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Key winter habitat of the ivory gull *Pagophila eburnea* in the Canadian Arctic

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ABSTRACT: The ivory gull *Pagophila eburnea* is a rare Arctic seabird that breeds in remote locations; little is known of its winter distribution and behaviour. It is listed under Canadian legislation as 'endangered', and as 'near threatened' by the International Union for the Conservation of Nature. A >70% population decline in the past 3 decades in Canada prompted research on ivory gulls to better understand their year-round movements and habitat requirements. Additionally, the identification of critical habitat is a research priority in the Recovery Strategy for the ivory gull in Canada. We used data from gulls tracked by satellite telemetry from the Canadian Arctic and Svalbard, Norway, as well as data from ship observations collected between 1969 and 2010. We determined that the area of highest use by these gulls in the winter was in Davis Strait, where 90% of their time was spent over sea ice. Agreement of findings among datasets through time and from different breeding regions suggests that the edge of the pack ice in Davis Strait is an annual, key habitat for ivory gulls in winter. Given the proximity of the core wintering area to known hooded seal *Crystophora cristata* whelping patches, we speculate that remains from seal breeding, as well as polar bear *Ursus maritimus* kills and pagophilic (ice-loving) fish accessed in the vicinity of pack ice have provided spatially and temporally predictable, and valuable, food resources for ivory gulls in the winter.

KEY WORDS: Arctic · Ivory gull · Pack ice · Telemetry · Surveys

INTRODUCTION

The Arctic marine environment is a dynamic habitat for marine birds, with sea ice covering ~15 × 10^6 km^2 at its maximum extent annually in March and ~ 6 × 10^6 km^2 at its minimum in September (1981 to 2010 average; Fetterer et al. 2002). This area forms the foraging habitat for ~ 10 × 10^6 seabirds breeding in Arctic Canada (Mallory & Fontaine 2004). The spatial and temporal extent of foraging opportunities changes through the year and across years as sea ice recedes and forms (Gaston et al. 2005). In addition to annual variation due to seasonality, minimum sea ice extent has decreased in the past 20 yr at a rate of 3% per decade due to global warming, with current models showing that by mid-century, most Arctic regions will be ice free in summer (Stephenson et al. 2011). This long-term, consistent change in ice thickness and extent is a significant concern for the sustainability of ice-associated organisms like the polar bear *Ursus maritimus* (Stirling & Parkinson 2006), the ringed seal *Pusa hispida* (Laidre et al. 2008) and the ivory gull *Pagophila eburnea* (Gilchrist & Mallory 2005).

For migratory animals, movements occur in accordance with seasonal cues; however, the current Arctic warming trend has the potential to alter the timing

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of these cues for seabirds (Walther et al. 2002). During the breeding season, altered timing of ice breakup in the Arctic can influence productivity or access to marine food supplies, and thereby influence avian reproduction (Gaston et al. 2005; Mallory et al. 2010). Less research has been given to marine birds that overwinter in or near sea ice, but evidence suggests that these same processes (altered timing of ice formation and breakup, or ice extent and access to open water) have similar effects on birds' access to marine fish or invertebrates, or other winter habitat needs, and can thereby affect winter survival (Robertson & Gilchrist 1998; Lovvorn et al. 2014). For the ivory gull, changing patterns of winter ice cover may reduce overall spatiotemporal predictability of suitable wintering habitat (Gilg et al. 2012).

The ivory gull is a small, all-white, colonial-nesting gull that spends its entire year in the Arctic, in Canada, Greenland, Svalbard (Norway), and Russia (Mallory et al. 2008). It was designated a species of 'special concern' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1979, re-examined in 1996 and 2001 and left as special concern, and then designated as 'endangered' in 2006 (COSEWIC 2006). The Canadian government listed the species as 'endangered' under the Species at Risk Act (SARA) in Canada in 2009 (SARA 2009), and it is listed as 'near-threatened' by the International Union for Conservation of Nature (IUCN) red list (COSEWIC 2006, Mallory et al. 2008, BirdLife International 2014). There are 49 known, extant nesting colonies in Canada, virtually all of which are close to either sea ice, glacial ice or both during the breeding season (Robertson et al. 2007). During the winter months, observational work at sea has shown that ivory gulls are often located near hooded seal *Crystophora cristata* whelping patches or following polar bears, likely to exploit foraging opportunities (Orr & Parsons 1982, Mallory et al. 2008). They are rarely seen over open water >5 km away from the ice edge (Mallory et al. 2008). Beyond this, little is known of ivory gull behaviour and distribution during the winter (Environment Canada 2014). The ivory gull has experienced a rapid population decline in the Canadian Arctic (Gaston et al. 2012), concurrent with changing sea ice conditions. Current population estimates in Canada are <1000 breeding pairs, suggesting a >70% decline in 30 yr (Gilchrist & Mallory 2005, COSEWIC 2006).

Threats to the ivory gull include illegal shooting, contaminants, and the shifting location and increased variability of sea ice habitat due to climate change (COSEWIC 2006). A research priority for the species is to use satellite telemetry to inform the process of critical habitat identification, a pivotal component of Canada's SARA legislation (Environment Canada 2014). Along with technological advances, climate change is expected to broaden the geographical scope of energy production and mining due to melting sea ice (Stephenson et al. 2011). The likelihood of increased exposure of wintering birds to threats highlighted above, and consequent increases in stress levels, makes identification of key marine habitats and development of appropriate conservation measures of paramount importance for this species (Environment Canada 2014). In this study, we assessed available information on winter distribution and propose areas that could be considered in the identification of winter critical habitat for the ivory gull in Canada.

MATERIALS AND METHODS

Field methods

Twelve ivory gulls were captured using a modified version of a bownet trap (Salyer 1962) from a single colony at the Seymour Island Migratory Bird Sanctuary, Nunavut (Fig. 1; 78.80° N, 101.27° W) on 29 and 30 June 2010. Five individuals were tagged with 20 g battery powered Platform Terminal Transmitters (PTTs; North Star Technologies). The remaining 7 individuals were tagged with 15 g solar powered PTTs, consisting of a customized PTT-100 12 g model (Microwave Telemetry) in a larger case to fit a larger solar chip. Individuals were caught during incubation to ensure they were actively breeding in Canada and a leg loop harness design was used to attach the transmitters, leaving flight muscles and major fat deposits unencumbered (Mallory & Gilbert 2008). Body masses of ivory gulls ranged from 465 to 650 g, and thus the transmitter plus the harness represented 2.7 ± 0.3% ivory gull body mass; below the 3% considered the maximum recommended load to minimize deleterious effects on individuals (Phillips et al. 2003, Mallory & Gilbert 2008). All birds flew off successfully after being equipped with the transmitters. All research was conducted following animal care committee approval for Canadian Wildlife Service Banding Permit 10694 as well as Canadian Wildlife Service Scientific Permit NUN-SCI-09-02 and Nunavut Wildlife Research License WL2010-032.

