Canadian *sedentaria* population) nested on the Sleeper Islands. In winter, eiders are restricted to areas of open water, and the majority of *S. m. sedentaria* apparently concentrate in the vicinity of open cracks and leads near the Belcher and Sleeper islands (Freeman 1970; Prach et al. 1981). In early winter, the eiders move in large numbers to permanent open water west and north of the Belcher Islands, off the Sleeper Islands (depending on the distribution of ice) (Freeman 1970), and in some years almost the entire *sedentaria* population (up to 100 000 birds) may be concentrated in a small region (Mallory and Fontaine 2004). This marine site also supports locally high concentrations of walrus and polar bear (Riewe 1992).

#### Site 29. Belcher Islands

Like the Sleeper Islands, the Belcher archipelago to the south consists of thousands of low, bedrock islands rising from southeastern Hudson Bay (Latour et al. 2008). Ice forms along shorelines in October, and this continues to increase until January, when



open water is only found in polynyas and recurrent leads (Montgomery 1950; Larnder 1968; Freeman 1970). However, recent hydroelectric projects are altering sea ice cycles and associated meiofauna in this region (e.g., Prinsenberg 1980; Grainger 1988; Rosenberg et al. 1995). Tides are only about 0.5 m around the islands but create very strong currents in the shallow water and these lead to the annual formation of up to 35 polynyas (McDonald et al. 1997; Gilchrist and Robertson 2000). Ice usually breaks up in May (Larnder 1968).

As noted for the Sleeper islands, ~125,000 pairs of Hudson Bay common eiders are year-round residents of James Bay and Hudson Bay and are a key source of food and down for nearby Inuit communities (Abraham and Finney 1986; Bowman et al. 2015). In winter, eiders concentrate in the vicinity of open cracks and leads near the Belcher and Sleeper islands (Freeman 1970). Open water around the Belcher Islands may support more than 10% of the Canadian population of the *sedentaria* subspecies of common eider in most winters. As these birds do not migrate, they are susceptible to mass starvation and population declines in heavy ice years (Robertson and Gilchrist 1998), which has significant effects on food supplies for local Inuit communities. In a typical year, wind, ice, and currents all combine to limit foraging time for eiders (Heath et al. 2010). Community-driven research and monitoring of eiders in this site continues through the Arctic Eider Society (SIKU 2018). This marine site also supports locally high concentrations of walrus, beluga, and polar bear (Manning 1976; Riewe 1992).

### Site 30. Northern Ontario Coastline

This marine site along the coastline of northern Ontario extends along the southern edge of Hudson Bay and south into James Bay, just offshore of the Hudson Bay lowlands (Mallory and Fontaine 2004). Waters here are shallow and currents flow east and then south into James Bay (McDonald et al. 1997). Ice forms in October and Hudson Bay and James Bay become mostly covered by January, but with some open water near the mouth of James Bay (Larnder 1968). Ice breaks up in these shallow waters by May.

This site is notable because approximately 90 000 male Black Scoters (*Melanitta nigra*) moult here (Ross 1983, 1994; note that survey data are several decades old), comprising possibly 50% of the breeding population of this species (45 000–185 000 breeding pairs; Bordage and Savard 2011). There are also important moulting or migration staging sites along the east coast of James Bay (Benoit et al. 1991), so the total population is probably larger than currently estimated. Nonetheless, it is clear that this marine site is critical to the annual biology of this species. Scoters moult at this location, feeding on blue mussels (*Mytilus edulis*) and other mollusks. These shallow coastal areas are also important for common eiders, geese, and long-tailed ducks (Manning 1952; Abraham and Finney 1986; McDonald et al. 1997; Mallory et al. 2006b). This site is also used in the spring by beluga, and these coastal areas are important for denning polar bears (McDonald et al. 1997).

### Considerations for key site delineation

In contrast to the terrestrial Arctic landscape, the marine component of the Arctic is more dynamic, supporting both recurrent and seasonal features important to marine birds (Gilchrist and Robertson 2000; Hannah et al. 2009). Arctic marine birds that use these marine areas adapt their timing of breeding and migration routes to match available habitats; this makes the identification of key marine habitat sites challenging. For some sites, the precise location of the key marine site will vary slightly among years as annual ice conditions vary. The 30 sites described above represent those areas for which we have scientific evidence that more than 1% of the Canadian population of a bird species uses the site annually for migration, breeding, feeding, moulting, or wintering. It is integral for any identification exercise to monitor or re-evaluate these sites in the future to confirm their importance; some of the

information we have used is quite outdated (e.g., western Arctic sea duck surveys). Moreover, the importance of individual sites will likely change through time in response to population fluctuations of birds (e.g., changes among colonies) and long-term changes in habitat conditions.