The PTTs were compatible with the Argos satellite positioning system. The duty cycle of battery-powered PTTs was programmed to send signals within an 8 h period then shut off for 72 h. Solar powered PTTs

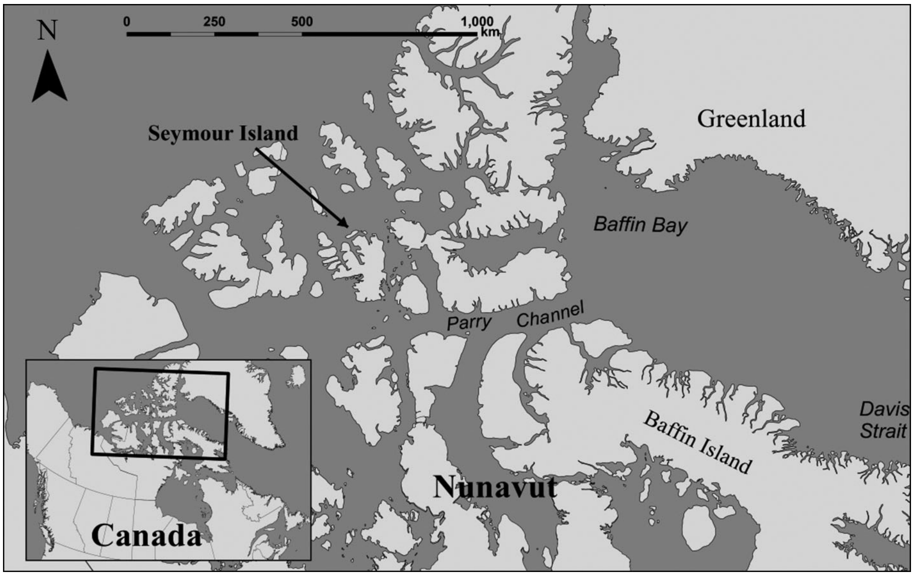

Fig. 1. Location of Seymour Island, Nunavut (78.80° N, 101.27° W), where 12 ivory gulls *Pagophila eburnea* were captured and tagged on 29 and 30 June 2010. Seymour Island is a small (3 km long) low-lying island, the largest breeding colony of this species in Canada and an Environment Canada Migratory Bird Sanctuary

had a 10 h on then 48 h off duty cycle with customized modifications to voltage by the manufacturer to accommodate the low incident light conditions of the Arctic fall and winter. Each message received from Argos was given an accuracy of the location estimate if 4 or more messages were sent to the satellite. We used only data with location class LC 1 (accuracy ≤1500 m; 45% of records), LC 2 (≤500 m; 35% of records) or LC 3 (≤250 m; 20% of records); collectively n = 12 586 records. The data were obtained between 1 January and 30 April in years 2010 to 2013 for our mapping work. A blackout period occurred each year for approximately 8 to 10 wk between November and January where the solar powered PTTs were not able to transmit data due to lack of sunlight at the latitude where the birds were wintering and consequently insufficient recharging and power to send signals. The 5 battery-powered PTTs and 3 solar-powered PTTs failed within the first 12 mo of the study, leaving 4 solar-powered PTTs that provided the bulk of our data between 2010 and 2013. There was a trade-off between the low number of birds tracked and the long periods of tracking (repeat observations) of the same individual birds.

Data processing and analysis

The statistical programs R version 2.15.1 (R Core Team) and ArcMap 10.1 (Environmental Systems Research Institute) were used for analyses.

To describe the winter season for the ivory gull, we estimated dates of arrival and departure to and from the wintering grounds (as identified by Orr & Parsons 1982). As individual rates of travel and distance flown varied within and across years, a single date to begin and end the winter period was not intuitive. Therefore, arrival to the wintering area, and the beginning of pre-breeding migration, were defined by movement patterns and speeds as described in Spencer et al. (2014). Using the range of arrival dates for individual ivory gulls, a median date was calculated to define the beginning of the wintering period to standardize analyses across birds and years, as in Gilg et al. (2013), even if the bird arrived during the blackout period (Spencer et al. 2014). As such, the median date of arrival to the wintering area was 19 December (range 20 November to 17 January) and the median date of departure, calculated using the range of departure dates, was 15 May (range 2 May to 28 May).

Suitable methods to identify and delineate marine hotspots are varied, each having different merits and assumptions. Kernel density estimation (KDE), the method adopted in this study, is most widely used and is particularly useful where sampling effort is uneven and data may sometimes be sparse (Worton 1995, Pebsworth et al. 2012). The analysis was conducted in program R using the *adehabitatHR* package (R Core Team 2012). Ivory gull records between the median arrival date at the wintering area (19 December) and the median departure date from the wintering area (15 May) of all years were used for analysis (n = 3707 records). We used a reference bandwidth (h_{ref}) as a smoothing parameter for the ivory gull UDs (utilization distributions), reducing the bandwidth by 10% to the point just before the 50% contour(s) began to fragment (e.g. Kie et al. 2010) to avoid the over-smoothing that is commonly associated with using h_{ref}. The 95% and 50% contours of the UD were used to determine home range and core areas (km^2), respectively. This subjective method of bandwidth selection may be both realistic and appropriate for large datasets with multiple centres of activity, as in the current study (Pebsworth et al. 2012). All means are reported ± standard deviation (SD).

Four KDE groups were created to assess potential sources of variation in the wintering areas. The first group assessed variation of wintering habitat for gulls breeding on Canadian colonies. KDEs were created for individuals that provided at least 1 full year or more of data (n = 6). Among these individuals, 4 gulls provided 2 yr or more data, allowing assessment of inter-annual habitat distribution using KDEs. The second group assessed winter habitat of gulls breeding on Canadian colonies compared with monthly sea ice extent. This group of KDEs pooled individuals for each winter month (January to April) and across each year (2010/2011, 2011/2012 and 2012/2013). December was excluded from analysis as there were too few observations as a result of the blackout period to create a KDE. May was also excluded as individuals began their migration in this month. Sample sizes for each of the 12 KDEs are shown in Table 1. The KDEs were compared with monthly sea ice extent lines, drawn from the last day of each month's daily sea ice chart provided by National Snow and Ice Data Center (NSIDC), to provide a coarse assessment of the proportion of each KDE that was over ice. The third group identified variation of winter habitat across years for tracked birds breeding on Canadian colonies. A KDE was created for each year of the study period, 2010/2011 (n = 8 individuals), 2011/2012 (n = 4) and 2012/2013 (n = 2). The fourth group assessed the overall winter habitat of all ivory gulls from Canadian satellite data. A KDE was created pooling all data from the study period to identify the overwintering areas most used by ivory gulls (n = 8 individuals).

Table 1. The sample size (number of individuals) for 12 kernel density estimations (KDEs) to assess key winter habitat of ivory gulls *Pagophila eburnea*, pooling individuals across each winter month (January to April) and across each year (2010/2011, 2011/2012 and 2012/2013)

	January	February	March	April
2010/2011	8	7	7	6
2011/2012	4	4	4	4
2012/2013	2	2	2	2

Historical dataset

We acquired a subset of records containing only those pertaining to the ivory gull from datasets maintained by Programme Intégré de Recherches sur les Oiseaux Pélagiques (PIROP), covering the period 1965 to 1992 (Brown 1986, Lock et al. 1994) and Environment Canada Seabirds At Sea (ECSAS), ongoing from 2006 (Gjerdrum et al. 2012). Both are large databases of georeferenced observations of seabirds taken from ships at-sea. Ivory gull records were derived from direct observations at sea spanning 41 yr (1969 to 2010), but with a gap between 1992 and 2006. From these data, we retained records (n = 4905) obtained between the median arrival date at the wintering area (19 December) and the median departure date from the wintering area (15 May), assuming departure and arrival dates calculated from our tracking data were consistent with historical patterns captured in the available at-sea data. We noted that, despite years of recent effort since 2006, no ivory gull observations were made during the time period covered by the ECSAS dataset, and thus our mapping from historical data comes from observations during the 1969 to 1992 period. A KDE was generated from the data acquired from ships at sea to compare and contrast with the KDE generated from the pooled ivory gull tracking data. Percent overlap was calculated to assess similarities and differences, including possible evidence of changing winter distribution.

Norwegian satellite data

We also acquired raw data from 9 satellite-tagged ivory gulls equipped with the same Microwave Telemetry transmitters as 7 of 12 gulls in this study from Seymour Island. These gulls originated from 2 colonies in Barentsøya, Svalbard, Norway (Auga and Freemanbreen). Data with LC 1, 2 and 3 obtained between 19 December and 15 May, 2010 to 2013 were used to create a KDE, for comparion with the KDE of pooled ivory gull data developed from the recent Canadian satellite transmitter study, and with the KDE generated from the at-sea data. In this way, we could assess differences in winter habitat among individuals from breeding colonies in Norway and Canada, and gulls of unknown origin (at-sea data). The percent of core area shared between the 3 data sources was calculated according to Hedd et al. (2014).

Sea ice

To determine the positions of KDEs in relation to sea ice, the 'Interpolate Time Series of Rasters at Points' tool was used in ArcGIS from the open source extension of Marine Geospatial Ecology Tools (Roberts et al. 2010). This enabled us to correlate NSIDC daily sea ice charts with all ivory gull locations in relation to date. Sea ice values of 254 and 253 indicated land, while values of 0 indicated no sea ice was present (i.e. open water) and all values in between represented varied concentrations of sea ice (see Maslanik & Stroeve 1999 for further details).

RESULTS

Variation of wintering habitat for gulls breeding on Canadian colonies

Ivory gulls traveled a great deal throughout the winter, represented by their large home range and core areas (Figs. S1–S6 in the Supplement at www.int-res.com/articles/suppl/031p033_supp.pdf). KDEs pooling all years across the 6 gulls showed a mean winter home range size of 446 758 ± 244 405 km^2 (range 146 299 to 624 579 km^2) and a core area of 87 495 ± 52 533 km^2 (range 3 491 390 202 km^2). Two of the 6 ivory gulls used the southern part of Labrador, north of the Strait of Belle Isle, as a wintering area, indicated by their 50% core areas (Figs. S4 & S6). Across years, individuals exhibited high site fidelity to their wintering locations.

Winter habitat of gulls breeding on Canadian colonies compared with monthly sea ice extent

Mean core area of ivory gulls across all years and months of January, February, March and April was 29215 ± 14 179 km^2 (range 14 808 to 192 130 km^2) and had a mean home range size of 138 567 ± 6669 km^2 (range 79 008 to 668 149 km^2; Fig. S7 in the Supplement). In relation to the sea ice edge, ivory gull core habitats extended farther west over the sea ice than east over the open water (Table 2). This was consistent January to April and across years, except in March in 2010 and 2011 (Fig. S7c). The mean maximum distance of the core area west of the ice edge in any month was 128 ± 40.2 km (range 55 to 363 km) compared with the mean maximum distance that the core area extended east over open water (64 ± 38.3 km; range 7 to 130 km; Table 2). Note, however, that in the winter of 2010/2011, one core area of 2 ivory gulls was located entirely over habitat classified as open water (Fig. S7c).