Of the sites we have identified, 21 are in the high Arctic and nine in the low Arctic oceanographic zones (Nettleship and Evans 1985). Using internationally identified management regions, 12 are in the Circumpolar Biodiversity Monitoring Program Arctic Archipelago area, nine are in the Davis–Baffin area, and nine are in the Hudson Complex. Nearly all the high Arctic sites are key marine areas for seabirds (alcids and procellariids) and gulls (larids). In contrast, many of the low Arctic sites are significant because they support nationally significant proportions of waterfowl populations at some point during the year, although the two largest thick-billed murre colonies in Canada are also found in this zone.

### Changes from early key site delineation

Mallory and Fontaine (2004) identified 34 sites across the same geographic region, but in this evaluation we added one site (Site 25, Central Davis Strait) and dropped five sites from their list (Skruis Point, Cresswell Bay, Foxe Basin, Cumberland Sound, Button Islands). For Foxe Basin, we deemed discrete observations insufficient to narrow down particular key sites within that vast area; additional surveys are clearly required. Cresswell Bay, Cumberland Sound, and the Button Islands might form key marine sites at times of the year, but survey data are insufficient at this time to delineate zones in those areas with scientific credibility. Skruis Point was surveyed multiple times between 2002 and 2010 (Mallory and Gilchrist unpublished data) and regularly found <2000 breeding pairs of black guillemots needed to reach 1% criterion, and thus it was removed from the list.

Note that recent, nonsystematic, ship-based surveys in August or September of 2007–2016 in Bellot Strait, between Prince Regent and Peel sounds, have regularly found 3000–10 000 northern fulmars, representing up to 3% of the Canadian population; this site may merit consideration in the future.

### Marine area currently with legislated protection

We have delineated a total of 349 160 km<sup>2</sup> of marine waters off the coasts of Canada's northern territories, as well as the coasts of Manitoba, Ontario, and Quebec, which constitute key marine habitats for Arctic-breeding migratory birds in Canada (an area slightly larger than Germany, Finland, or Norway). This total key area forms 9.6% of Canadian Arctic marine waters (~3,600,000 km<sup>2</sup>; DFO 2009). Our new delineations of key habitats represent a 117% increase from Mallory and Fontaine (2004; 161 000 km<sup>2</sup>), principally because we now know that many species forage much farther from their colonies than previously thought. As new tracking data and other types of information are gathered, we expect these values to be adjusted further.

Approximately 128 000 km<sup>2</sup> of marine area currently have legislated protection in the Canadian Arctic, as they are within the boundaries of existing migratory bird sanctuaries, national wildlife areas, or national parks (~19,000 km<sup>2</sup>); the remainder is in the new Tallurutiup Imanga – Lancaster Sound National Marine Conservation Area (CCEA 2017); although this overlaps with existing bird sanctuaries in this region and has not been finalized as of May 2018. However, only 4495 km<sup>2</sup> (~1%) of the key marine sites we delineated overlap with existing protected areas; once Tallurutiup Imanga is finalized, the proportion of total key marine habitat sites will increase to 13% (~44 945 km<sup>2</sup>). While the Tallurutiup Imanga protected area is a strong move forward for conservation, we stress three points: (i) 87% of the marine habitat area we identified as important for Arctic marine birds in Canada will still lack any protection; (ii) the level of protection offered by different legislated designations can vary substantially (e.g., some protections may be specific to a group or organisms, such as benthic



corals, but may offer little protection for birds); and (iii) certain zones, like Hudson Strait or Amundsen Gulf, currently have no protection yet they support huge, critical sites for marine birds.

### Habitat protection and threats in the Arctic

Marine birds face numerous threats on the oceans (e.g., Fort et al. 2013; McFarlane-Tranquilla et al. 2013; Wilcox et al. 2015; Dias et al. 2017), which have been reviewed extensively (e.g., Croxall et al. 2012). Our intent here has not been to conduct a review on threats to marine birds in the Arctic. However, the delineation of key habitat sites for marine birds stems for conservation needs to protect locations essential to these species at critical points of their annual cycle. In turn, this begs the question “Are there threats in Arctic marine waters that might deleteriously affect seabird marine habitats?” The answer to this is “yes”, and cumulatively, threats are increasing.