Table 2. The maximum distance (km) of 50% kernels (core area) of ivory gull *Pagophila eburnea* wintering habitat west over sea ice and east of the ice edge over open water in January, February, March and April over the study period 2010 to 2013. Two distances provided for 1 month indicate that there were 2 centres of activity

Winter	Month	Max. distance over ice (km)	Max. distance over water (km)
2010/2011	Jan	363	44
	Feb	146	44
	Feb	129	7
	Mar	143	127
	Mar[a]	–	120
	Apr	150	–
2011/2012	Jan	188	95
	Jan	110	33
	Feb	140	71
	Mar	140	68
	Apr	106	–
	Apr	85	75
2012/2013	Jan	96	–
	Feb	125	20
	Feb	123	–
	Mar	55	25
	Mar	174	74
	Apr	194	–

[a] This core area, representing 2 ivory gulls, was almost exclusively over open water

Variation of winter habitat across years for tracked birds breeding on Canadian colonies

In winter of 2010/2011, 1681 of 1851 records (91%) were over sea ice and 276 (15%) of those were found over >50% sea ice concentration (Fig. 2a). Home range and core areas were 386 801 and 55 304 km^2, respectively. In 2011/2012, 1372 records of 1390 (99%) were over sea ice and 699 (50%) of those were over >50% sea ice concentration. The home range area was 444 023 km^2 and the core area was 73 062 km^2

(Fig. 2b). Finally, 450 records of 466 (96%) in 2012/2013 were over ice and 191 (41%) of those records were over >50% sea ice concentration. The home range was 145 564 km^2 and the core area was 31 455 km^2 (Fig. 2c). In all years, ivory gulls used similar core areas in Davis Strait; however, home range area in 2010/2011 and 2011/2012 also included the offshore region within 300 km of the Labrador coast (Fig. 2a,b). Consistently across all 3 yr, ivory gulls used an overlapping area of approximately 8050 km^2.

Ivory gull winter core areas were on average within 172 ± 72 km of each other (as measured between centroids) across all years of the study (Fig. 2). Distance between ivory gull core areas in 2010/2011 and 2011/2012 was 121 km. Ivory gull core areas in 2010/2011 and 2012/2013 were 255 km apart and core areas in 2011/2012 and 2012/2013 were 141 km apart.

Winter habitat of all ivory gulls from Canadian satellite data

Collectively, ivory gulls equipped with satellite transmitters from all years of the study period and which provided data into the winter (n = 8) had a combined home range size of 521 975 km^2 and a core area of 70 352 km^2 (h_{ref} bandwidth reduced by 50%). Bounds of the core area were approximately 60° N to 64° N and 61° W to 59° W (Fig. 3).

Winter habitat of ivory gulls from at-sea and Norwegian datasets

Over a 23 yr period, ivory gull observations from the at-sea dataset (n = 2969) estimated an overall home range of 543 026 km^2 and a core area of 92 743 km^2 (Fig. 4). The bounds of the 2 centres of activity were approximately 61° N to 64° N and 59° W to 56° W and 57° N to 58° N and 60° W to 57° W. Available data from 9 satellite-tagged ivory gulls from Norwegian colonies (Fig. 5) provided a combined home range of 1 228 741 km^2 and a core area of 182 837 km^2. Bounds of the core area were 58° N to 64° N and 63° W to 58° W.

Overlap in ivory gull KDEs from different data sources

The core area of pooled data from satellite-tagged ivory gulls breeding on colonies in Canada, pooled

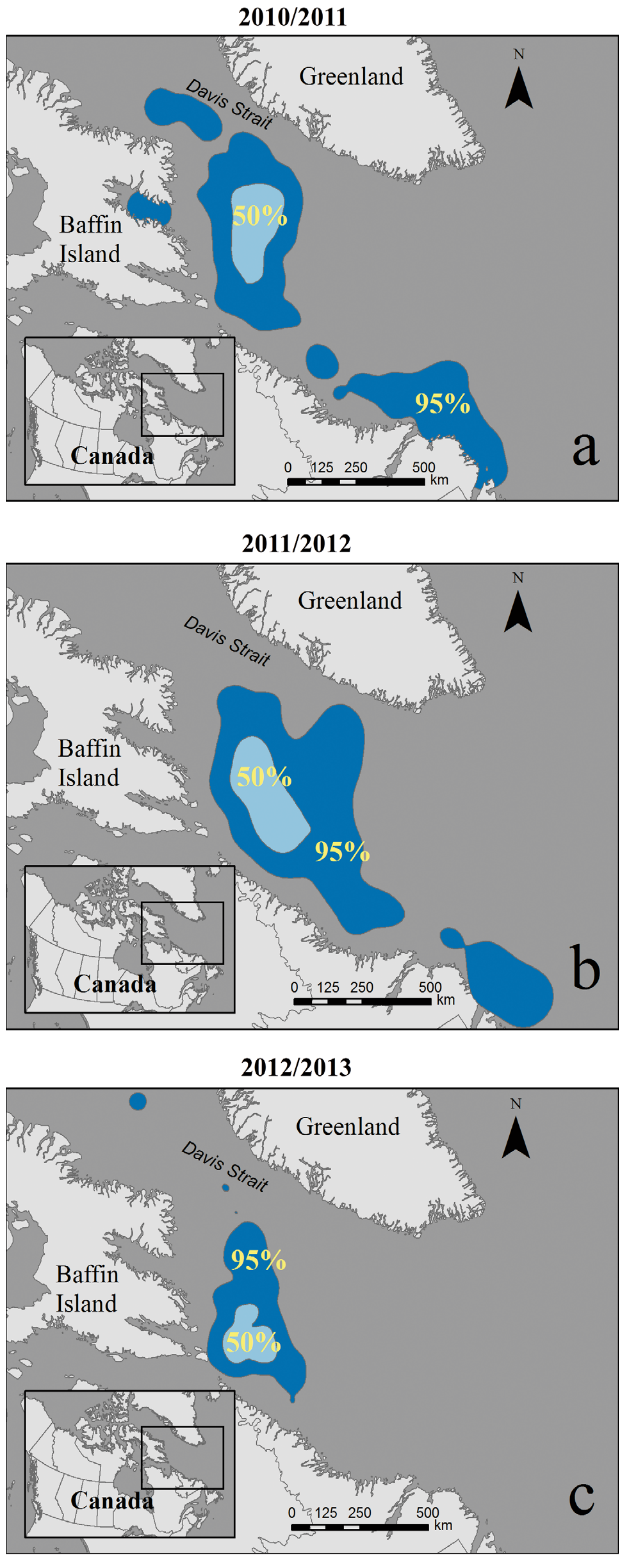

Fig. 2. Utilization distribution (95%) area and core (50%) area in Davis Strait, Nunavut, of wintering satellite-tagged ivory gulls breeding on colonies in Canada, pooled across each year of the study period: (a) 2010/2011 (n = 8); (b) 2011/2012 (n = 4); (c) 2012/2013 (n = 2)

data from satellite-tagged ivory gulls breeding on colonies in Norway, and ivory gulls observed at-sea suggest winter habitat overlap in Davis Strait (Figs. 6 & 7). Overlap between any combination of 2 core areas from the 3 sources of data was a minimum of 45 930 km^2, and overlap in core areas among Norwegian data, Canadian data, and at-sea data was 18% (8267 km^2). The overlap represented 25% of the core area used by the Norwegian ivory gulls, 65% of the core area used by at-sea data ivory gulls and 50% of the core area used by Canadian ivory gulls. Approximate bounds of the area were 61° to 64° N and 61° to 57° W.

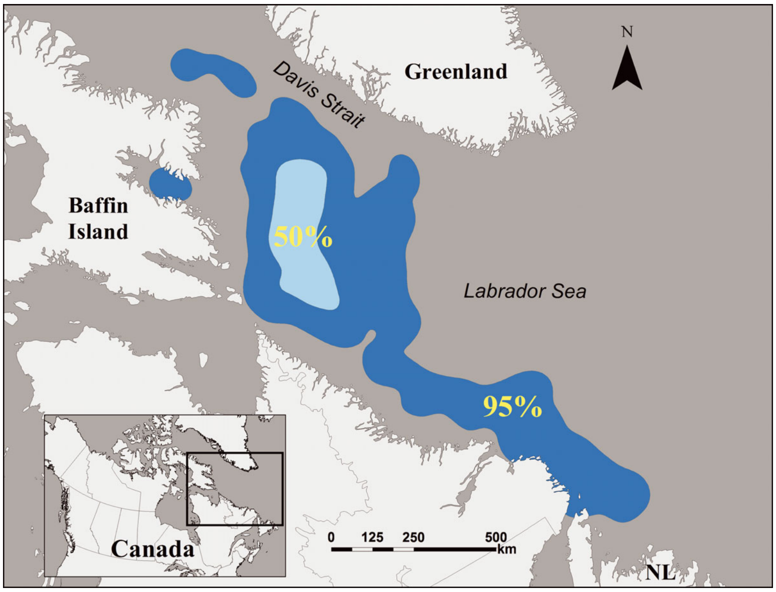

Fig. 3. Utilization distribution (95%) area and core (50%) area in Davis Strait, Nunavut, and Labrador Sea, Newfoundland and Labrador, of wintering satellite-tagged ivory gulls breeding on colonies in Canada (n = 8), throughout all years of the study (2010 to 2013)

DISCUSSION

This is the first coarse scale study of use of habitat by the ivory gull at large spatial scales in winter in Canada, with the only previous winter research being an aerial survey conducted in 1978 to 1979 (Orr & Parsons 1982). Wintering ivory gulls occupy extremely remote habitats which are difficult to access, and this has precluded a comprehensive analysis of their core wintering area, which for this species is a key national and international management priority (Gilchrist et al. 2008, Environment Canada 2014). However, the use of satellite telemetry, and in particular technical adjustments to transmitters that have permitted tolerance of long dark periods, has provided an affordable approach to data acquisition in such instances. Moreover, improvements to spatial analysis techniques, and better understanding of ivory gull biology (Gilg et al. 2010 Spencer et al. 2014), have improved our ability to make inferences from these types of data.

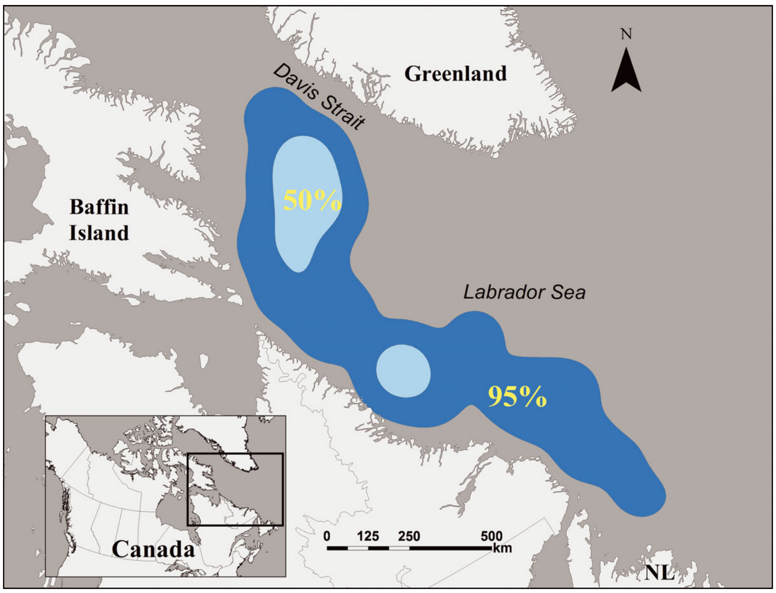

Fig. 4. Utilization distribution (95%) area and core (50%) area in Davis Strait and Labrador Sea of wintering ivory gulls, based on observations by at-sea surveys carried out by Programme Intégré de Recherches sur les Oiseaux Pélagiques (PIROP) from 1969 to1992

Surviving winter in Davis Strait

Collectively, we found considerable consistency among individuals and across years in the distributions of the 50% core areas of kernels (i.e. winter habitat). Sizes of kernels varied as expected, given that conditions differ each winter, and that individual behaviour varies, likely reflecting availability of foraging resources. Gulls originating from the Seymour Island colony clearly used Davis Strait as a main wintering ground, although some gulls also used the