Pronounced effects of climate change in Arctic regions are leading to changing sea ice phenology and reduced ice extent and extent, which has ecological consequences for marine communities and food webs (reviewed in Stroeve et al. 2012; Post et al. 2013). Perhaps a more immediate concern that results from reduced ice cover is that various types of economic activity are more feasible due to better vessel access. This includes exploration for hydrocarbons, mining, increased tourism, and fisheries (Christiansen et al. 2001; Gregersen and Bidstrup 2008; Gauthier et al. 2009; Fort et al. 2013; Pizzolato et al. 2014). Increasing intensity of vessel activity inherently escalates contact (or disturbance) with birds on the water, which can negatively influence essential time birds require for resting and foraging (e.g., Velando and Munilla 2011). Cruise ship and private yacht tourism activities may also increase disturbance at nesting colonies if not properly managed (Chardine and Mendenhall 1998; Marquez and Eagles 2007). As well, exploration activities from vessels can negatively influence marine prey, degrading the quality of feeding sites (McCauley et al. 2017). Furthermore, the risk of chronic oil discharges or large oil spills at sea increase with additional vessel traffic, and oil spills are likely the greatest threat to catastrophic loss of marine birds (Piatt and Ford 1996; Wiese and Robertson 2004; Wiese et al. 2004; Munilla et al. 2011). Additionally, increasing fishery activity (Christiansen et al. 2014) inevitably elevates the risk of seabird bycatch, depending on the fishing method used. Gillnets, longlines, and trawling all occur in the Arctic and result in bird mortality (Hedd et al. 2016). In all of these cases, the potential negative effects of anthropogenic threats will be much greater in key sites where birds aggregate and (or) forage, as large proportions of a population are vulnerable at these locations and times. For these reasons, identification and delineation of key marine habitat sites is urgently required at a time when risks to wildlife are increasing.

### Limitations of current information

In reviewing the primary and “grey” scientific literature available on these sites, a disparity in the strength of the available information is apparent. We have high confidence in breeding season data near seabird colonies and, to a lesser extent, recurrent polynyas. At colonies, high survival and breeding philopatry mean that counts of birds generally change little across years (Gaston et al. 2012). At polynyas, which are used during migration staging, there are few other open water sites available, so counts tend to be similar because all birds in the area are forced to use the sites. Moreover, repeat surveys at polynyas continue to find large concentrations of birds (e.g., Alexander et al. 1997; Black et al. 2012). Thus, in these two situations, the location of the key marine site changes very little among years, and we have high confidence in the estimated number of birds using the site.

For some of the other sites, our assessment of key habitat status is based on estimates of bird use derived principally from one set of surveys, and subsequent expert opinion or local ecological knowledge that suggests that conditions remain consistent with

the old surveys. This is particularly true for sites along the floe edge and pack ice in Baffin Bay and Davis Strait (e.g., McLaren 1982). Although we have acquired new information on some of these sites since 2000, in general survey work and broadscale monitoring has declined dramatically and consequently data for many sites are now dated.

Moreover, we stress that the annual patterns of distribution, extent, and thickness of sea ice in the Arctic are changing rapidly (Parkinson 2000; Grumet et al. 2001; Arntsen et al. 2015). This is already having an effect on the timing of marine bird arrival at some sites (e.g., Gaston et al. 2009b), and it is reasonable to expect that the distribution of migrating birds may be changing too. Consequently, the delineation of the bounds of key sites will likely change in the future; Harris et al. (2017) described the challenge of identifying areas for protection of Arctic marine wildlife in an era of rapidly changing climate.

### Future plans

The identification of key marine habitats for migratory birds in the Arctic is an iterative, ongoing process. Continued assessment of these sites is essential, as climate change is altering sea ice conditions, and consequently the relative conservation value of different sites will change through time under new ice regimes (Harris et al. 2017). We have made much progress since the Mallory and Fontaine (2004) report, notably with the use of telemetry technology to track birds seasonally and annually. However, population monitoring at many sites has been cut back (Gaston et al. 2009a), and there have been virtually no new systematic surveys of colonies or at-sea surveys during spring migration or wintering since the 1970s. Moreover, the natural history, breeding ecology, and population dynamics of some Arctic marine birds require more investigation to better understand their habitat requirements (e.g., jaegers, Iceland gulls). Many of the habitat sites need updated information to assess the current use and value of the area to wildlife, while other sites require increased attention to refine our current habitat delineations.