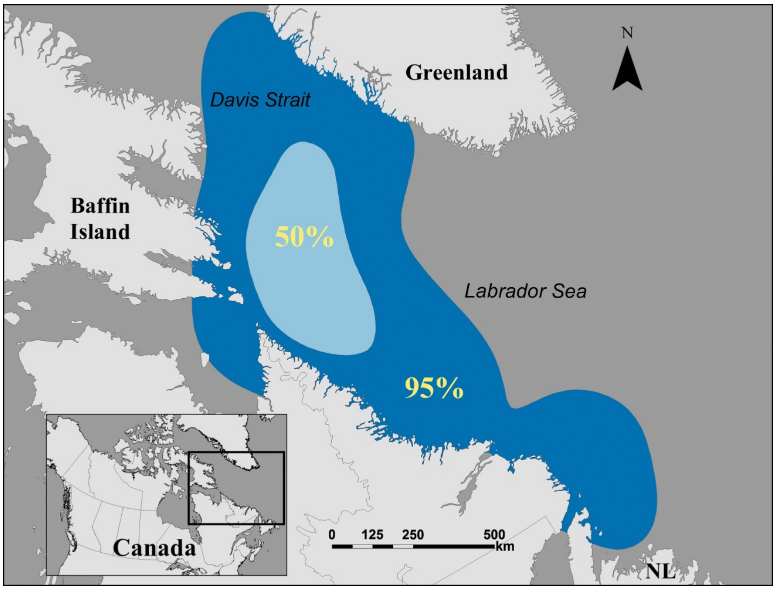

Fig. 5. Utilization distribution (95%) area and core (50%) area in Davis Strait, Labrador Sea and east of Greenland of wintering satellite-tagged ivory gulls (n = 9) breeding on colonies in Norway based on observations from 2010 to 2013

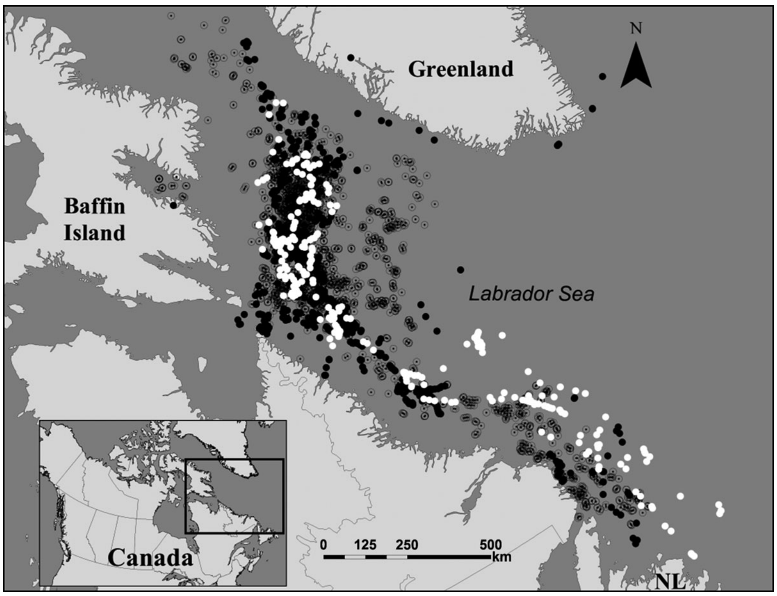

Fig. 6. All detections of wintering satellite-tagged ivory gull individuals breeding on colonies in Canada (circle with dot) and Norway (black circles) over 3 yr (2010 to 2013) and observations of ivory gulls by at-sea surveys (PIROP, 1969 to 1992) (white circles) in Davis Strait and Labrador Sea

area east of the Labrador coast, which is not surprising as they are known to occur in this area during winter (Chubbs & Phillips 2007).

Ivory gulls are opportunistic feeders, so the food subsidies provided by wintering hooded seals (dropped or regurgitated food, dead pups and adults, remains of polar bear kills) could provide a predictable food source if they winter in similar locations (Mallory et al. 2008), in addition to myctophid lanternfishes (Orr & Parsons 1982) and the other fish and marine invertebrates that are also known to comprise much of their diet (Hobson et al. 2002, Karnovsky et al. 2009). Hooded seal breeding locations were found mostly near the ice edge (Orr & Parsons 1982; Fig. 8), but could be seen as far west of the ice edge as 100 km, which may explain why ivory gulls occurred so far from the ice edge in the winter. This is not a surprising finding as ivory gulls prefer dense pack ice between 70 to 90% concentrations (Orr & Parsons 1982, Mosbech & Johnson 1999). One core area for 2 ivory gulls was located over water off the Labrador coast in March 2010/2011. Perhaps the 2 ivory gulls roosted on icebergs or ice floes to perch while foraging, as this would not be identified as 'ice' at the scale of our measurements. Observations of ivory gulls over open water are very uncommon (Mallory et al. 2008), including in the at-sea observer data which typically recorded birds on or over sea ice.

Ivory gulls are often also associated with polar bears (Mallory et al. 2008). The 95% home range contours for polar bears in Taylor et al. (2001) overlap substantially with ivory gull winter ranges from our data (Fig. 9). Among polar bear populations, bears inhabiting northern Davis Strait have the highest proportion of hooded seal in their diet (Stirling & Parkinson 2006). During the winter, hooded seal whelping patches are located in Davis Strait and Labrador shelf (Andersen et al. 2009) along the edge of pack ice, varying in position with annual conditions (Fig. 8; Sergeant 1974, Orr & Parsons 1982, Bowen et al. 1987, Stenson et al. 1996, Frie et al. 2012). Given the migratory movements and whelping patch locations of hooded seal, as well as the locations of ivory gull core areas in Davis Strait and Labrador coast, we suspect ivory gulls use hooded seals as an important food source through some of

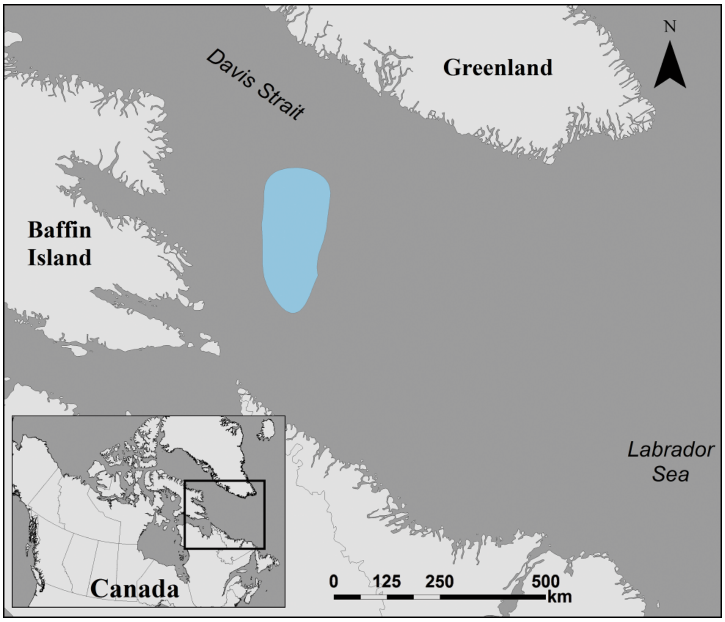

Fig. 7. Overlapping core (50%) area in Davis Strait of wintering satellite-tagged ivory gull individuals breeding on colonies in Canada and Norway (2010 to 2013) and observations of wintering ivory gulls by at-sea surveys (PIROP, 1969 to 1992)

the winter. By association, ivory gulls also likely follow polar bears to scavenge carcasses of other marine mammals that bears kill. This diet would also expose them to high trophic level prey through the winter. In support of this interpretation, ivory gulls have very high mercury (Hg) levels in all tissues sampled (Braune et al. 2006, Bond et al. 2015, Mallory et al. 2015), suggesting that they feed near the top of the Arctic marine food chain, probably year round. Other species like glaucous gulls *Larus hyperboreus* have a similar diet to ivory gulls in the summer, but many shift to a lower trophic level in the winter, exploiting dumps and human food sources (Weiser & Gilchrist 2012).

Area of international significance

Few studies have been conducted on seabird wintering distribution in the northwest Atlantic (but see Brown 1986, Huettmann & Diamond 2000, Wong et al. 2014), and of those most only include the northernmost area of Davis Strait (Orr & Parsons 1982, Mosbech & Johnson 1999). Studies from Greenland have noted that northern Davis Strait is an internationally significant wintering area for seabirds because of the continuing productivity of the Greenland Open Water polynya throughout most winters (Mosbech & Johnson 1999, Merkel et al. 2002, Boertmann et al. 2004). Gilg et al. (2010) provided evidence that this area is used by the ivory gull; however, the species may not be a frequent visitor to this area except during heavy ice years (Mosbech & Johnson 1999). Our analyses suggest that southern Davis Strait is also an area of international significance for the ivory gull, given the large overlap between our temporally and spatially extensive datasets. This also suggests that ivory gull winter distribution may not have changed greatly since the late 1960s. The at-sea data generated 2 core areas, one in Davis Strait and the second east of the Labrador coast, while the Canadian and Norwegian satellite transmitter data only had 1 core area, in Davis Strait. Overall, these results suggest that ivory gulls exhibit site fidelity to this main wintering location, Davis Strait, both across years and individuals. Presumably winter food availability of this region is a key reason why so many

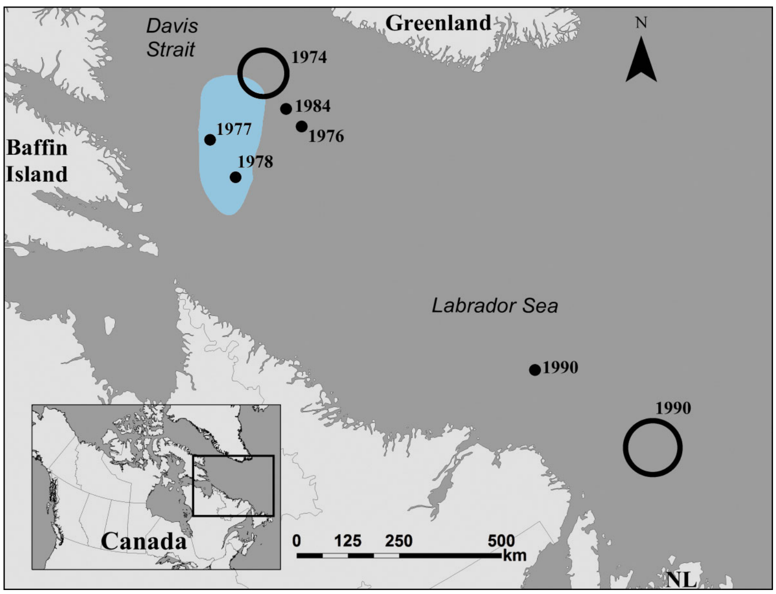

Fig. 8. Approximate historic hooded seal whelping locations (small black circles) and bounds (large hollow circles) as described in Sergeant (1974), Orr & Parsons (1982), Bowen et al. (1987) and Stenson et al. (1996). These correspond well to the overlapping area in Davis Strait of wintering satellite-tagged ivory gull individuals breeding on colonies in Canada and Norway and observations of wintering ivory gulls by at-sea surveys (PIROP, 1969–1992)

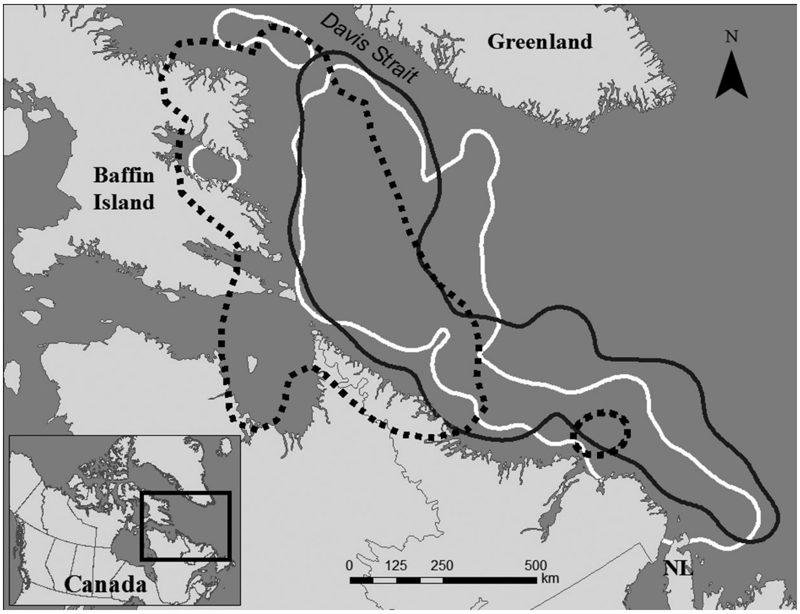

Fig. 9. The approximate 95% utilization distribution of polar bears from the Davis Strait population as derived from Taylor et al. (2001) (dashed contours) superimposed on the 95% winter utilization distribution of satellite-tagged ivory gulls breeding on colonies in Canada (solid black contour) and the 95% utilization distribution of wintering ivory gull observations by at-sea surveys (PIROP, 1969–1992; solid white contours)

birds are there, and continuing research on the wintering distribution and behaviour of seabirds in the northwest Atlantic will help us understand how ivory gulls and other seabirds may be affected by anthropogenic disturbances of this region of the Arctic (Gaston et al. 2009), and aid in the development of appropriate conservation measures to actively address threats in areas identified.