Using traditional approaches of data collection, some of the next steps needed for the recognition and eventual protection of key habitat sites for marine birds in Arctic Canada include: (i) a commitment to regular monitoring at more colonies to determine annual variability in numbers and (ii) new surveys of some marine regions, timed to monitor the distribution of birds at key stages of their annual cycle (e.g., Iverson et al. 2014). However, new approaches are desirable. As described above, the use of telemetry has changed our perception of key sites for these species (e.g., Spencer et al. 2014). Tracking studies on additional species (notably guillemots and large gulls) and at different colonies (particularly at some major colonies in the high Arctic) are essential to properly determine year-round habitats for these species. For example, recent tracking studies have demonstrated that there are colony-specific differences in foraging range during the breeding season (e.g., Gaston et al. 2013; Jovani et al. 2015).

There is a growing need to know not just where animals are, but also what they are doing at each location, which provides insights into the functional importance of these locations (Wilson et al. 2008). A fuller understanding of why animals are at a particular location will help predict how hotspots may evolve in the future in response to changes in lower trophic levels (Fort et al. 2009; Shepard et al. 2013). The energy landscape concept can be a particularly useful conceptual model for understanding the mechanism underlying hotspots (Shepard et al. 2013). Miniaturized accelerometers record both prey capture events (energy intake) and dynamic body acceleration (mechanical energy expenditure), allowing for the calculation of net energy intake (Elliott et al. 2013; Sato et al. 2015). Coupled with spatial data from GPS loggers or similar devices, an energy landscape can be created (e.g., Amélineau et al. 2018). The energy landscape will change with ice,

wind, and prey availability. Critical habitats for animal fitness are those habitats with high net energy intake, especially if those habitats persist across time and the energy landscape can identify such critical habitats. The coupling of energetics and tracking data are a fruitful area of current study (Fort et al. 2009; Shepard et al. 2013).

Another key consideration is that we have focused on key sites derived from studies of principally seven common species, which we have assumed serve as suitable proxies for many marine birds in the region. However, there are several species that have behaviours or nesting sites that do not match any of the proxy species for which data are available. For example, phalaropes (*Phalaropus* spp.) and loons (*Gavia* spp.) may have different nesting and migration strategies than the species we have used, and consequently there could be critical marine sites for those birds (e.g., certain estuaries; MacDonald and Mallory 2017) that we have not recognized. Additional research on these groups will clarify whether there are important sites in the Canadian Arctic not currently identified which merit identification for conservation and marine spatial planning.

Finally, we will need to increase focus on knowledge exchange through our collaborative research and dissemination efforts. Certainly, there are many examples elsewhere that have shown how data from different sources (e.g., bird population monitoring, telemetry, fisheries data, and local ecological knowledge; Louzao et al. 2006; Sherley et al. 2017) make a much stronger case for key site identification. However, it is not simply for ornithologists to collaborate with other types of scientists that will improve the message and strength of the conservation argument. What is required is a process where science on marine areas is done hand-in-hand with stakeholders and decision-makers; this is considered to be a novel and more effective approach to the sustainable governance of marine resources (Cvitanovic et al. 2015). There have been some success stories in the Canadian Arctic using this approach with local communities (e.g., Mallory et al. 2006a; Provencher et al. 2013), and continued efforts to gather local ecological knowledge on marine birds and establish support for the recognition and protection of key marine habitats for birds with hunters and resource users will accelerate conservation actions.

Early in the 21st century, the Arctic marine environment is experiencing rapid change. More vessels are moving through this area to resupply communities and for tourism purposes (Hall and Johnston 1995; Stewart et al. 2007; Arctic Council 2009; Johnston et al. 2016). As sea ice thins and contracts (Parkinson 2000; Arntsen et al. 2015), newspapers in Arctic communities are speculating on the possibility of regular transport through the Northwest Passage. The recent boom in mining exploration and activity has revived concerns about potential damage for Arctic marine environments. Increased attention to key marine habitat sites for migratory birds is critical to ensure the long-term conservation of this international wildlife resource.

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