Future threats

Ivory gulls are already experiencing changes in their marine habitats in Canada. Satellite-based monitoring has shown that the extent of sea ice cover and sea ice thickness are declining, and with a ~2 to 4°C increase in Arctic air temperatures predicted by the end of the century, scientists expect a further, deleterious effect on the extent and thickness of the sea ice (Maslanik et al. 2007, Stephenson et al. 2011). With increased interest in resource exploitation in the Arctic as warming progresses, more opportunities will be available for increased intensity of shipping and possible expansion of shipping lanes, and for longer periods of the year (Humphries & Huettmann 2014). It is predicted that Canada will have almost year-round access to its Arctic waters by mid-century, making resource exploitation and shipping achievable during the winter months (Stephenson et al. 2011). If energy production and mining activity increase in this region, as hydrocarbon work may move north from currently active areas south of the species' winter range (Wiese et al. 2001; Gregersen & Bidstrup 2008; Arctic Council 2009), these activities may increase threats to ivory gulls in 3 ways. First, more frequent or intense shipping in Arctic waters increases the possibilities of oil spills, which could have direct, deleterious effects on birds, or negative, indirect effects on their food chains (e.g. Agness et al. 2008, Arctic Council 2009). Second, increased disturbance (forcing short- and long-term movements of birds from preferred feeding sites by ice-breaking, ship traffic, or noise) could reduce the suitability of this region as wintering habitat. Finally, warming conditions may facilitate the northward expansion of competitor species for ivory gulls, potentially reducing access to food supplies.

Critical habitat, marine protected areas and other marine conservation measures

As defined in subsection 2(1) of the SARA in Canada, (critical habitat is 'the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species'. Our results suggest that ivory gulls spent 90% of their winter over sea ice, where 30% of daily gull positions were over relatively dense ice (≥50% ice concentration). This suggests that sea ice, and perhaps the sea ice–open water interface, likely are key habitat components of what may constitute legal critical habitat for the ivory gull during winter. Spatially, these important habitat features occur each year near the edge of the pack ice in Davis Strait and the Labrador Sea, typically within the range of the winter distribution of hooded seals and polar bears. Satellite tracking data (obtained from individuals breeding on colonies in Canada) from Canada's largest colony (but representing only a portion of the Canadian breeding population) strongly suggest that Davis

Strait is a particularly important wintering area for the species. Furthermore, tracking data obtained from birds breeding on colonies in Norway exhibited high overlap with tracking data obtained from birds breeding on colonies in Canada, and additional evidence from Gilg et al. (2010) on Greenlandic, Russian and Norwegian ivory gulls also points to Davis Strait as being a significant wintering area. Finally, at-sea survey data, unbiased towards any single colony or population, also showed strong spatial overlap with the Seymour Island wintering birds. In combination, available data derived from ivory gulls of all origins provided evidence showing the ivory gull consistently winters in similar habitats and in a similar region, strongly suggesting Davis Strait constitutes key winter habitat not only for the Canadian but also for a substantial portion of the global ivory gull population.

However, assigning precise or fine-scale, geo-referenced bounds for habitat protection for the ivory gull based on sea ice in highly dynamic environments remains challenging (i.e. delineating boundaries of a marine protected area). Our data, from a limited sample, showed that individual variation among birds, and annual variation within and among birds, can lead to some annual variation in core habitats, presumably in response to variable ice conditions. This complicates the establishment of marine protected areas (MPAs) in response to known and emerging threats to the ivory gull in this key winter habitat area.

Incorporating multiple sources of data (as in our study) such as tracking studies and at-sea surveys, can help capture as much of this variation as possible and help distinguish overlap between the sources (Camphuysen et al. 2012). One solution may be to develop adaptive marine MPAs, which in Canada may be referred to as the adoption of management measures over areas with flexible boundaries defined by water column properties, species' distribution, life history, ocean temperature, annual ice conditions and chlorophyll (Hyrenbach et al. 2000; Polovina et al. 2000). For example, predictive modelling using ocean temperature has been used to help reduce bycatch of the southern bluefin tuna *Thunnus maccoyii* in their winter habitat, where boundaries of the area-based conservation measure are updated regularly to reflect the current oceanographic state (Hobday & Hartmann 2006). A similar approach could also be applied for identification of ivory gull critical habitat. Importantly, across 3 yr of data from at least 4 individual birds, despite some annual and individual variation, we identified a key, consistent, conservative core area that we recommend as an initial site meriting protection for the conservation and recovery of the ivory gull (e.g. SARA critical habitat). We suggest this as an initial area to be considered, while recommending caution because of the challenges of interpreting ranges from relatively few individual birds (e.g. Soanes et al. 2013, Gutowsky et al. 2015). However, despite our small sample size of tracked birds, the ancillary information from birds tracked from Norway, the many years of observations of birds at sea, and the aerial survey work of Orr & Parsons (1982) all corroborate interpretations from our small sample. Thus, the area that we suggest merits conservation consideration comprises ~90 900 km^2 with approximate bounds of 61.36 to 64.0°N and 62.34 to 56.64°W, where the current satellite data and at-sea data overlap.

We have identified key winter habitat in Canada for the ivory gull, which is the first step in the conservation process and an important part of identifying critical habitat (SARA 2009, Environment Canada 2014). However, establishing some form of formal protection to address known and emerging threats for the bird in this remote and dynamic environment poses many challenges. While we believe our data lay the foundation for mapping critical habitat for the ivory gull, we currently lack a winter ecology study on the species to better understand its specific needs in winter, particularly how our assumption that it relies heavily on polar bears and hooded seals for food might affect critical habitat designation. Thus, we recommend a winter ecology study be conducted to evaluate the importance of hooded seals and polar bear kills to the ivory gull, as an additional step to identifying, defining and more accurately delineating the winter critical habitat of this species.

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